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GEOLOGY OF THE BROKEN RIVER PROVINCE, NORTH QUEENSLAND

I.W.Withnall & S.C.Lang (Editors)

with contributions from:

I.W.Withnall, S.C.Lang, J.J.Draper, C.R.Fielding, J.S.Jell, J.A.Talent, R.Mawson, P.J.G.Fleming, A.Simpson, P.R.Blake, M.Humphries, P.Jorgensen, K.G.Grimes & M.Scott

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SUMMARY

The Broken River Province, together with the Hodgkinson Province, forms the northern part of the Tasman Fold Belt. The provinces are separated from each other by a broad belt of late Palaeozoic igneous rocks, but were probably originally continuous. The Broken River Province is bounded to the west by a system of major faults separating it from the Georgetown Province. This margin is partly formed by the Burdekin Fault. It may bend to the northwest to become the Palmerville Fault, which bounds the Hodgkinson Province to the west. Most current interpretations of the Palmerville and Burdekin Faults regard them as thrusts. The Clarke River Fault, a ductile mylonite zone, on which later brittle movement also occurred, forms the southern margin of the province, separating it from the Lolworth-Ravenswood Province.

The Broken River Province is divided into two subprovinces. The Camel Creek Subprovince in the east is separated from the Graveyard Creek Subprovince to the west by the Gray Creek Fault which may be a continuation of the Burdekin Fault. The Halls Reward Fault, which is a mylonite zone, and the Teddy Mount Fault, which is a brittle fault, together define the northern margin of the Graveyard Creek Subprovince. The two subprovinces had distinctly different structural histories.

The Camel Creek Subprovince consists predominantly of turbidites. In addition to the turbidites, a narrow, very heterogeneous belt of rocks of the Carriers Well Formation and Everetts Creek Volcanics crops out along the western edge of the province, and includes calc-alkaline basaltic to dacitic lavas and volcaniclastics. Quartz-rich arenite and oolitic limestone containing Late Ordovician corals and conodonts are also present.

The turbidite units can be divided into quartz-rich and quartz-intermediate lithofacies. The quartz-rich units (the Wairuna Formation, Pelican Range Formation, and Tribute Hills Arenite) also include tholeiitic basalt and chert. The age of the units is uncertain, but they are probably Ordovician. The quartz-intermediate rocks have been divided into three units. The Greenvale Formation which contains relatively lithic arenite is the westernmost. The lithic detritus includes mafic to felsic volcanics and metamorphics. The age of the Greenvale Formation is uncertain, but is probably Late Ordovician and/or Early Silurian. It is bounded to the east by the Perry Creek Formation, which is lithofeldspathic and relatively more quartzose (quartz-intermediate to quartz-rich). The lithic detritus still includes some (mainly felsic) volcanics and metamorphics. It contains minor tholeiitic basalt and chert, and allochthonous limestone as clasts in conglomerate and as blocks up to 1 km long. Conodonts indicate an age range of Early Silurian to earliest Devonian for these limestones. The Kangaroo Hills Formation contains relatively feldspathic arenite, but minor volcanic detritus is still evident. Limestone clasts in conglomerate contain Early Devonian conodonts.

The relationships between most of the units in the Camel Creek Subprovince are probably mainly tectonic, although interfingering stratigraphic relationships occur, at least locally, between the Pelican Range Formation and Greenvale Formation. All units are characterised by extensive melange, although it is best developed in the Ordovician rocks. The melange may be mostly syn-D_1 and associated with the first main slaty cleavage, but some melange may have predated this event.

The western half of the subprovince is dominated by westward-younging, alternating belts of quartz-rich and quartz-intermediate turbidite units. Together with the overall eastward younging from Late Ordovician to Early Devonian, these features suggest that the subprovince is an imbricate stack of thrust sheets. In the Kangaroo Hills Formation, younging reversals are more common, and folds can be mapped out, but the same westward asymmetry is evident. Later northeast-trending folds reoriented the F_1 folds in the Kangaroo Hills Formation. The major folds have wavelengths of about 20 km, but also occur at outcrop scale, and are locally associated with a slaty cleavage. In the southern part of the subprovince, all the units as well as the slaty cleavage have been folded into a major orocline with a NE-trending axial plane. Later folds with easterly trends can be recognised at outcrop scale.

The ages of D_1 and D_2 are constrained by the Early Devonian conodont age of the Kangaroo Hills Formation, and the age of the unconformably overlying, weakly deformed Clarke River Group. The latter consists of a latest Devonian? to Tournaisian fluviatile to shallow marine quartzose sandstone sequence overlain by a Visean volcaniclastic sequence. D_1 is generally regarded as Early Devonian from relationships in the Graveyard Creek Subprovince, but this is by no means certain. D_2 could be Frasnian, also from relationships in the Graveyard Creek Subprovince. It is also possible that both events are closely related in time, and occurred at one or other of the suggested times.

In contrast to the Camel Creek Subprovince, the Graveyard Creek Subprovince has a coherent stratigraphy and the structure is less complex. Possible basement to the subprovince is represented by the Gray Creek Complex, a belt of Proterozoic mafic to ultramafic rocks, which is either overlain by, or is in thrust contact with the Judea Formation, a quartz-rich turbidite unit containing tholeiitic basalt and keratophyre. The age of the unit is Early Ordovician based on graptolites. Melange is locally developed **only** in the Judea Formation, unlike the Camel Creek Subprovince, where it is present in all units through to the Early Devonian. The Judea Formation was therefore tectonised before the deposition of the overlying Graveyard Creek Group. The deformation appears to have been related to low-angle or bedding-parallel thrusting rather than folding, because there is no strong angular discordance between the units.

The Graveyard Creek Group in the north consists of quartz-intermediate turbidites about 6 000 m thick. The arenites are mainly feldspathic with minor volcanic and metamorphic input. The provenance was the Georgetown Province. Conglomerates and diamictites at the base contain olistoliths of metamorphic rocks from the adjacent Georgetown Province and allochthonous limestone. The sequence thins dramatically to the southeast. In the south, about 500 m of arenite, conglomerate, and mudstone was deposited on a storm-influenced shelf. The arenites are lithofeldspathic and relatively quartz-rich, and are overlain by Late Silurian to earliest Devonian limestone and quartzose arenite.

After a hiatus the Graveyard Creek Group was overlain by feldspathic arenite and limestone of the Shield Creek Formation. The hiatus and abrupt change probably reflect uplift and tectonism in the adjacent Georgetown and Lolworth-Ravenswood Provinces. It has generally also been regarded as timing D_1 in the Camel Creek Subprovince, although the lack of any significant angular discordance is a problem with this interpretation.

After another hiatus, suggested by palaeontological evidence, the Shield Creek Formation was overlain by the Early to Middle Devonian Broken River Group. The Broken River Group consists of shelf sediments, including abundant limestone, as well as mudstone and sandstone. Outliers on the Georgetown Province, such as near Conjuboy, indicate that the Teddy Mount Fault was the basin margin at this time.

A slight unconformity of a few degrees separates the Broken River Group from the Late Devonian to Carboniferous Bundock Group. This unconformity has been correlated with D_2 in the Camel Creek Subprovince. The lower part of the group accumulated during a series of regressive and transgressive phases in a foreland basin setting adjacent to active faults; it begins with a shallow marine sequence, but it is mainly a fluviatile and alluvial plain sequence, including abundant redbeds. Outliers also occur on the Georgetown Province. A subsequent latest Devonian to Early Carboniferous marine transgression was followed conformably by a regressive phase of fluviatile quartzose to volcaniclastic sediments similar to the Clarke River Group. Large rhyolite sills intrude the Bundock Creek Group, and may have been contemporaneous with the tuffs and volcaniclastic rocks in the uppermost part of the Group.

The structure of the Graveyard Creek Subprovince is quite different to that of the Camel Creek Subprovince. The main deformation in the Graveyard Creek Subprovince produced northeast-trending folds at the end of the Early Carboniferous, and had little effect on the adjacent Camel Creek Subprovince, where the Early Carboniferous rocks in the Clarke River Group are only weakly deformed.

A suite of granodiorite to granite plutons, assigned to the Montgomery Range Igneous Complex, intruded the Bundock Creek Group after the main deformation, probably in the Late Carboniferous or Permian.

The tectonic history appears to have been one of alternating extensional and convergent regimes. In the Late Cambrian to Early Ordovician, and again in the Late Ordovician, the northern part of the Tasman Orogen was probably a convergent margin with calc-alkaline volcanism. These episodes may have been separated by a passive phase in which quartz-rich turbidites and tholeiitic volcanic rocks were deposited. Subsequently, in the Silurian, the region underwent extension forming a large turbidite basin which included the Camel Creek Subprovince and the Hodgkinson Province to the north. No rocks younger than Early Devonian have been recognised in the Camel Creek Subprovince, whereas, in the Hodgkinson Province, deposition continued at least until the latest Devonian. The Camel Creek Subprovince was deformed at least twice before the Frasnian, resulting in an imbricate stack of thrust slices and later large-scale folds. The pervasive melange may be related to thrusting.

The Graveyard Creek Subprovince formed adjacent to the Camel Creek Subprovince, possibly initially as a pull-apart basin on stable crust. The deformation history contrasts markedly with that of both the Hodgkinson Province and Camel Creek Subprovince. In the Graveyard Creek Subprovince, melange is present only in Early Ordovician rocks. No **major** angular unconformities have been recognised in the overlying marine to non-marine sequence, which ranges from Early Silurian to Early Carboniferous. The two events in the Camel Creek Subprovince had only minor effects in the Graveyard Creek Subprovince. Hiatuses and a slight angular unconformities within the Devonian, may be related to these events. The Late Devonian to Early Carboniferous depositional history of the Bundock Creek Group was also strongly influenced by tectonism in adjacent terranes. The major deformation in the Graveyard Creek Subprovince in the Early Carboniferous had only slight effects in the Camel Creek Subprovince. The Clarke River Fault was probably the single most important influence on both sedimentation and deformation in the Broken River Province.

Keywords: Regional geology; stratigraphy; sedimentology; biostratigraphy; plutonic rocks; volcanic rocks; structural geology; geochemistry; tectonics; Carriers Well Formation; Everetts Creek Volcanics; Wairuna Formation; Greenvale Formation; Pelican Range Formation; Perry Creek Formation; Tribute Hills Formation; Kangaroo Hills Formation; Clarke River Group; Gray Creek Complex; Saddington Tonalite; Netherwood Tonalite; Judea Formation; Graveyard Creek Group; Shield Creek Formation; Broken River Group; Wando Vale Subgroup; Bundock Creek Group; Montgomery Range Igneous Complex; Broken River Province; Camel Creek Subprovince; Graveyard Creek Subprovince; Proterozoic; Ordovician; Silurian; Devonian; Carboniferous; Permian; Tertiary; Quaternary; Queensland; SE5513, SE5509, SE5514, 7758, 7759, 7858, 7859, 7860, 7958, 7959, 7960, 8059.

INTRODUCTION

(I.W. Withnall)

SCOPE OF THIS REPORT

Field work in the Broken River Province by the Geological Survey of Queensland (GSQ) of the Queensland Department of Mines (now Department of Minerals and Energy) commenced in 1983 (by IWW) with logistic support from the Bureau of Mineral Resources (BMR). In 1984, the Queensland Government initiated the Regional Geological Mapping Program (RGMP), after withdrawal of the BMR from active participation in systematic regional geological mapping in Queensland. As a result, additional geologists were employed and a party was set up to continue the mapping of the Einasleigh and Clarke River 1:250 000 Sheet areas, which started as part of the joint BMR-GSQ Georgetown Project in 1979. Field work in these sheets was completed in 1986, and mapping of the parts of the Broken River Province in the Townsville 1:250 000 Sheet area was completed in 1988. The part of the province which extends into the Ingham 1:250 000 Sheet area was not mapped.

This report describes the stratigraphy, sedimentology, structure, and tectonics of the Broken River. The most detailed work was done in the southern part of the Graveyard Creek Subprovince (see Geological Setting) where the structure is relatively simple and the sequence is well preserved. Because of the wealth of data available there and its importance in understanding the Palaeozoic geology of Australia, the GSQ party collaborated closely with personnel from other institutions who were interested in the area. These included staff from the University of Queensland (Drs J.S. Jell, C.R. Fielding and R. Holcombe), Macquarie University (Prof. J.A. Talent and Dr R. Mawson) and their respective students who have been carrying out detailed research on the Early to Middle Devonian rocks in the Graveyard Creek Subprovince. Jell's work has involved detailed mapping and studies of the coral faunas continuing on from his Ph.D. research (Jell, 1967). Talent and Mawson with their students sampled numerous detailed sections for conodont studies. Other collaborators included Dr S. Turner (Queensland Museum) and Dr R. Hammond (formerly James Cook University).

Two maps accompany this report - the Camel Creek 1:250 000 Special (Map 1) and the Broken River 1:100 000 Special (Map 2). Field compilation sheets at approximately 1:25 000 scale, and composite sheets at 1:100 000 scale are available from the Department of Minerals and Energy as diazo paper or film prints. Digital map data should be available as part of the Department's Geoscience and Resource Data Base (GRDB) by the end of 1993.

Although overall responsibility for the compilation of this report and the maps rested with I.W. Withnall and S.C. Lang, the individuals contributing to various sections of the report are indicated under the first-order and second-order headings.

LOCATION AND ACCESS

The location of the Broken River Province is shown in Figure 1. It lies in the Townsville-Ingham hinterland in north Queensland and is centred about 200 km west of Townsville. It covers an area of approximately 15 000 km^2. Access to the area is from Townsville and Charters Towers by sealed road to Greenvale (Gregory Developmental Road), by sealed road from Cairns via the Lynd junction (Kennedy Developmental Road), and by unsealed roads from Ingham through Camel Creek, and from Hughenden to the Lynd junction (Kennedy Developmental Road). The main settlement in the area is Greenvale township, constructed to service the Greenvale nickel mine. The mine closed in late 1992, and after rehabilitation of the mine site is completed, most of the township may be dismantled. Most station homesteads are serviced by graded roads. Networks of vehicle tracks to bores and cattle yards occur throughout the area, particularly in the east. Access in the western part of the area, the Broken River and its headwaters and along the Clarke River is poor. A track connects Greenvale with Wando Vale homestead, but is not regularly maintained. During our survey, we were able to make use of a series of tracks constructed during uranium exploration in the late 1970s. Some of these were re-established during gold exploration in the late 1980s, but are likely to deteriorate rapidly if not maintained.

The area is covered by aerial photography at a variety of scales. Black-and-white photography at 1:80 000 was flown by the Commonwealth over the whole area in 1967. The aerial photography used for individual 1:100 000 sheet areas was as follows: a coloured set flown by the Commonwealth at 1:25 000 scale for Burges (1978); and black-and-white sets flown by the State at 1:25 000 scale for Cashmere (1978), Clarke River (1980), Chudleigh Park (1976), Ewan (1980), Valley of Lagoons (1979) and Wando Vale (1976).

Grazing and mining are the only industries in the area. The nickel mine at Greenvale which closed in late 1992 is just outside of the Broken River Province, but alluvial gold and tin deposits have been worked in the area in the late 1970s and 1980s. Company-scale mineral exploration has been active through the region since the late 1960s.

PREVIOUS WORK

Daintree (1872) recorded the first notes on the Broken River area, when he measured nearly 23 000 feet (7 000 m) of 'Broken River Devonian rocks'. Jack (1887) also made a traverse along the Broken River. He considered the whole section to be one unit and later equated it with the Middle Devonian Burdekin Formation (Jack, 1889; Jack & Etheridge, 1892). Jack & Etheridge (1892) also commented on the similarities between the red shales in the uppermost part of the section with those of the Lower Old Red Sandstone of Perthshire, Scotland. Reid (1930) critically examined the correlation of the rocks with those of the Burdekin area, and strongly suggested further examination of the areas. Hill (1960) proposed the term 'Broken River Embayment' for a distinctive re-entrant or embayment along the 'Tasman Line' which was defined by Hill (1951) as "the boundary between the Precambrian craton and the Tasman Geosyncline".

In 1953 and 1954 the CSIRO (Commonwealth Scientific and Industrial Research Organisation) carried out a land-use survey of the Leichhardt-Gilbert area, which included the area (Perry & others, 1964; Twidale, 1956a,b, 1966). This survey included a brief geological study as well as geomorphological studies.

Frome-Broken Hill Ltd investigated the stratigraphy of the Broken River area as part of a petroleum exploration survey in 1956-57 (Dixon, 1957).

In 1956 the BMR and GSQ commenced detailed studies of the stratigraphy during systematic regional geological mapping of the region. The results of the survey relevant to the Broken River Province were published by White (1962a,b; 1965) and Wyatt & others (1970). Progress reports and field sheets were compiled by White & Hughes (1957), White & others (1959a, b), and Green (1958). They recognised that the sequence in the Broken River area also included Silurian and Carboniferous rocks, and probably several unconformities, based mainly on the palaeontological determinations (particularly of corals) by Professor Dorothy Hill at the University of Queensland (*in* White, 1965; and in the various progress reports). Graptolites (White & Stewart, 1959; Thomas, 1960) and other faunas were also found. Jell (1967, 1968) studied the Early to Middle Devonian rocks of the Pandanus Creek area and their coral fauna, and Mallett (1968) studied stromatoporoids from the same area. Telford (1975) provided a reconnaissance conodont biostratigraphy, mainly for the Early to Middle Devonian rocks.

Arnold (1975), Arnold & Rubenach (1976), and Arnold & Henderson (1976) undertook detailed studies of the Silurian and older rocks of the Greenvale and Broken River area, and made some important re-interpretations of the stratigraphy and structure. In particular, they recognised that one of White's unconformities was wrongly located, and demonstrated that the ultramafic/mafic complexes of the Greenvale area were probably Precambrian basement, not Devonian intrusions. They also recognised the fundamental division of the Broken River Province into two subprovinces, on the basis of deformation styles. This work was reviewed by Arnold & Fawckner (1980).

B.Sc. (Honours) theses undertaken before the present work were by Spring (1979) on the Gray Creek area, Munson (1979) on the Jack Hills Gorge area, Edwards (1977) on the Blue Range area, and Simpson (1983) on the Silurian to Early Devonian biostratigraphy of the Broken River area.

Important studies of the stratigraphy of the Late Devonian to Carboniferous rocks were undertaken by several companies during the uranium exploration boom in the late 1970's. Minatome (Australia) Pty Ltd and Urangesellschaft Australia Pty Ltd studied the rocks herein referred to as the Bundock Creek Group in the Graveyard Creek Subprovince. They recognised two informal 'Groups', each containing four units (Guillebert & others 1979). They interpreted an unconformity between the 'Groups'. The main part of the Clarke River Basin was studied by AFMECO Pty Ltd (Mouthier & Rippert, 1980) who recognised five units.

Wyatt & Jell (1980) reviewed the Devonian-Carboniferous geology of the Townsville hinterland. They used the informal subdivisions of the mining companies, although they gave only brief descriptions because the data was then confidential. Jell & Playford (1985) also reviewed the Carboniferous geology and included palynological data from the Clarke River Basin.

The Mesozoic sediments of the Gilbert Tableland, which extend onto the south-western part of the Broken River area, were described by Doutch & others (1970) and Smart & others (1980). The Chudleigh and Nulla Basalt Provinces, which overlie the Broken River Province in the south, were studied by Twidale (1956a), Stephenson & others (1980) and Stephenson (1989). Burger (1987) studied the Cainozoic sediments, palaeo-drainage lines and deep weathering profiles of the region.

OTHER REPORTS FROM THIS STUDY AND CONCURRENT WORK

Progress reports on the early stages of the current phase of GSQ mapping were given by Withnall & others (1985, 1986), and more detailed reports on some aspects by Withnall (1985), Scott (1985), and Fleming (1986). Three of the party members used detailed studies of parts of the area towards the thesis requirements of B.Sc. (Honours) degrees at the University of Queensland (UQ) (Lang, 1985, 1986a; Law, 1985, 1986a; McLennan, 1986,), and support was given to three other students in 1990 (Blake, 1990; Humphries, 1990; Jorgensen, 1990). Other B.Sc. (Honours) degrees at the UQ completed concurrently with our work were by Savory (1987), Munson (1987) and Aung (1991). Results of the stratigraphic drilling program were given by Lang (1986b), Law (1986b) and Scott (1986, 1988). Definitions of new and revised stratigraphic units were given by Withnall (1989a) and Lang & others (1989a, b). In 1987, to mark the completion of work in the Clarke River 1:250 000 Sheet area, a field conference was organised jointly by the GSQ and Australasian Sedimentologists Group; a comprehensive guidebook was issued in conjunction with the conference (Withnall & others, 1988b). The geology of that part of the Broken River Province cropping out in the Einasleigh 1:250 000 Sheet area was summarised by Withnall & Grimes (1991). Other relevant reports and papers resulting from the GSQ mapping are by Lang (1988), Lang & Fielding (1989, 1991, 1992), Lang & others (1988), Withnall (1990), Withnall & Lang (1988, 1990) and Withnall & others (1987).

Results of the work by the Macquarie University group have been published by Mawson (1987), Mawson & others (1985, 1988), Mawson & Talent (1989) and Talent & Yolkin (1987). Other palaeontological and biostratigraphic studies have been published by Jell & others (1988), Yu & Jell (1990), Turner (1982) and Playford (1986, 1988).

CLIMATE, VEGETATION AND PHYSIOGRAPHY

The climate of the Broken River region is humid tropical. The average annual rainfall ranges from 800 mm in the northeast to 600 mm in the southwest, most falling between November and April. Only light rain falls during the remainder of the year, mainly in the northeast. January is the wettest month with an average of 190 mm. The average daily temperature ranges are 20-33° in January and 10-25° in July. The area generally experiences frosts on fewer than 5 days per year.

The vegetation of the area was described by Perry & others (1964). Most of the area is covered by ironbark woodland and forest, but lancewood woodland occurs on some lateritic mesas and plateaux, and Reid River box woodland is characteristic of deeply weathered rocks of the Broken River Province. The ground cover is mostly kangaroo grass, blue grass, black spear grass, and three-awn grasses, but spinifex grows in some areas, particularly on felsic rocks such as the late Palaeozoic granites.

The Broken River Province lies at the south-eastern edge of the 'Einasleigh Uplands' (Twidale, 1956b, 1966; Perry & others, 1964). The Einasleigh Uplands are drained by the Einasleigh and Copperfield Rivers, which flow northwest towards the Gulf of Carpentaria; and the Herbert, Burdekin, Broken and Clarke Rivers which flow east into the South Pacific Ocean. The Einasleigh Uplands can be divided into several physiographical units as shown in Figure 2.

The Broken River Province mostly lies within the *Burdekin Uplands* which range in elevation from 400 m in the east to 800 m in the southwest and northeast. The local relief is up to 200 m, but is usually less than 100 m. The uplands comprise undulating country developed on folded Palaeozoic sedimentary, volcanic and granitic rocks, together with small isolated tablelands, of which the Lucy Tableland of about 500 km^2 is the largest. These tablelands consist of Mesozoic, Tertiary and Quaternary sediments and deeply weathered basement rocks. Scattered small remnant mesas are common in many areas.

The *Einasleigh-Copperfield Plain*, which partly flanks the Broken River Province in the southwest, consists of Proterozoic and early Palaeozoic metamorphic rocks and

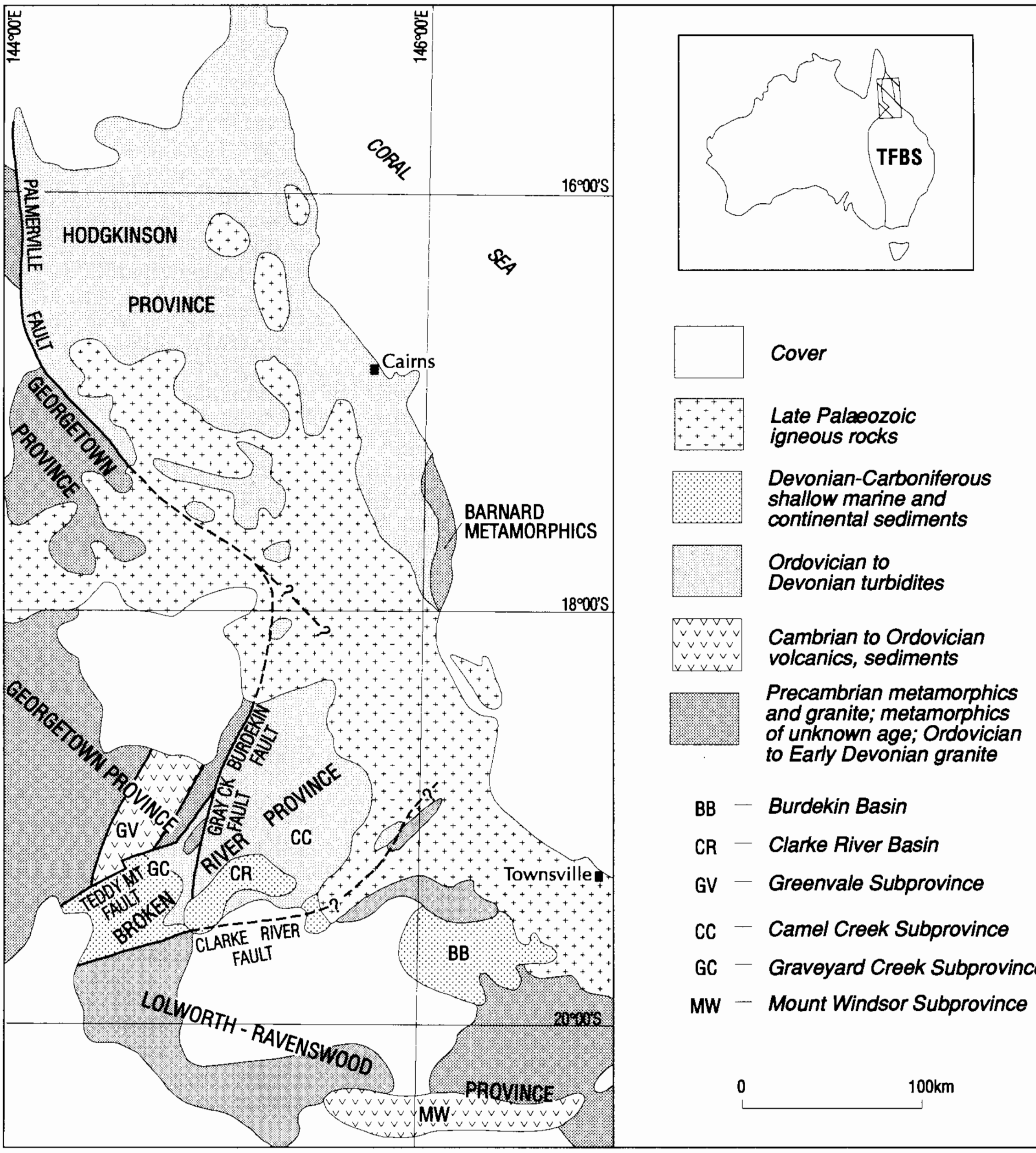


Figure 1. Structural framework of the Cairns-Townsville hinterland.

granitoids, with isolated hills of more resistant metamorphics (generally calc-silicate gneiss), basalt-capped mesas, and granite tors. The elevation is mostly 400 to 500 m; local relief rarely exceeds 200 m and is usually much less.

The Einasleigh-Copperfield Plain and the Burdekin Uplands merge into the *Uplands of the Divide*, which also partly flank the Broken River Province, and comprise the high plains and ridges on and slightly to the east of the Great Dividing Range. They are composed mainly of metamorphic rocks (in particular felsic metavolcanics) and laterite capped mesas.

In the north of the Province, the Burdekin Uplands are flanked by the *McBride Plateau*, a circular area about 80 km in diameter, consisting of Cainozoic basalt flows and volcanic centres. Although some basalts as old as 8 Ma are known, most are younger than 3 Ma. The most recent flow, from the Kinrara crater (<40000 years BP), flowed down the Burdekin River. Lakes formed along the eastern margin of the plateau by damming of the river systems by the flows (e.g. near the Valley of Lagoons).

The *Chudleigh Plateau* in the southwest of the area is formed mainly by basaltic lava flows. Elevations range from 800 to 1000 m. Umbrella Mountain at the western end of the Stopem Blockem Range is a lava shield with a central crater. Scoria cones occur about most of the other vents. A short lava tube is known on the southern side of Barkers Crater. The plateau also has some small areas of Featherby Surface (see below) developed on deeply weathered Mesozoic sandstones. Basaltic lava flows originating on the plateau have flowed down several of the valleys cut into the Burdekin Uplands.

The *Nulla Plateau* in the southeast of the area is also formed from basaltic lavas, mainly at elevations between 520 and 620 m, although there are also isolated basalt mesas up to 820 m high in the area between the Nulla and Chudleigh Plateaux. Scoria cones occur to the south of the map area. A basaltic lava flow originating in the headwaters of the Clarke River flowed for at least 85 km down the river.

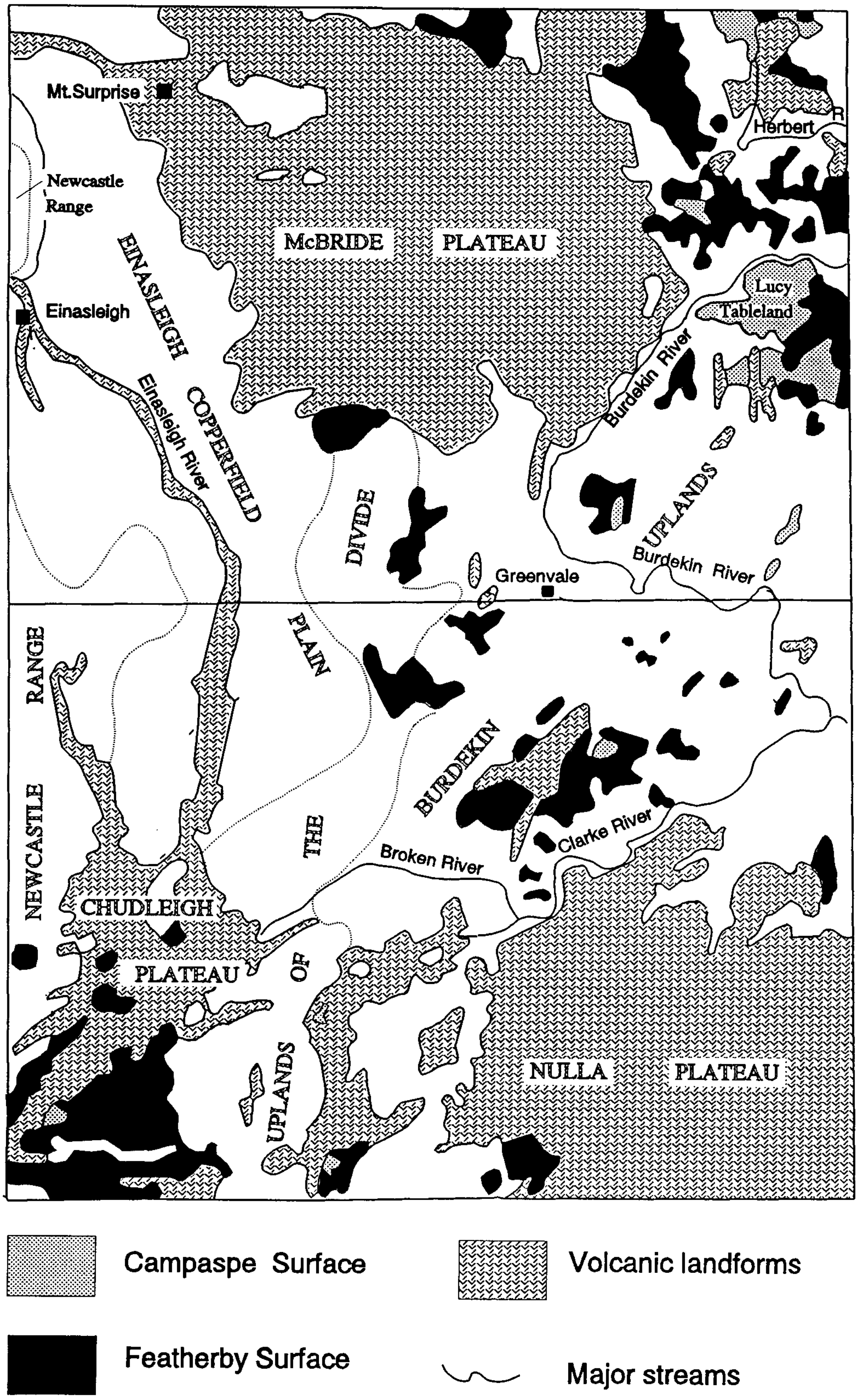


Figure 2. Physiographic units and erosion surfaces in the Einasleigh and Clarke River 1:250 000 Sheet areas.

Twidale (1956b) recognised lateritised surfaces, valley-side facets, and nick points, representing three cycles of erosion. Grimes (1979) correlated the two main old land surfaces in the region with named surfaces in the Charters Towers area: The Featherby Surface is an undulating deeply weathered surface, and the younger, less extensive, Campaspe Surface is a flat, partly ferruginised, depositional surface which buries parts of the Featherby Surface. The distribution of these surfaces within the region is shown in Figure 2.

GEOLOGICAL SETTING

The structural framework of the Cairns-Townsville hinterland is shown in Figure 1. The Palaeozoic Broken River Province (Arnold & Henderson, 1976; Henderson, 1980) which is also known in the literature as the Broken River Embayment (Hill, 1960; White, 1965; Day & others 1983) or Broken River Rift (Harrington, 1981), may be a continuation of the Hodgkinson Province, but the two are separated by younger rocks and their exact relationship is unknown. The Hodgkinson Province is largely dominated by turbidites.Arnold (1975) and Arnold & Henderson (1976) recognised two subprovinces with distinct tectonic styles within the Broken River Province; the Camel Creek Subprovince in the east and the Graveyard Creek to the west are separated by the meridional Gray Creek Fault. The type of movement is not definitely known, but it may be a thrust.

The Broken River Province is separated from the Georgetown Province to the west by a major fault system including the Burdekin and Halls Reward Faults. The Georgetown Province (White, 1965; Withnall & others 1980, 1988a; Withnall, 1984, 1989b; Withnall & Grimes, 1991), consists predominantly of Proterozoic metamorphic rocks, Proterozoic and early Palaeozoic granitoids, and in the eastern part, early Palaeozoic metavolcanic and metasedimentary rocks (Withnall, 1982, 1989b).

The nature of the eastern margin of the inlier is not definitely known; the Burdekin and Halls Reward Faults are associated with mylonite zones and may be thrust faults, although the southeastern margin is a normal fault (the Teddy Mount Fault). To the south, the Lolworth-Ravenswood Province or Block (Wyatt & others 1970, 1971; Levingston, 1981; Hutton & others, 1990b; Withnall & McLennan, 1991) consists of probable Proterozoic metamorphic basement and Early Palaeozoic volcanic and sedimentary rocks intruded by Ordovician to Early Devonian granitoids. The boundary between the Lolworth-Ravenswood Block and the Broken River Province is the Clarke River Fault a ductile mylonite zone interpreted here as a transcurrent fault. It is mainly obscured by younger rocks to the east along the southern margin of the Camel Creek Subprovince. A later brittle fault with vertical movement, marking the southern edge of the Graveyard Creek Subprovince, mainly follows the older ductile fault.

Both subprovinces contain quartz-rich and labile turbidite sequences, and some submarine volcanic rocks. Intense deformation resulting in the development of broken formation or melange is evident throughout the Camel Creek Subprovince, but is restricted to the oldest rocks in the Graveyard Creek Subprovince. The geology of the Camel Creek and Graveyard Creek Subprovinces is shown in Maps 1 and 2 and generalised in Figures 3 and 11 (respectively).

Unlike the Camel Creek Subprovince, a coherent stratigraphy can be recognised in the Graveyard Creek Subprovince. The stratigraphic framework resulting from the current work, together with previous nomenclature is presented in Figure 12 The Graveyard Creek Subprovince contains an Early to Middle Devonian shelf sequence not present in the Camel Creek Subprovince. It also includes Late Devonian to Carboniferous fluviatile to shallow marine sedimentary rocks, and minor volcanic rocks. These later rocks were deformed with the older rocks in one main deformation, presumably in the Carboniferous before being intruded by a group of granitic plutons. On the other hand, the Camel Creek Subprovince was deformed by at least two events before it was overlain unconformably by the weakly deformed, mainly fluviatile Carboniferous rocks of the Clarke River Basin. Widespread deep-weathering occurred during the Tertiary, and extensive, plateau-forming laterite covers parts of the area. Tertiary to Quaternary basalt flows, from the Chudleigh and Nulla Basalt Provinces overlie the Broken River Province on its western and southern margins respectively.

ECONOMIC GEOLOGY

The Broken River Province is host to a range of generally small mineral deposits. They were not studied in any detail during our survey, but will be covered by mineral occurrence mapping as part of the joint AGSO-GSQ National Geoscience Mapping Accord North Queensland Project, and published separately. The deposits were previously reviewed briefly by White (1965). Some of the deposits that occur in VALLEY OF LAGOONS were described by Withnall & Grimes (1991). The region has been investigated intensively by exploration companies, particularly in the last 20 years. Reports recording the results of these surveys are filed at the Department of Minerals and Energy, and can be accessed with the aid of the Department's QERI bibliographic database.

Gold deposits are the most economically significant deposits in the area. The most important are in the Camel Creek area, the so-called 'Amanda Bel goldfield'. They were described by Teale & others (1989), and occur in shear zones (possibly melanges) in the Kangaroo Hills Formation. Since 1986, alluvial gold has been worked extensively in the Broken River-Diggers Creek area. The deposits are now exhausted. The source of the gold is not known. Other small hard-rock gold prospects discovered by recent exploration are shown on the Broken River Special map. Antimony was worked at the Phar Lap mine and other small deposits in the Broken River area (White, 1965), and is also associated with some of the gold lodes in the Camel Creek area.

The Bundock Creek Group was considered to have potential for stratabound and hydrothermal uranium deposits, and was explored intensively by Urangesellchaft (Australia) Pty Ltd and Minatome (Australia) Pty Ltd in the 1970s (Guillebert & others, 1979). Numerous small uranium anomalies were investigated, and the most significant of these are shown on the Broken River Special map as prospects. The largest was the Teddy Mount prospect where fracture controlled uranium mineralisation was hosted by a rhyolite intrusion. Alluvial tin was mined in the 1970s and early 1980s in Recent alluvial deposits in the headwaters of Redbank and Perry Creeks. Tertiary alluvial deposits were mined at Ruxton and Sandy Flat in CLARKE RIVER (Burger, 1987).

Other deposits include tungsten, chromite and nickel. Tungsten was mined on a small scale in the Perry Creek area (Withnall & Grimes, 1991). Small pods of chromite in the Gray Creek Complex were described by Krosch (1990). The nickel deposits are in laterite developed on serpentinite at the northern end of the Gray Creek Complex. They are similar to, but much smaller than the nearby Greenvale deposit in the Boiler Gully Complex, which was mined between 1974 and 1992 (Burger, 1979, 1987; Withnall & Grimes, 1991).

STRATIGRAPHY OF THE CAMEL CREEK SUBPROVINCE

(I.W. Withnall)

The Camel Creek Subprovince consists mainly of highly deformed flyschoid and mafic volcanic rocks which were divided by White (1959, 1962a, b, 1965) into six formations, the Wairuna, Greenvale, Kangaroo Hills, Pelican Range, and Perry Creek Formations and Tribute Hills Sandstone. Arnold (1975) suggested that applying normal stratigraphic procedures as White had done was inappropriate and misleading, because of the strong deformation, stratal disruption due to thrusting, and lack of age control, all of which make resolution of primary superpositional relationships very difficult. He also found little support for sharp subdivisions between rocks included by White in the Greenvale, Wairuna, and Kangaroo Hills Formations, although he admitted that very few well exposed parts of the Wairuna Formation had been examined, and that more detailed sedimentological studies may provide a basis for future subdivision.

As a result of our study, White's subdivisions have been justified. The formations are distinct mappable units, although the relationships between them have been re-interpreted, some boundaries extensively modified, and significant areas of rocks re-assigned to different units. The problem of applying normal stratigraphic procedures in the strict sense remains. However, no satisfactory alternative to the formation type of nomenclature currently exists for strongly deformed sedimentary rocks. White's nomenclature is well-established, and is retained here even if internal stratigraphy, thickness, and boundary or superpositional relationships are unclear or unknown. With metamorphic and igneous rocks, some of the rules of stratigraphic nomenclature are relaxed, and a similar procedure has been adopted here. White (1959) designated only type areas and not type sections. Where possible, type sections have herein been designated to include the boundaries with adjoining units. However, none of these is likely to be a complete section, and most are likely to contain numerous repetitions due to faulting and folding. Another problem, which resulted from the remapping of the units, is that some of White's type areas (although generally rather vague) no longer fall within the units for which they were designated. Rather than introduce new names for well-established units, the units in question are taken to be as White (1962a, b) generally mapped them, and new type sections are designated.

CARRIERS WELL FORMATION

Introduction

The Carriers Well Formation is the westernmost unit in the Camel Creek Subprovince and forms a belt 20 km long and 1 km wide abutting the Gray Creek Complex, from which it is separated by the Gray Creek Fault. About 5 km farther east another belt of similar lithologies, 15 km long and up to 2 km wide, is tentatively assigned to the Carriers Well Formation.

The Carriers Well Formation was previously defined by White (1959, 1965) as the Carriers Well Limestone Member of the Wairuna Formation, along with the Everetts Creek Volcanic Member. Because of the uncertainty of the relationships of these units to the Wairuna Formation, Withnall & others (1988b) regarded them as separate units and assigned them formation status. The name Carriers Well Formation was used because limestone is not the dominant lithology.

Type and reference sections

White (1959) gave the type area 'in Spring Creek between Spring Creek yard and Gray Creek and also in Dinner Creek east of the track crossing'. Neither of these sections is complete, being faulted to the west against the Gray Creek Complex. However, as the entire western margin of the unit is faulted, no complete section exists anywhere. Both sections are disrupted by folds and melange zones, but that in Dinner Creek is less affected, and is here designated as the type section. Because of the folding the overall younging of the sections is unclear, but it is likely to be westward as for the rest of the Camel Creek Subprovince. Younging directions determined in the field tend to support this. If younging is westward, the contact with the Everetts Creek Volcanics is the base. The section in Dinner Creek is from 7859-840878 (about 200 m east of the present road crossing, which is much farther east than that in 1959) upstream to 821867, the contact with the Gray Creek Complex.

About 200 m of chaotic, very weathered breccia, consisting of feldsparphyric volcanic clasts in a muddy to sandy matrix overlies spilitised mafic lavas of the Everetts Creek Volcanics. These breccias may be olistostromal deposits or debris flows. Some primary(?) crystal-lithic tuff, volcanilithic arenite, and chert also crop out. The arenite has graded beds and load casts.

Overlying this sequence at the road bridge is about 20 m of purple to cream, thin-bedded, very fine to coarse-grained volcanilithic arenite and mudstone. The arenites are graded and locally have flame structures and load casts, and young to the west. Interbedded with the arenites are thin to medium beds of conglomerate which are poorly sorted and consist of angular volcanic and chert clasts. Clasts are pebble-size, but some boulders, thicker than the beds in which they occur, are present. The volcanic conglomerates are probably debris flows, and the arenites are turbidites from a volcanic source. These rocks are overlain by 5 to 10 m of green altered volcanic rocks, probably lavas. About 50 m upstream of the road, thin to medium beds of black laminated radiolarian chert, locally tightly folded, are interbedded with conglomerate similar to those near the road.

The sequence upstream for about 2 km is similar to that near the bridge, although beds of quartzose arenite also crop out, and lenses of fine-grained, poorly fossiliferous limestone occur locally. The sequence is locally tightly folded and some melange is present, so the overall thickness is unknown. The contact with the Gray Creek Complex is marked by sheared serpentinite.

The section in Spring Creek extends from 7859-857919 (about 100 m above the junction with Gray Creek, where pillow lavas of the Everetts Creek Volcanics crop out) to the Gray Creek Fault at 848918, just downstream of the causeway. It consists of a strongly disrupted sequence of volcanic breccia and volcaniclastic arenite with pods of limestone, locally oolitic, up to 10 m long. The limestone occurs mainly in the upper (?) part of the section, within 500 m of the Gray Creek Fault. Quartzose arenite, mudstone, and chert are also intercalated with the volcaniclastic rocks.

The section is 800 m long but the true thickness is unknown because of the folding and disruption. Overall younging is also difficult to determine, but is probably to the west.

Lithology

In the main belt, the Carriers Well Formation is a very heterogeneous unit containing mafic to intermediate lavas and breccias, volcaniclastic arenite, quartzose arenite, limestone, and chert as described above in the type and reference sections. Like other units in the Camel Creek Subprovince, the Carriers Well Formation is strongly disrupted internally and melange is common. Some of these disrupted assemblages may be solely tectonic, but others may be tectonised olistostromes and debris flows.

The volcanic breccias, which are probably largely subaqueous debris flows rather than primary pyroclastic deposits, are extremely poorly sorted, and consist mainly of purple to green, angular, volcanic clasts, as well as chert, siltstone, and mudstone. The rocks are commonly unbedded to very thick bedded and massive. Clasts are generally pebble to cobble size, but locally slabs of chert up to 1 m long occur. The volcanic clasts include fragments of andesite or basaltic lava, as well as fine-grained tuff, but commonly the clasts are chloritised and original texture and composition are difficult to determine. The matrix consists of sand to silt-sized volcanic material, but individual grains are commonly not resolvable in thin section; scattered plagioclase crystal fragments up to 2 mm are common in the matrix.

Volcaniclastic arenites are generally purple to cream, thin to thick-bedded, commonly graded, with flame structures, load clasts, and other features suggestive of turbidites. They range from very fine to very coarse-grained, and are locally interbedded with, or grade into conglomerate (Plate 1a). The arenites are quartz-poor (%) and consist largely of fine-grained mafic to felsic volcanic grains and plagioclase. Some also contain chert clasts.

An interesting feature of the unit is the intercalation of quartz-rich arenite and siltstone with the volcaniclastic rocks. Quartzose arenite is characteristic of the Wairuna Formation. In most places, outcrop is too poor to see actual contacts between the different lithofacies, and it is possible that they are tectonically interlayered on a small scale. The quartz-rich rocks are grey to brown and commonly thick to very thick-bedded and massive; thinner beds occur locally and some contain planar and convolute laminae and ripple cross laminae. The rocks are very fine to fine-grained and poorly sorted with up to 40% matrix, which consists of silt-sized quartz and phyllosilicates. They grade into siltstone. The quartz is generally monocrystalline with undulose extinction, moderate to low sphericity, and is subangular to subrounded. Minor plagioclase and sedimentary lithic clasts are present. The latter are mainly pelite and minor chert. The arenites are interbedded with mudstone which generally has a strong bedding-parallel cleavage. Commonly outcrops are strongly disrupted and pass into melange as described later.

Cherts are dark grey to green and generally laminated. They mainly consist of microcrystalline silica, but angular, silt-sized plagioclase clasts are common suggesting that the rocks are partly tuffaceous. Whitish laminae up to 2 mm thick in some beds are concentrations of such plagioclase.

Casts of radiolaria are common, but no skeletons were preserved in the thin sections examined.

The limestone, which White (1959, 1965) regarded as characterising the unit, occurs as sporadic lenses. These are generally only a few tens of metres long (or less), but a few are up to 200 m long. They consist mainly of massive, fine-grained muddy limestone and locally, coarse to very coarse-grained calcarenite and calcirudite, containing organic debris including crinoids, brachiopods, nautiloids and corals. Oolitic limestones, generally well-sorted oolitic grainstones, are present locally. Some of the muddier limestones also contain sporadic reworked ooids. The relationships of the larger lenses could not be determined, because they are surrounded by areas of no outcrop. The limestones in the Spring Creek section are commonly associated with debris flow deposits and may be allochthonous; others could be blocks in tectonic melanges. However some thin beds appear to be *in situ* and may be carbonate turbidites. The limestones are strongly stylolitised and some calcirudites may be stylo-breccias.

The belt of rocks tentatively assigned to the Carriers Well Formation to the east of Gray Creek has not been examined as closely. It appears to contain a similar assemblage of rocks, although breccias (debris-flow deposits) appear to be less abundant, and andesite or basalt and locally dacite (or keratophyre) lavas are more common. The mafic lavas consist of sericitised plagioclase (albite) with interstitial chlorite and opaques and are commonly veined by calcite. One sample of keratophyre (GSQR 13588, Appendix) consists mainly of plagioclase with minor interstitial quartz and chlorite. Quartzose arenite, mudstone, and chert are present, and limestone is common. Most of the limestone lenses are less than 100 m long, but in the headwaters of Stockyard Creek towards the northern end of the belt, one lens is about 2.5 km long and up to 400 m thick. Like the others it is commonly oolitic, consisting of massive, medium to thick beds of medium to coarse-grained oolitic grainstone and some finer, muddy limestone. The ooids are nucleated mainly on skeletal grains or fine grained micritic carbonate with algal cell remains. The sparry cement was deposited early in the diagenetic history, before compaction. The rocks are strongly stylolitised, and much of the bedding is modified by pressure-solution. As in the west, the relationship of the limestones to the surrounding rocks is unknown and they could be allochthonous. However, the apparent lack of debris-flow deposits suggests that they could be *in situ* and have developed on the top of shallowly submerged volcanic rises.

Relationships

The Carriers Well Formation is faulted to the west against the Gray Creek Complex along the Gray Creek Fault. The nature of this fault is uncertain, but it may be a thrust (see later in this report). The Everetts Creek Volcanics bound the Carriers Well Formation to the east. They are distinguished from the Carriers Well Formation by being largely mafic lavas and some volcaniclastics, and lacking limestone and quartzose arenite. The overall younging is uncertain, but it is probably to the west as for the rest of the Camel Creek Subprovince. If so, the Carriers Well Formation overlies the Everetts Creek Volcanics, assuming that the contact is stratigraphic. The relationship of the eastern belt of Carriers Well Formation to the Wairuna Formation which surrounds it is not known. It could be a thrust slice, and the small serpentinite bodies which occur in and around it may have been emplaced along such thrusts.

Fauna and age

Fragments of corals, brachiopods, crinoids and nautiloids are present in some of the limestone outcrops. The best preserved and most diverse coral fauna is from outcrops of the Carriers Well Formation in Gray Creek near the stream gauging station at 7859-867939. It has yielded a rich tabulate fauna, consisting of sixteen species of heliolitids, seven species of halysitids, two *Favosites* spp., *Agetolitella* sp. and ?*Pachyfavosites* sp. Rugose corals are less common with eight genera being recognised, and of these *Grewingkia* is the most common (Jell & others *in* Withnall & others, 1988b).

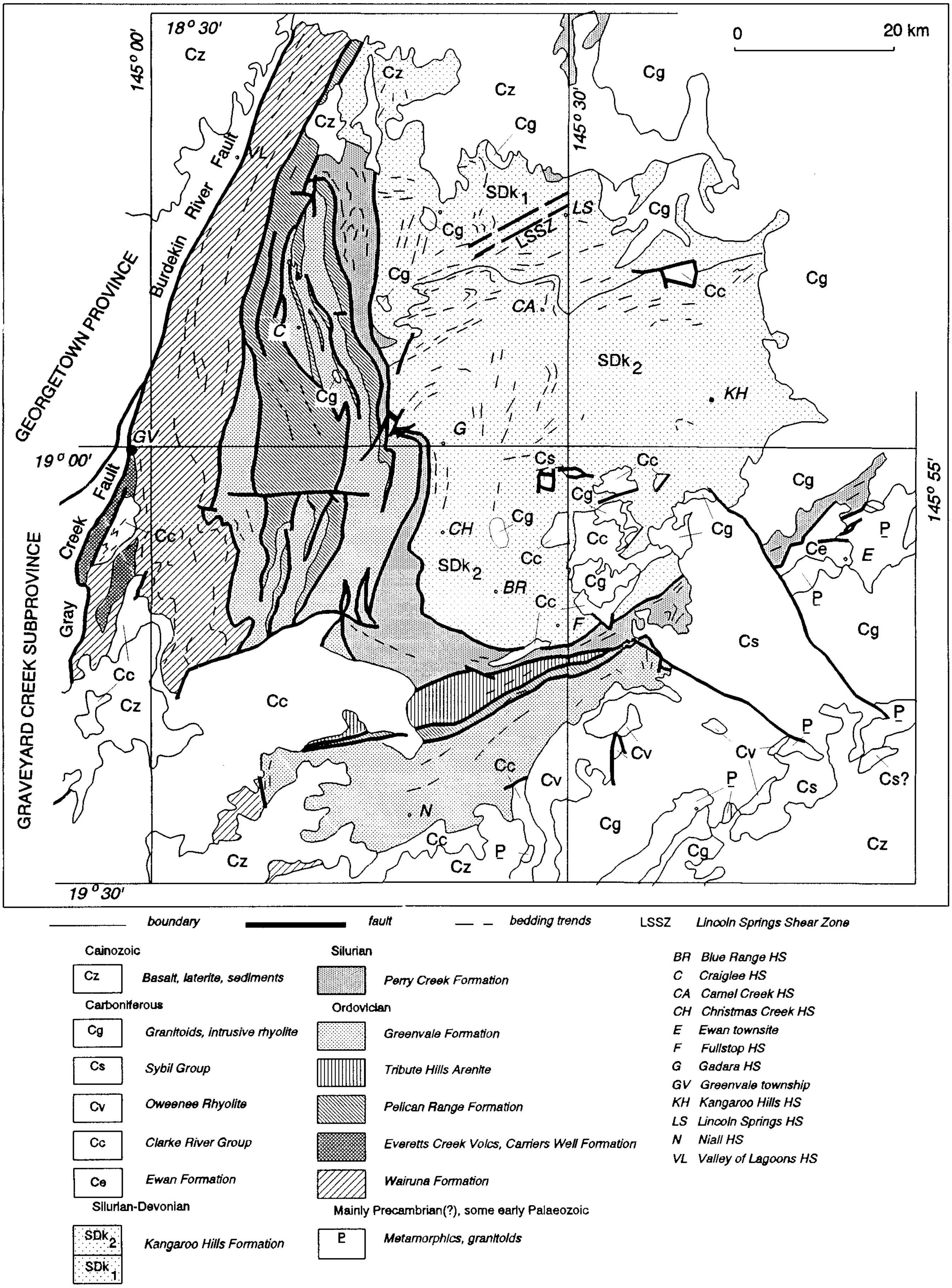


Figure 3. Simplified geological map of the Camel Creek Subprovince.

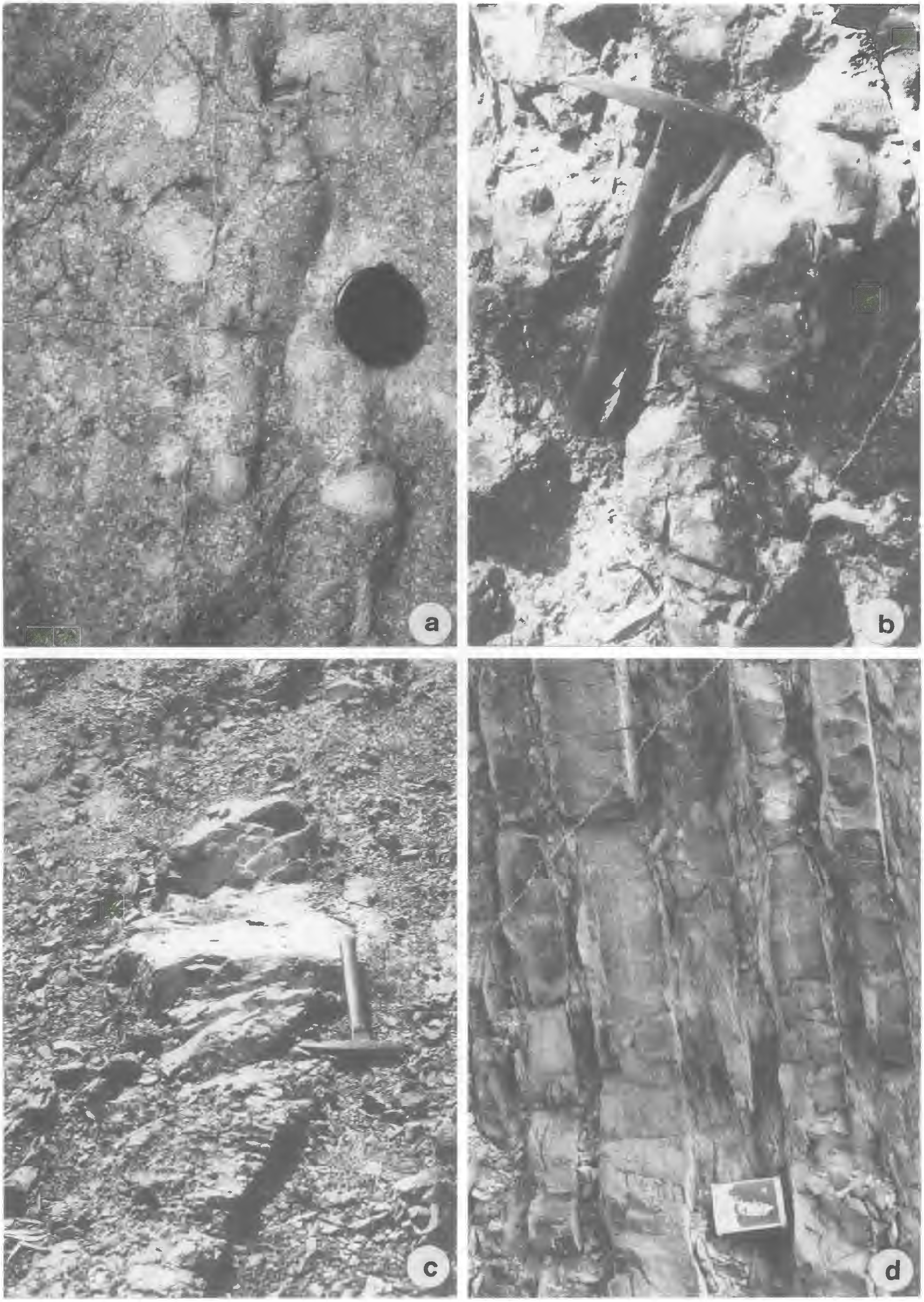


Plate 1. Everetts Creek Volcanics, Carriers Well Formation and Wairuna Formation.

Conodonts from the above locality are listed in Palmieri (1978, pp. 5,6) and are considered by him as Late Ordovician and the same age as the upper conodont fauna of the Fork Lagoons Beds in the Anakie Inlier. The conodonts and corals from the other limestones of the Carriers Well Formation are not as well preserved nor as abundant, but they are consistent with a Late Ordovician age (Palmieri, 1984).

EVERETTS CREEK VOLCANICS

Introduction

As noted above, the Everetts Creek Volcanics, along with the Carriers Well Formation, were originally defined as a member of the Wairuna Formation. Because of the uncertainty of its relationship with the Wairuna Formation, the unit is now given formation status (Withnall & others, 1988b). It is restricted to a narrow north-trending belt about 1 km wide straddling Gray Creek for about 15 km south from Greenvale.

Type area

White (1959) gave the type area "along Gray Creek and Dinner Creek". No detailed section was examined during this survey, but the unit is well exposed between 7859-840878 (the boundary with the Carriers Well Formation) in Dinner Creek, and 859919 the junction between and Gray Creek and Spring Creek. The full range of lithologies as described below is exposed in this area.

Lithology

The Everetts Creek Volcanics consist predominantly of variously altered mafic volcanics. The rocks are mainly lavas, and are green to purple, aphyric to feldsparphyric, commonly strongly veined by calcite and epidote, and locally amygdaloidal and pillowed (Plate 1b). The primary mineralogy is mostly altered (plagioclase is sericitised and albitised, and pyroxene is replaced by chlorite). Chlorite also fills vughs, amygdales, and joints. Less altered samples (e.g. GSQR 13585, Appendix) contain unaltered augite and opaques, interstitial to randomly orientated laths of plagioclase (albite?). Some lavas (e.g. GSQR 13584) have a trachytic texture with strongly aligned plagioclase laths.

Geochemistry (see later) shows that Na_20 is relatively high in these rocks, suggesting that they have been spilitised. The $Si0_2$ content suggests that both basalt and andesite are present. More felsic lavas such as porphyritic dacite (e.g. GSQR 13586, Appendix) also occur. These are grey to purple and consist of plagioclase and minor quartz phenocrysts in a groundmass of intergrown feldspar laths and quartz.

Also interbedded with the lavas are volcaniclastic rocks (crystal-rich and lithic-rich arenite and breccia - Plate 1a) and minor chert and siltstone.

Relationships

The Everetts Creek Volcanics are probably overlain by and grade into the Carriers Well Formation from which they are distinguished by the abundance of lavas and less abundant sedimentary rocks including limestone. The relationship to the Wairuna Formation to the east in not known. It could be stratigraphic (?overlying the Wairuna Formation) or faulted. The unit is overlain by and faulted against an outlier of Late Devonian to Carboniferous Venetia Formation of the Clarke River Group.

Age

No direct evidence for the age of the unit is available, but because of the gradational relationships, it is probably not much older than the Carriers Well Formation. It is therefore considered to be Late Ordovician.

WAIRUNA FORMATION

Introduction

The name Wairuna Formation as defined by White (1959) is retained, but as described above, the Everetts Creek Volcanic Member and Carriers Well Limestone Member are excluded and given formation status. Arnold (1975), Arnold & Henderson (1976), and Arnold & Rubenach (1976) assigned the rocks west of the Gray Creek Fault in the Graveyard Creek Subprovince to the Judea Beds (since renamed the Judea Formation by Withnall & others (1988b)), although they are similar lithologically, and may be related in age and origin to the Wairuna Formation. Some areas mapped by White (1962a, 1965) as Greenvale Formation in the Porphyry Creek area in CLARKE RIVER are here assigned to the Wairuna Formation.

As now mapped, therefore, the Wairuna Formation crops out along the western edge of the Camel Creek Subprovince as a belt 8 to 15 km wide, extending for about 80 km south from near Wairuna homestead to the headwaters of Porphyry Creek in CLARKE RIVER. Farther south a small area (about 10 km^2) adjacent to the Clarke River Fault and centred about 4 km northeast of Craigie Outstation, is also assigned to the Wairuna Formation.

Type and reference sections

White (1959) gave the type area as Wairuna Station. This area is generally deeply weathered and no sections were examined there during this survey. Outcrops consist predominantly of mudstone, quartzose arenite, and minor altered basalt and jasper. White also mentioned that "good reference sections are exposed in the Broken River and Gray Creek". The former is now mapped as Judea Formation (Arnold & Henderson, 1976; Withnall & others, 1988b; Withnall, 1989a), but the section along Gray Creek from 7859-882958 downstream to the railway bridge at 7959-937966 does cut through the Wairuna Formation and exposes most of the lithologies.

The Lynd Highway from Redbank Creek at 7859-888975 to about 200 m west of Porphyry Creek at 7959-982936 (the approximate position of the boundary with the Greenvale Formation) traverses the whole belt from west to east; road cuttings and outcrops in adjacent gullies expose all of the known lithologies, and it is therefore also designated as a reference section.

PLATE 1:

a. **Volcanic breccia showing subangular andesite clasts in a sand-sized matrix of crystal and lithic clasts. Everetts Creek Volcanics. 7859-825848, Gray Creek.**

b. **Pillow basalt. Everetts Creek Volcanics. 7859-858918, Spring Creek, 100 m upstream of junction with Gray Creek.**

c. **Large volcanic block in medium bed of volcaniclastic conglomerate. Carriers Well Formation. 7859-837877, Dinner Creek near Greenvale-Broken River road bridge.**

d. **Thin beds of quartzose arenite showing ripple cross-laminated tops and interbedded with mudstone. Wairuna Formation. 7859-888975, road cutting on Lynd Highway road, 1 km east of Greenvale township.**

Lithology

The Wairuna Formation consists predominantly of cleaved mudstone, siltstone grading into mainly fine-grained quartzose arenite, altered basalt, chert, and jasper. Cleaved mudstone and basalt are the most abundant lithologies accounting for the generally subdued relief (except in areas of dissected laterite plateaux). The mudstones are generally grey or green where fresh, and are strongly cleaved. Interbeds of arenite and chert are commonly disrupted, and the outcrops can be described as tectonic melange.

The basalts are generally green to purple, very fine-grained, aphyric rocks. Most outcrops are massive and strongly jointed and veined by epidote and calcite, but amygdales and rare pillows are present locally. The rocks generally consist of randomly orientated laths of saussuritised plagioclase with interstitial clinopyroxene and leucoxene. Calcite has replaced plagioclase in some specimens, and the pyroxene is altered to chlorite which also occurs along joints and in amygdales. Amygdales are usually filled by calcite. As described later, the basalts are similar geochemically to ocean-floor or low-K tholeiites. The basalts form lenticular bodies 1 to 2 km long, but one unit can be traced for about 40 km from near Lake Lucy in the northern part of VALLEY OF LAGOONS to at least Poison Lake as a single belt 1 to 2 km wide. The volcanic rocks were originally mapped as dolerite (White, 1962a, b, 1965). Jasper is commonly associated with the basalt as massive 'blows' or thin beds.

Quartzose arenite is commonly interbedded with the mudstone, and where more abundant, forms more prominent hills. The arenite is generally thin to medium-bedded and fine-grained. It is commonly massive, but locally, partial Bouma cycles (grading, planar and ripple cross laminae, and convolute bedding) are present (Plate 1d). The rocks are poorly sorted and consist predominantly of subangular, monocrystalline, strained quartz grains with low sphericity. Minor feldspar (mainly plagioclase), detrital mica, chert, and pelitic sedimentary clasts are also present, along with a matrix of silt-sized quartz and fine phyllosilicates. Coarser grained arenites are generally not common, but they are the dominant lithology in a range of hills east of Gray Creek between Big Stockyard Creek and the headwaters of Tomcat Creek. Thick to very thick bedded, massive, medium to coarse-grained quartzose arenite and minor mudstone crop out there. Rare, matrix supported conglomerate has been recorded elsewhere. The pebbles are largely aggregates of strained, commonly elongate quartz grains, as well as quartz tectonites, metaquartzite, and less abundant chert, siltstone and mudstone clasts. The matrix is dominantly quartzose with minor feldspar.

Chert and jasper, although commonly associated with the basalts, are also interbedded with the sedimentary rocks. They commonly form prominent ridges, and range from thinly bedded to unbedded outcrops up to 20 m thick. Beds are commonly boudinaged and strongly folded, probably due in part to slumping. The rocks are generally red, but grey or green varieties also occur. They consist of relatively pure microcrystalline silica with sporadic circular radiolarian casts.

Relationships

The Wairuna Formation is faulted against the Proterozoic Halls Reward Metamorphics along the Burdekin Fault which is the boundary between the Georgetown Province and the Camel Creek Subprovince. South of the Lucky Downs homestead, the fault becomes the Gray Creek Fault, which separates the Graveyard Creek and Camel Creek Subprovinces. Both this fault and the Burdekin Fault may be thrusts, as outlined later in this report. North of Greenvale township, the Wairuna Formation extends right to the Gray Creek Fault, but to the south the Everetts Creek Volcanics and Carriers Well Formation crop out between the Wairuna Formation and the fault. The relationships between the Wairuna Formation and the Everetts Creek Volcanics and Carriers Well Formation are uncertain. They may be entirely tectonic, or they could be stratigraphic and interfingering at least in part. The quartzose arenite intercalated with immature volcaniclastic rocks in the Carriers Well Formation is identical to that in the Wairuna Formation.

The relationship with the Greenvale Formation is uncertain. The contact appears to be marked by a relatively abrupt change from quartzose to labile arenite. In the headwaters of Gill Creek in CLARKE RIVER, the Greenvale Formation youngs westwards towards the contact, suggesting that the Wairuna Formation is younger. However, if, as discussed below, the Camel Creek Subprovince is a pile of imbricately stacked thrust sheets, the contact between them may be tectonic, the Wairuna Formation having been thrust over the Greenvale Formation.

Bodies of serpentinite (including some clinopyroxenite and metagabbro lenses) intrude the Wairuna Formation. They were probably emplaced tectonically along and adjacent to major thrust(?) faults. The largest body, in the northern part of VALLEY OF LAGOONS, is up to 1 km wide and at least 15 km long. It is parallel to and about 1.5 km east of the Burdekin Fault. Small bodies, 1 to 5 km long, occur farther south along the Gray Creek Fault and up to 4 km east in the headwaters of Big Stockyard Creek (BURGES). Some also occur in the Wairuna Formation in the Craigie area, along the Clarke River Fault and near a postulated continuation of the Gray Creek Fault, along which rocks assigned to the Wairuna Formation are faulted against the Broken River Group.

The Wairuna Formation is unconformably overlain by the Carboniferous Clarke River Group and Cainozoic basalt and sediments.

Age

No fossils are known from the Wairuna Formation as now mapped. The rocks from which White (1965) described fossils are now assigned to other units. An Ordovician age is however considered likely, because of the lithological similarities with the Judea Formation, which is probably Early to Middle Ordovician.

GREENVALE FORMATION

Introduction

White (1959) first named and defined the Greenvale Formation for a belt of rocks extending from the southern edge of the Lucy Tableland to the headwaters of Gill and Porphyry Creeks, and consisting of "quartz siltstone, shale with lenses of quartz greywacke, greywacke, and pebble greywacke conglomerate". The rocks immediately south of the Lucy Tableland were thought to be unconformably overlain by the Kangaroo Hills Formation (White, 1959, 1962b, 1965; White & Wyatt, 1960). This relationship is now known to be conformable, and the rocks are included in the Kangaroo Hills Formation. The two formations are similar in many respects, and Withnall & others (1988b, p. 15) suggested that the name Greenvale Formation might be discarded. However, the arenites in the Greenvale Formation are more lithic (Figure 5), and the unit locally contains basalts, and is conveniently separated from the Kangaroo Hills Formation by a continuous belt of Perry Creek Formation. The name is therefore retained. Some quartzose arenite and mudstone in the headwaters of Porphyry Creek are now assigned to the Wairuna Formation.

Rocks on the southern limb of the Clarke River Orocline (see later in this report) were assigned by White (1962a, 1965) to the Kangaroo Hills Formation in CLARKE RIVER. In adjoining EWAN, Wyatt & others (1970) assigned them to the Greenvale Formation, although the reasoning used is not valid. Nevertheless, we too have assigned them to the Greenvale Formation because the arenites are lithic and the rocks occupy the same position with respect to the Perry Creek Formation as the Greenvale Formation on the other limb of the orocline.

Therefore, as now mapped, the Greenvale Formation crops out in two areas. On the western limb of the Clarke River Orocline, it forms a belt 60 km long and up to 20 km wide between Cleanskin Creek in VALLEY OF LAGOONS and the headwaters of Gill Creek in CLARKE RIVER. In this belt, it alternates with fault slices of Pelican Range Formation. On the southern limb it forms a belt about 10 km wide, from the headwaters of Black Gin Creek in EWAN for at least 40 km west-southwest to Niall in CLARKE RIVER. It probably extends another 20 km west-southwest, but this area was not examined because the rocks are mostly poorly exposed and deeply weathered, and access is poor. In general, the Greenvale Formation forms low undulating topography in contrast to the hilly Pelican Range and Perry Creek Formations. It is best exposed in small creeks and gullies.

Type and reference sections

White (1959) gave the type area as 'Porphyry Creek, about 6 miles (10 km) south-southeast of Greenvale Station. Also well-exposed along the Greenvale Camel Creek road between the Pelican Lake Range and Black Dog Creek'. The latter, as now mapped, includes some Pelican Range, Perry Creek and Kangaroo Hills Formations; the Greenvale Formation is exposed between 7960-080088 and 166056 with several fault slices of Pelican Range Formation. The locality in Porphyry Creek was not re-examined, but lithic arenite and polymictic conglomerate are exposed 3 km downstream at the bridge where the Lynd Highway crosses the creek.

Because of the tectonic disruption, which has resulted in the unit forming alternating fault slices with the Pelican Range Formation, it is not possible to define a type section in the strict sense with a base and top. Sections exposed along the Lynd Highway are more accessible and better exposed than either of White's type areas, and are here designated as reference sections. The sections are: (a) between 7959-984936 (the bridge over Porphyry Creek, close to the boundary with Wairuna Formation) and 042898 (the western boundary of a large slice of Pelican Range Formation); and (b) between 137864 (the eastern boundary of another slice of Pelican Range Formation) and 209869 (the western boundary of the Perry Creek Formation). All of the contacts are probably tectonic. The typical range of lithologies and facies associations as outlined below are exposed in these sections.

Lithology

The Greenvale Formation consists of lithic arenite and mudstone with subordinate polymictic conglomerate and mafic volcanic rocks. Three broad intergradational facies can be recognised - thickly bedded arenite, alternating arenite/mudstone, and areas of predominantly mudstone and siltstone. Similar facies are recognised in the Pelican Range, Perry Creek and Kangaroo Hills Formations and Tribute Hills Arenite.

In the thickly bedded facies, mudstone beds are subordinate to absent. The arenites are generally coarse-grained, and individual beds range from less than 1 m to more than 5 m; in some road cuttings on the Lynd Highway, sections of more than 30 m without an obvious bedding plane or break can be observed. The beds are commonly internally massive, but parallel laminae and normal and inverse grading occur locally. Medium-scale cross-laminae are present in rare outcrops. Bases are commonly scoured, and angular mudstone clasts occur at the bases of some beds. The thickly bedded facies can range up to 500 m in thickness with only minor intervals of the other facies. Elsewhere packets of thick beds less than 100 m or even single very thick beds may alternate with the other facies. The extent along strike of such packets is difficult to determine because of poor outcrop and structural complications, and no attempt was made to map them out.

The arenites are generally olive-green to brown, poorly sorted, and generally medium to very coarse-grained in the thickly-bedded arenite facies. Quartz is generally abundant (ca. 50%) and consists of angular, strained grains with low sphericity. The smaller grains are dominantly monocrystalline, but larger ones are composite, consisting of elongate interlocking subgrains. Quartz is commonly coarser than the other framework grains and forms conspicuous "eyes" in coarse-grained samples. Polycrystalline quartz as chert, metaquartzite, and quartz tectonites is also present. Minor slightly strained to unstrained quartz grains with embayed margins may be of volcanic origin, but most quartz is from a deformed plutonic/ metamorphic terrane. Feldspar is subordinate to lithic clasts. It is mainly plagioclase with bent twin lamellae, but also includes minor K-feldspar. Some composite quartz-feldspar (granitoid) clasts occur in coarser arenites. Lithic clasts are abundant, and although relative proportions are variable, the following types are usually present - fine-grained dacitic to andesitic or basaltic volcanics, quartzose arenite or siltstone, metaquartzite, cleaved mudstone to phyllite, and fine-grained quartz-mica schist. Amphibolite is present in some arenites. Detrital muscovite, biotite, and chlorite are common, and heavy mineral grains include epidote, tourmaline, and sphene, and less commonly garnet and hornblende. Matrix proportion is variable (10 to 20%), although in many rocks, matrix and diagenetically degraded lithic clasts are difficult to distinguish.

Pebbly arenites and matrix-supported polymictic conglomerate are present in the thick-bedded arenite facies, but are subordinate. Pebbles and cobbles include quartz, arenite, siltstone, shale, felsic volcanics, chert, mica schist, and rare granite, gneiss, and amphibolite. Limestone clasts are extremely rare in contrast to the Kangaroo Hills Formation (only one occurrence was recorded in the Greenvale Formation during this survey). The volcanic pebbles are generally cream, grey, or pink, and probably largely dacitic or rhyolitic, with quartz and feldspar phenocrysts or crystal fragments. One sample examined (GSQR 18362) is a tuff and contains unstrained, embayed quartz, K-feldspar, plagioclase, and lithic clasts in a fine-grained, recrystallised matrix.

In the alternating arenite/mudstone facies (Plate 2c), arenite and mudstone are in subequal proportions, and beds are commonly in the thin to medium range. The arenite beds commonly exhibit partial or complete Bouma cycles (generally the BCE divisions). Sole markings include load casts, flame structures, and trails. Rare burrows are also present. The arenites are very fine to medium-grained and grade into siltstone.

In the third facies, arenites are absent or subordinate, and mudstone and siltstone predominate. The mudstone is generally grey, where fresh, and cleaved. Siltstone generally forms thin to very thin beds or laminae in the mudstone, which is itself massive to laminated. The siltstone beds are locally cross-laminated and may form starved ripples.

As discussed later, the Greenvale Formation is interpreted as a turbidite sequence with both proximal and distal turbidites (corresponding qualitatively to the thick-bedded arenite and alternating arenite/mudstone to mudstone/siltstone facies respectively. No attempt to determine the relative proportions of these facies in a quantitative manner was attempted. The alternating arenite/mudstone facies is probably the most abundant.

Melange is common in the Greenvale Formation particularly in the alternating arenite/mudstone facies and mudstone/ siltstone facies. It corresponds to the "podded conglomerate" of White (1965, p. 45) which he interpreted as "wildflysch". Most is probably of tectonic origin and is associated with a strong "scaly" foliation, but some less cleaved outcrops of "pebbly mudstone" could be olistostromal.

Basalts are not common in the Greenvale Formation, but several lenses were mapped along the western edge near the contact with the Wairuna Formation. They may be *in situ*, or could be fault slices of Wairuna Formation. On the southeastern edge of the Camel Creek Subprovince, mafic volcanics, largely basaltic lavas, crop out within or adjacent to the Greenvale Formation. One area is 15 km east of Niall homestead where they are overlain by the Carboniferous Lyall Formation and Tertiary sediments. The other is 25 km northeast along strike where they are intruded by Carboniferous granite. The basalts are green, aphyric, and generally massive rocks, which consist of plagioclase (albite?) and completely uralitised pyroxene. Where they have been hornfelsed, they contain actinolite or bluish green hornblende. In the Niall area, volcanic arenite and rudite are interbedded with the basalts. They are poorly sorted and consist of angular plagioclase (0.1 to 1 mm) and lithic clasts (up to several centimetres). The lithic clasts are mainly grey to green, very fine-grained, and aphyric, consisting largely of plagioclase and minor interstitial chlorite and iron oxides. They are probably dacitic or andesitic in composition. A chemical analysis of one of these arenites (GSQR 13487, Appendix) shows the rock to be dacitic in overall composition. Hyaloclastic breccia (Plate 2d), associated with the basalt, consists of angular fragments of devitrified glass with spherulitic textures and pyroxene microlites in a calcite matrix. Grey to reddish chert or jasper is interbedded with the basalts as very thick, massive to crudely laminated beds or lenses.

Relationships

As noted above, the relationship with the Wairuna Formation is uncertain, but is likely to be a tectonic one, and the Wairuna Formation may have been thrust over the Greenvale Formation.

The Greenvale and Pelican Range Formations form a zone 10 to 15 km wide of alternating north-trending belts. Withnall & others (1985) suggested that the contacts between the belts may have been largely tectonic, and that the alternation of the "quartz-rich" and "quartz-intermediate" turbidite facies (after the terminology of Crook, 1974) represents imbricately stacked thrust sheets. Some of the large belts are clearly fault-bounded, because bedding trends are truncated at low angles. However, detailed examination of some contacts north of Craiglee homestead indicates that some of the smaller belts of quartzose arenite there are actually interbedded with the more liable arenites. Similarly, in almost continuous outcrop in cuttings along the Greenvale railway line at 7959-114863, the contact between very thick-bedded arenite of the Greenvale Formation and shales and quartzose arenite in a belt of Pelican Range Formation is abrupt, but shows no evidence of a fault; this suggests that the Greenvale Formation underlies the Pelican Range Formation at that point.

Therefore the Pelican Range and Greenvale Formations may represent two interfingering lithofacies, deposited at least partly contemporaneously, presumably from two different sources. A detailed palaeocurrent study, to determine whether different transport directions were involved, has not been attempted. However, the limited palaeocurrent data collected suggest currents from the southwestern quadrant for both formations.

It is probable that both imbricate stacking of thrust sheets and sedimentary interfingering account for the pattern of alternating belts. Zones of broken formation or melange which occur in both units may be related to thrusting; in places melange occurs at or near boundaries. The greatest development of such melange is in the westernmost belt of Pelican Range Formation, which extends for 60 km from near Lake Lucy to south of the Gregory Developmental Road. Melange is well exposed in cuttings along the road.

The contact with the Perry Creek Formation is also abrupt and is probably a fault. In Thatch Creek at 7959-210871, it is marked by a melange zone about 10 m wide consisting of chert phacoids in mudstone.

The Greenvale Formation is unconformably overlain by, and locally faulted against, the Carboniferous Clarke River Group and Oweenee Rhyolite. Tertiary basalt and poorly consolidated sediments also unconformably overlie the unit in places.

Age

No fossils have been found in the Greenvale Formation. The age is therefore uncertain. The volcanic source was possibly the Late Ordovician Carriers Well Formation and Everetts Creek Volcanics and their equivalents. It could therefore postdate these units or have been deposited contemporaneously as a forearc sequence. The greater abundance of mafic volcanic detritus in the Greenvale Formation than in the Kangaroo Hills Formation (which extends into the Early Devonian) and Perry Creek Formation (which is Silurian) could reflect the source having been largely eroded by the Early Silurian. The Greenvale Formation could therefore be Late Ordovician to Early Silurian in age.

PELICAN RANGE FORMATION

Introduction

White (1959) first defined the name Pelican Range Formation for a belt of quartzose arenite forming the main part of the Pelican Lake Range. White (1962b, 1965) showed a large part of the Pelican Lake Range as Greenvale Formation, although this may be a cartographic error.

The Pelican Range Formation forms several parallel belts alternating with Greenvale Formation and extending from near Lake Lucy in VALLEY OF LAGOONS for about 70 km to Gill Creek in CLARKE RIVER. The westernmost belt, the largest, is up to 10 km wide, but near the Lynd highway and to the south it breaks up into several smaller belts which alternate with the Greenvale Formation. The overall belt is up to 18 km wide. The unit generally forms hilly, densely wooded country in contrast to the lower topography of the Greenvale Formation. The main belt forms the Pelican Lake Range, which is locally capped by laterite.

On the southern limb of the Clarke River Orocline, a narrow belt of strongly deformed quartzose arenite and mudstone up to 1 km wide crops out between the Greenvale Formation and Tribute Hills Arenite, and is assigned to the Pelican Range Formation.

Type section

White gave the type area as the Pelican Lake Range. The most appropriate type section in this area is along the Greenvale-Camel Creek road which traverses the unit between 7960-028076 and 081088. Both contacts are faults against the Greenvale Formation. Quartzose arenite, mudstone, and minor basalt and chert are exposed in this section.

Lithology

The Pelican Range Formation is characterised by quartzose to sublabile arenite. The arenite is generally brown in outcrop, or purplish grey where less weathered, and is thin to very thick-bedded (Plate 2a), and interbedded with cleaved mudstone. The thick to very thick beds are generally massive or only weakly laminated. They are usually very fine to medium-grained. Coarse-grained arenites are very rare in the unit. Unlike the Greenvale Formation and Tribute Hills Arenite, the Pelican Range Formation rarely contains large intervals of very thick or unbedded arenite. Load and flute casts are common on the bases of the thick arenite beds. The thin bedded arenites are very fine-grained and grade into siltstone; planar laminae, cross-laminae, and convolute laminae are common (Plate 2b), and represent partial Bouma cycles. They are therefore interpreted as largely turbidites.

Strained, monocrystalline quartz is the most abundant framework grain in the arenites (80%). It is angular to subrounded, and generally has low sphericity. Small amounts of polycrystalline quartz include chert and metaquartzite. Minor feldspar is present, but is commonly sericitised and difficult to distinguish from the rare lithic clasts (which are mainly shale or metapelite). The rocks contain up to 40% matrix, which is recrystallised to fine-grained muscovite and chlorite. Detrital mica is common, and tourmaline is the most common heavy mineral. The interbedded shale or mudstone generally has a strong bedding-parallel fissility, and less commonly a cross-cutting cleavage. It is generally greenish grey, weathering to brown or purple.

The Pelican Range Formation is strongly disrupted, and zones of melange are common throughout the unit, particularly within the western belt.

Green, fine-grained, aphyric basalt occurs as a 6 km-long lens along Jacks and Hopewell Creeks near 'Craiglee'. It is associated with thin-bedded jasper and is locally pillowed. Another lens of similar basalt, about 3 km long, crops out about 10 km north of 'Niall' on the southern limb of the Clarke River Orocline. The basalt in Hopewell Creek (GSQR 18385) consists of laths of plagioclase (now albite), interstitial clinopyroxene crystals up to 1 mm, irregular patches of chlorite to 0.5 mm, and abundant opaques partly altered to leucoxene. Some of the chlorite may have replaced olivine. The rock is strongly fractured and veined by chlorite, saussurite, calcite, and minor zeolite. The basalt north of 'Niall' (GSQR 13491) is finer grained and not as altered. It consists of laths of albite to 0.25 mm, interstitial clinopyroxene to 0.1 mm, and leucoxene.

Radiolarian chert and jasper (without any obvious associated basalt) crops out in the Black Gin Creek area, north of Tribute dam at 8059-(501736).

Relationships

As discussed above for the Greenvale Formation, the Greenvale Formation and Pelican Range Formation crop out as alternating belts, which are may be due to both imbricate stacking of thrust sheets and sedimentary interfingering.

The Pelican Range Formation is probably faulted against the Wairuna Formation north of Camel Creek-Greenvale road in the Pelican Lake Range. The narrow belt of Pelican Range Formation on the southern limb of the Clarke River Orocline is probably also fault-bounded against the Tribute Hills Arenite, Perry Creek Formation, and Greenvale Formation.

Age

The Pelican Range Formation is unfossiliferous and its age is therefore uncertain. It is lithologically similar to the Judea and Wairuna Formations, which are both characterised by fine-grained quartzose arenite. The Judea Formation is known to be Early Ordovician (see later in this report). Quartz-rich turbidites similar to these units characterise the Ordovician of the Lachlan Fold Belt (Powell *in* Veevers, 1984, p. 293) and the same underlying reasons for this may have operated in the northern Tasman Orogen. The Mulgrave Formation, the only quartz-rich unit in the Hodgkinson Province (Shaw & others, 1987), has also recently been shown to be of Early Ordovician age (Bultitude, 1989; Bultitude & others, 1990).

It is therefore probable that the Pelican Range Formation is of Ordovician age.

TRIBUTE HILLS ARENITE

Introduction

White (1959) named and defined the Tribute Hills Sandstone as a unit of 'quartz sandstone with some quartz siltstone' forming the Tribute Hills in the Clarke River 1:250 000 Sheet area. The name was applied by Wyatt (1968) and Wyatt & others (1970) to rocks forming a continuation of the Tribute Hills in EWAN, but as noted below, most of these rocks are now mapped as Perry Creek Formation. The name is herein changed to Tribute Hills Arenite, because 'Sandstone' implies deposition by traction currents (Crook, 1960), whereas many of the rocks are probably turbidites.

As now mapped, the Tribute Hills Arenite forms a narrow belt, about 40 km long and up to 5 km wide, mainly to the south of the Clarke River in CLARKE RIVER, and extending as far east as Black Gin Creek in EWAN. It forms hilly topography with up to 140 m relief. However, unlike the adjacent Perry Creek Formation, which is also hilly, the Tribute Hills Arenite lacks strike ridges.

Type section

White (1959) designated Tribute Hills as the type area. The unit is well exposed from 7959-302687 in Maryvale Creek (the boundary with the Perry Creek Formation) upstream to 328351 in Owen Creek (the boundary with the Pelican Range Formation), and this is therefore designated as the type section. Neither contact is actually exposed, but both are sharp and may be faulted. The section contains mainly thick to very thick-bedded arenite with minor thin-bedded mudstone. Overall younging in the section is difficult to determine because of common reversals, but is probably to the south, as in adjacent units. Some outcrops are downward facing with respect to S_1. The Tribute Hills Arenite is recognised by the predominance of arenite whereas the Pelican Range and Perry Creek Formations contain abundant mudstone as well as arenite.

Lithology

The Tribute Hills Arenite consists predominantly of fine to very fine-grained quartzose arenite similar to that in the Pelican Range Formation. The main difference is that mudstone is relatively minor and thin bedded.

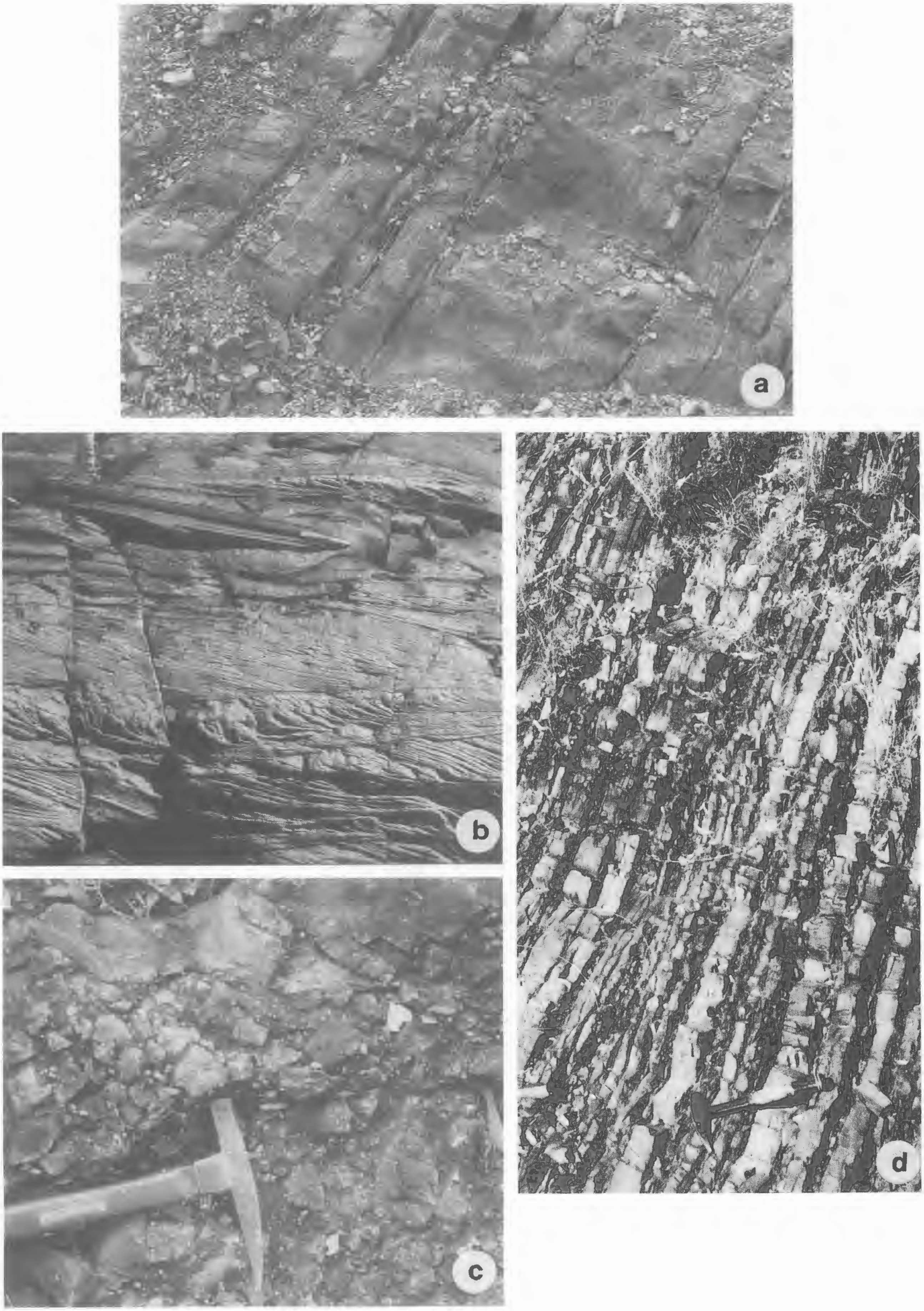


Plate 2. Pelican Range and Greenvale Formations.

The arenites are generally thick to very thick-bedded, and commonly amalgamated or have only thin mudstone partings. The beds are massive to laminated, and ripple cross laminae are common, particularly in thinner beds. Grading, erosive bases, and load casts are locally present. Partial Bouma cycles (AB, BCE and CE) suggest that the rocks are turbidites. A common feature of the quartzose arenites in the Tribute Hills Arenite is a diffuse layering, commonly parallel to bedding, but locally also crosscutting (Plate 7c). This is probably a tectonic layering. In thin section, the layering can be seen to be due to concentrations of phyllosilicates, commonly adjacent to fractures. Therefore the layering is probably due to dissolution, and similar to the 'rough' cleavage described from psammitic rocks by Gray (1978). Similar fabrics are present in fine-grained quartz-rich arenite and siltstone in the Pelican Range and Perry Creek Formations. Where the layering is parallel to bedding (eg. Plate 2a), it is difficult to distinguish from sedimentary layering, except for its diffuse, somewhat anastomosing appearance.

The arenites consist mainly of monocrystalline quartz, with minor quartz tectonites and chert. The minor labile components are mica, feldspar, and pelite clasts. The rocks are poorly sorted with up to 40% matrix consisting of silt-sized quartz and fine phyllosilicates. Detrital mica is locally abundant, giving some outcrops a flaggy nature.

Relationships

The Tribute Hills Arenite is probably fault-bounded to the north against the Perry Creek Formation, and to the south against a thin belt of Pelican Range Formation. The contact with the Pelican Range Formation is exposed in a cutting along the Lynd Highway at 7959-407700, where the Pelican Range Formation consists of strongly cleaved mudstone with thin phacoids of quartzose arenite; the boundary with the Tribute Hills Arenite is marked by the incoming of thick phacoids and boudinaged arenite beds. The contact, although apparently gradational, could be a fault, represented by a relatively wide melange zone. The Perry Creek Formation is also strongly deformed adjacent to boundary with the Tribute Hills Arenite. Intense melange occurs in Black Gin Creek at 8059-468725, and mudstone with strong platy foliation and arenite phacoids occurs in a gully at 7959-421689.

The Early Carboniferous Venetia Formation of the Clarke River Group unconformably overlies the Tribute Hills Arenite. A small pluton of Carboniferous or Permian hornblende quartz-diorite about 1 km in diameter intrudes the Tribute Hills Arenite about 2 km west of the Lynd Highway, and is surrounded by an aureole of cordierite hornfels.

Age

No fossils have been found in the Tribute Hills Arenite, and its age is therefore uncertain. However, as for the Pelican Range Formation, its quartz-rich nature suggests that it is Ordovician like the Judea Formation.

PERRY CREEK FORMATION

Introduction

White (1959) defined the Perry Creek Formation as "quartz sandstone, quartz siltstone with lenses of limestone and limestone conglomerate" from near 'Christmas Creek' to the Clarke River and east to the edge of the Clarke River 1:250 000 Sheet area. The presence of limestone conglomerate appears to have been regarded as a significant feature of the unit, because a separate smaller area in which limestone conglomerate occurs was also assigned to the Perry Creek Formation. This area is along and to the west of Perry Creek, about 5 km upstream from the junction with the Burdekin River. We have interpreted this as part of the Kangaroo Hills Formation, because the arenites are less quartzose than those in the Perry Creek Formation. We have found limestone-bearing conglomerates to be widespread in the Kangaroo Hills Formation also. White designated the type area of the unit in this area. However, because the unit is well-established, and no actual type section was designated, the name is retained here for the main area of Perry Creek Formation as mapped by White (1962a). The unit is also extended to include a belt of rocks previously included in the Greenvale Formation (White, 1962b) east of the Pelican Range Formation in VALLEY OF LAGOONS. In EWAN, it also now includes most of the Tribute Hills Sandstone and some of the Ewan Beds as mapped by Wyatt (1968) and Wyatt & others (1970).

As now mapped, the Perry Creek Formation extends almost continuously from the headwaters of Cleanskin Creek in VALLEY OF LAGOONS south for 70 km to the Clarke River in CLARKE RIVER, and then about 40 km northeast to Mount Fullstop Range on the western edge of the Sybil Graben in EWAN. It crops out east of the Sybil Graben as a narrow northeast-trending belt about 20 km long. A small area tentatively assigned to the Perry Creek Formation outside this main belt occurs on the southern edge of the Lucy Tableland at the head of Camel Creek.

The unit is topographically more prominent than either the Greenvale or Kangaroo Hills Formation, particularly in CLARKE RIVER and EWAN, where relief is up to 100 m. The Tribute Hills Arenite also forms hilly topography, but lacks the prominent strike ridges of the Perry Creek Formation.

Type section

A type section is designated in Thatch Creek, and cuttings along the adjacent Lynd Highway and Greenvale railway line between 7959-223861 (presumed faulted contact with the Kangaroo Hills Formation) and 210871 (faulted contact with the Greenvale Formation). The section youngs westwards, and includes medium to coarse-grained quartzose to lithofeldspathic arenite, polymictic conglomerate (containing limestone pebbles and boulders), mudstone, and chert.

PLATE 2:

a. **Thin to thick-bedded quartzose arenite and mudstone; arenite beds show anastomosing, dissolution cleavage parallel to bedding. Pelican Range Formation. 7959-050901, cutting on Greenvale railway line.**

b. **Cross-laminated quartzose arenite. Pelican Range Formation. 7960-138150, 6.5 km northeast of Craiglee homestead.**

c. **Typical thin-bedded arenite/mudstone turbidite facies. Greenvale Formation. 7959-173874, Marble Creek, at bridge on Lynd Highway.**

d. **Hyaloclastic breccia of altered mafic volcanics. Greenvale Formation. 7959-366530, 14 km east-northeast of Niall homestead.**

Lithology

The Perry Creek Formation consists predominantly of arenite and mudstone, although chert, basalt, and lenses of limestone and conglomerate also occur in places. Like the Greenvale and Kangaroo Hills Formations, the Perry Creek Formation is interpreted as a sequence of proximal to distal turbidites. The three facies associations of the Greenvale and Kangaroo Hills Formations are present, although the mudstone dominated facies is less common. The thin to thick-bedded, alternating arenite/mudstone facies is the most common (Plate 3b,d). The thickly bedded arenite facies is most common north of the Clarke River, and is particularly well-developed in the area of the Lynd Highway where it forms prominent ridges. It is associated with conglomerate containing clasts of quartz, green chert, quartzose siltstone and arenite, and limestone (Plate 3a). The limestone clasts range from pebbles to boulders and blocks up to 10 m long, as well as the larger olistoliths described below. The thick-bedded arenites are generally medium to very coarse-grained, are commonly massive, but grading (Plate 3c), channelled bases with shale rip-up-clasts (Plate 3a), and rare medium-scale, planar cross-beds can be observed. The beds are generally less than 5 m thick, but in cuttings along the Lynd Highway some beds are apparently more than 20 m thick, with no well-defined bedding planes or breaks.

The thin-bedded facies occurs throughout the unit, but is dominant on the southern limb of the Clarke River Orocline in EWAN. The arenites are generally very fine to fine-grained, and grade into siltstone. They are commonly laminated. Ripple cross laminae, convolute laminae, flutes and load casts are also common. The beds are generally less than 1 m thick.

The arenites of the Perry Creek Formation are generally more quartzose than the Greenvale or Kangaroo Hills Formations, but show a considerable compositional range from lithofeldspathic to lithic sublabile (Figure 5). Many fall within the quartz-rich field of Crook (1974). Quartz ranges from about 50% to 80% of framework grains. It is strained, and polycrystalline quartz of tectonic origin is also generally present. Feldspar is commonly partly sericitised, and includes both plagioclase (with deformed twin lamellae) and perthitic K-feldspar. The main lithic clasts are mica schist, pelite, chert, and felsite. The coarse-grained arenites generally contain less than 20% matrix of silt-sized quartz and feldspar, and phyllosilicates which have replaced clays. The coarser-grained arenites are generally more lithic than the fine to very fine-grained arenites, because of the breakdown of the mica schist into its components during transport and abrasion. These components are generally silt to very fine sand-sized quartz and mica. Dissolution cleavage similar to that in the arenites of the Tribute Hills Arenite is common in the Perry Creek Formation, particularly the finer-grained, more quartzose arenites in EWAN.

Chert, in units of up to 50 m thick, forms prominent ridges in several parts of the Perry Creek Formation. The chert is generally grey to greenish grey and thin-bedded, with very thin interbeds or partings of shale. Casts of radiolaria are abundant in some of the cherts, but no skeletons are preserved in any of the specimens examined in thin section. Ridge-forming cherts occur in the large basalt lens east of Hopewell Creek in the central part of VALLEY OF LAGOONS. However, the several large ridge-forming chert units which extend discontinuously from the Burdekin River to about 5 km south of the Lynd Highway are mainly interbedded with arenite and mudstone. A small lens of basalt occurs along the old telephone line just north of the Lynd Highway, adjacent to one of the ridges, although it probably overlies the chert and is separated from it by about 20 m of mudstone and arenite.

Basalt occurs sporadically through the Perry Creek Formation. It is most abundant in VALLEY OF LAGOONS where it forms two large lenses. The largest is east of Hopewell Creek and outlines a large fold. Total strike length is about 15 km and it is up to 1500 m thick. The other is about 14 km long and about 300 m thick. A lens of basalt at least 2 km long and 500 m thick also occurs in the rocks tentatively assigned to the Perry Creek Formation on the edge of the Lucy Tableland near Lincoln Springs homestead. In CLARKE RIVER small lenses of basalt have been observed north of Marble Creek at 7959-235918, along the old telephone line at 220876, and near Gill Creek at 193715. In EWAN it occurs in the Mount Fullstop Range at 8059-547760, and the Oaky Creek/Ewan area at 693837 and 783905. Most of these localities are too small to show at 1:250 000 scale and are probably no more than a few hundred metres long and a few tens of metres thick.

The basalt is green, very fine-grained, and aphyric. Amygdales are common and pillows (Plate 3e) and hyaloclastic breccias can be recognised locally. They are petrographically similar to basalts in the other units. Randomly orientated plagioclase laths up to 0.5 mm are generally altered to albite and variably sericitised and saussuritised. Clinopyroxene is generally interstitial to the plagioclase along with leucoxene and opaque oxides (magnetite?), although in some cases it forms subophitic intergrowths with plagioclase. Chlorite is a common alteration product, generally after clinopyroxene, but in one sample (GSQR 12463) it appears to be replacing olivine. Sporadic patches of zeolite, partly replacing plagioclase, also occur in this sample. The basalts are usually unfoliated, but some altered samples have a weak cleavage defined by the alignment of chlorite, calcite, and leucoxene aggregates.

Limestone, apart from occurring as clasts and larger blocks in conglomerate and arenite, also forms several large lenses in the Christmas Creek area, along the eastern boundary of the Perry Creek Formation. The largest (just north of Marble Creek) is 2 km long and 500 m thick, and the others range from 100 m to 500 m long. The limestone is mainly massive, recrystallised calcilutite, but locally

PLATE 3:

a. Coarse-grained, feldspathic arenite, showing large mudstone rip-up clasts and a boulder of limestone. 7959-213866, Thatch Creek.

b. Interbedded thin to thick-bedded, quartzose to sublabile arenite and mudstone arenite. 7959-231900, in Marble Creek, 4 km northwest of Christmas Creek homestead.

c. Thick bed of coarse to very coarse-grained, subfeldspathic arenite showing well-developed grading, and limestone cobbles and pebbles at the base. Thin bed at bottom left contains abundant pebbles. Location as for (a).

d. Amalgamated, thin to medium-bedded, fine to medium-grained quartzose arenite. 7959-270706 on bank of the Clarke River, 10 km upstream of the Lynd Highway.

e. Pillow lava (basalt). 7960-162216, 11 km northeast of 'Craiglee'.

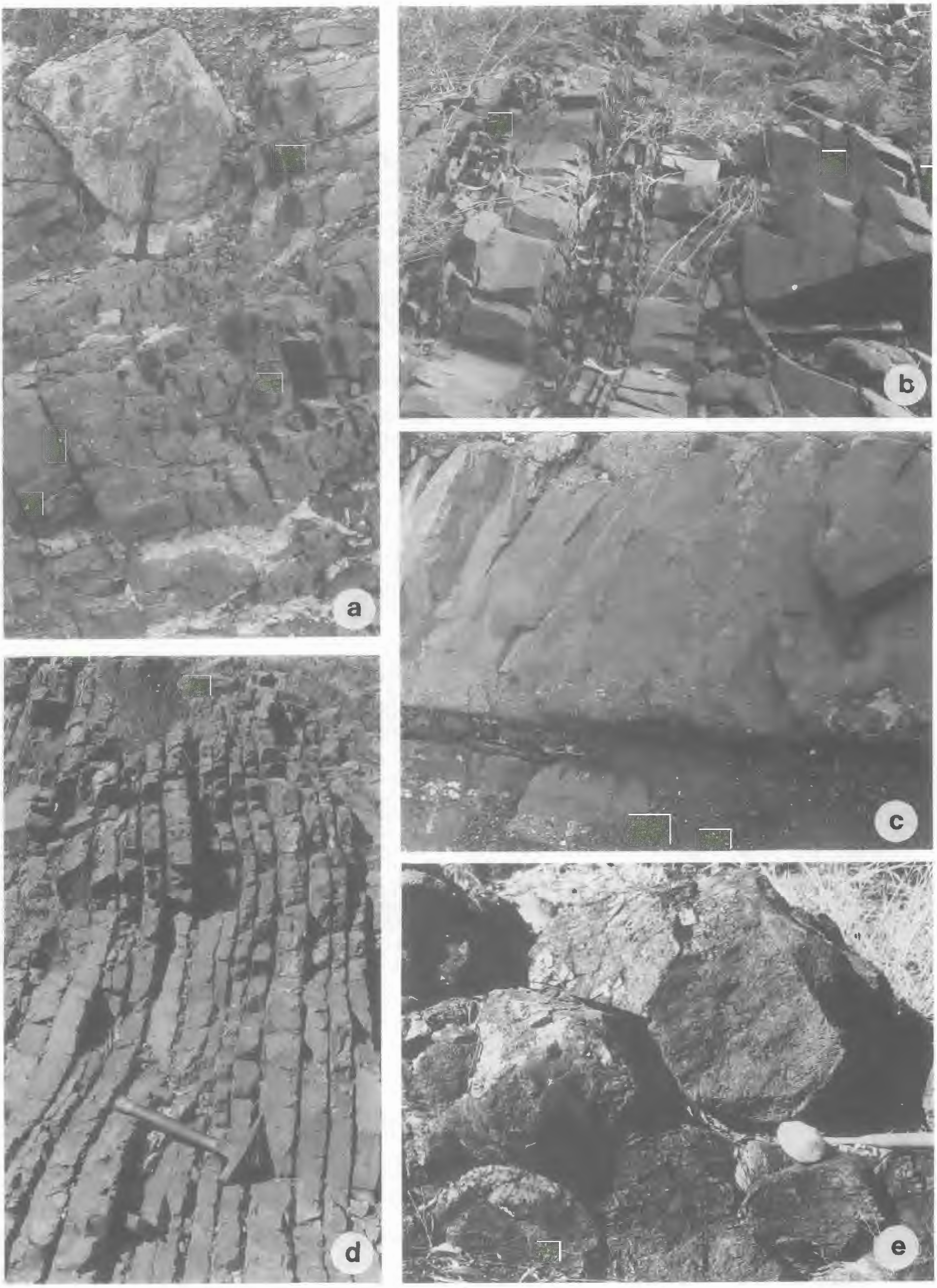


Plate 3. Perry Creek Formation.

bioclastic calcarenite and calcirudite crop out. The calcarenites range from crinoidal grainstones to wackestone with sporadic coralline and crinoidal debris.

The relationship of the limestones to the surrounding rocks is difficult to determine because they are generally surrounded by areas of no outcrop. It is likely that they are allochthonous because of the turbiditic nature of the sequence in which they occur. Allochthonous limestones were reported from the Chillagoe Formation in the Hodgkinson Province (Green, 1990).

Limestone also occurs in the Ewan area along with sheared mudstone, arenite, and chert (melange), within a belt 5 km long and up to 500 m wide (Withnall, 1990). The lenses are generally only a few hundred metres or less in length, but the northeastern end of the belt is formed by a lens about 2 km long. The limestone is generally fine-grained and strongly sheared and stylolitised. Because of the deformation it is difficult to identify organic remains but crinoidal debris is locally discernible, and Wyatt & others (1970) reported the occurrence of *Halysites*, probably from the outcrop beside the Ewan-Endeavour road at 8059-755867. They regarded the belt as part of the Ewan beds. At the northeastern end of the belt, the limestone is converted to marble and skarn, and hosts magnetite deposits at Willetts Knob. The belt is interpreted as a series of fault slices of Perry Creek Formation and is surrounded by the Running River Metamorphics. It occurs about 1.5 km south of the major fault which separates the Running River Metamorphics from the main belt of Perry Creek Formation, and which is probably a continuation of the Clarke River Fault.

Relationships

The relationships with the Tribute Hills Arenite, and Pelican Range, Greenvale and Kangaroo Hills Formations are discussed in detail under the description of those units; all are interpreted to be in fault contact with the Perry Creek Formation. The Perry Creek Formation is unconformably overlain by and faulted against the ?Middle Devonian Ewan beds and the Carboniferous Venetia Formation and Hells Gate Rhyolite. It is intruded by Carboniferous granite and rhyolite in the Ewan area.

Age

The limestone clasts in conglomerate and large, probably allochthonous limestone blocks are of Silurian to possibly earliest Devonian age. Halysitids are present in the limestone lenses along the eastern margin of the unit, but conodonts provide the best evidence. The large limestone lens near Marble Creek in the east contains an Early to Middle Silurian fauna (*amorphognathoides* zone) whereas limestone clasts from conglomerates in Thatch Creek in the west may be earliest Devonian (*woschmidti* zone) (B.G. Fordham, personal communication, 1987). The westward younging indicated by these faunas is consistent with younging indicated by sedimentary structures.

Because the limestones, particularly those in Thatch Creek, are allochthonous, the depositional age could be somewhat younger. However, it is thought likely that the clasts and blocks were derived from limestones being deposited almost contemporaneously with the Perry Creek Formation on a nearby shelf (cf. Green, 1990), and that the formation itself is mainly of Silurian age, probably just extending into the Early Devonian.

KANGAROO HILLS FORMATION

Introduction

Saint-Smith (1922) applied the name 'Kangaroo Hills Series' to the rocks of the Kangaroo Hills Mineral Field. In it he included 'quartzite, slate, mudstone, grits, limestone and interbedded rhyolite and andesite'. It was correlated with the 'Chillagoe Series' by Reid (1930) and with the 'Broken River Series' by Bryan & Jones (1946). Denmead (1948) reported the presence of Late Silurian to Early Devonian corals in the 'Kangaroo Hills Series'. White (1959) formally defined the Kangaroo Hills Formation, and it was discussed in more detail by White & Wyatt (1960) and White (1965).

The Kangaroo Hills Formation is the most extensive unit in the Camel Creek Subprovince, and crops out over about 3000 km^2. It extends from the Lucy Tableland in the north to the Clarke and Burdekin Rivers in the south, and from Perry Creek in the west to the Kangaroo Hills area in the east. It forms low, undulating topography, outcrop generally being restricted to streams.

Type and reference sections

White (1959) gave the type area as 'Camel Creek, a few miles (5 km) south of Camel Creek Station', and also noted that the formation is well exposed in Perry Creek near the Greenvale-Camel Creek road crossing.

No complete section displaying a base and a top is available in the unit, and it is likely that neither base nor top is exposed anywhere. In view of this, a type section (which includes White's type area) is designated along Camel Creek from 7960-403326 (the contact with rocks tentatively assigned to the Perry Creek Formation) downstream to 7959-287980, the junction with the Burdekin River. The contact with the Perry Creek Formation could be stratigraphic, but is not exposed well enough to determine the relationship. Younging along this section is predominantly to the south or southwest (see later in this report), but numerous repetitions by folding and faulting or thrusting occur along the 40 km of section. The section includes the supposed unconformable

PLATE 4:

a. Thin-bedded arenite and mudstone, showing small thrusts and bedding-parallel faulting. 7959-374746 in a small tributary of the Clarke River, 0.5 km southwest of the Clarke River railway bridge.

b. Limestone conglomerate showing subangular to rounded pebble to boulder-sized clasts of limestone in a coarse-grained lithofeldspathic arenite matrix. 7960-249048, Perry Creek, 5 km north-northwest of Gadara homestead.

c. Polymictic conglomerate - clasts are mainly quartz and reworked arenite but also include porphyritic rhyolite (to left of lens cap) and a partially dissolved limestone pebble. 7959-340740, Clarke River, 700 m upstream of road bridge.

d. Ripple cross-laminated, fine-grained arenite and mudstone. 7960-213075 in Black Dog Creek, 9.5 km northwest of Gadara homestead.

e. Typical thin to medium-bedded arenite and mudstone (medial turbidites). 7959-348740, road cutting at southern approach to Clarke River road bridge, Lynd Highway.

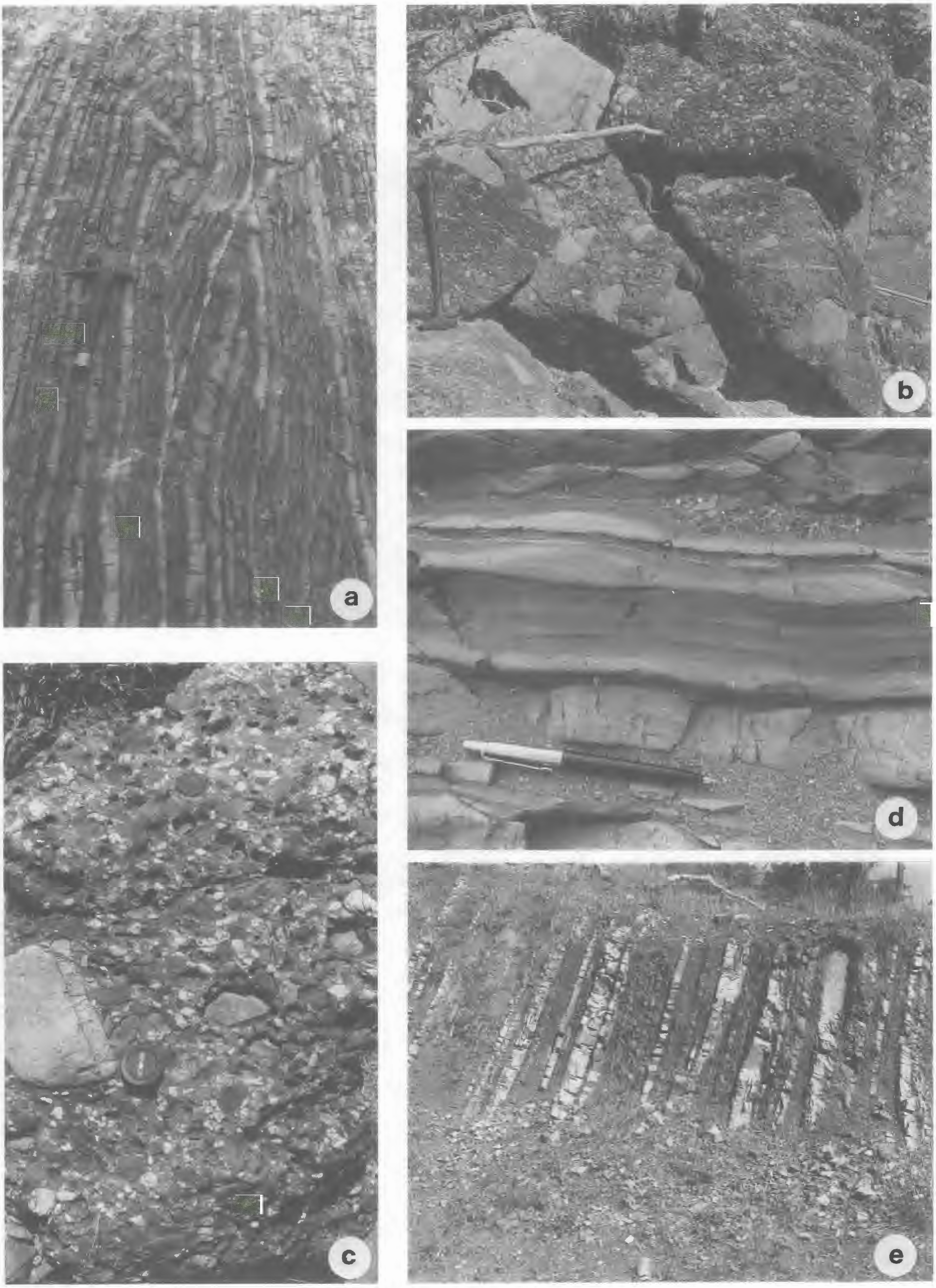


Plate 4. Kangaroo Hills Formation.

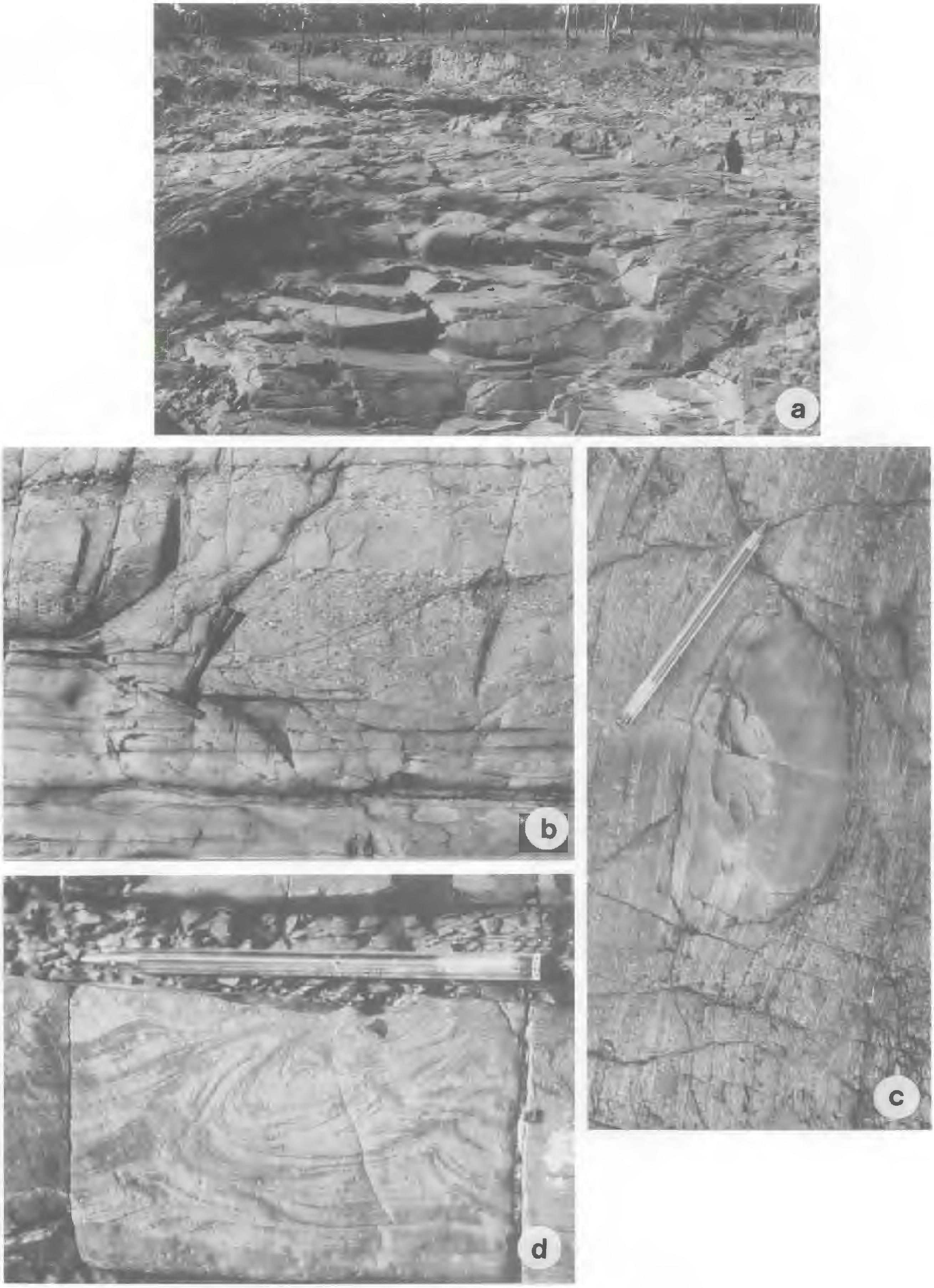


Plate 5. Kangaroo Hills Formation.

boundary mapped by White (1962b) between the Greenvale Formation and Kangaroo Hills Formation. All rocks are now assigned to the Kangaroo Hills Formation, and the boundary which occurs at 7960-404205 is marked by the incoming of polymictic conglomerate and more abundant, very thick-bedded, coarse-grained arenite, in contrast to generally thinner bedded and finer grained arenite-mudstone sequences upstream.

A slightly more accessible reference section is along the Clarke River from 7959-318735, the faulted(?) contact with the Perry Creek Formation, downstream to the junction with the Burdekin River (402762). This section which youngs predominantly to the east includes excellent examples of the thicker bedded coarse-grained arenite and polymictic conglomerate, which form rock bars across the river. However the finer-grained and thin-bedded turbidite facies are also exposed in the banks and pavements. An example of a prograding turbidite sequence is well-exposed at the Clarke River railway bridge (375752, Figure 4).

Lithology

The Kangaroo Hills Formation is similar in many respects to the Greenvale Formation, hence the confusion in assigning rocks in certain areas. However the arenites in the Kangaroo Hills Formation are less lithic (Figure 5) and the polymictic conglomerates contain common limestone clasts (Plate 4b, c). The same three facies associations can be recognised (Plates 4a, e, 5a), but the thickly-bedded arenite facies is not common north of Camel Creek homestead. In some parts of this area, such as the headwaters of Noname and Redbank Creeks, mudstone predominates, and arenites are generally thin-bedded and fine-grained. These rocks were previously mapped by White (1962b, 1965) as the Greenvale Formation, and the boundary with the Kangaroo Hills Formation was interpreted as an unconformity (White & Wyatt, 1960). It corresponds with the incoming of abundant very thick-bedded arenite and polymictic conglomerate with sporadic to abundant limestone clasts. No angular discordance was found during this survey or by Arnold (1975). The rocks underlying the conglomerate (that is, to the north) are assigned to map-unit SDk_1; the remainder of the Kangaroo Hills Formation, largely corresponding to the unit as White (1962a, b, 1965) mapped it, are assigned to map-unit SDk_2. In the latter, the thick-bedded arenite facies is widespread throughout, and is commonly associated with polymictic conglomerate containing limestone pebbles. Nevertheless, it is probably still subordinate to the thin-bedded arenite/mudstone facies, which also probably predominates over the mudstone/siltstone facies.

The rocks show a similar range of sedimentary structures to the Greenvale Formation (Plates 4d, 5b, d), and are interpreted as a turbidite sequence. The few sections that were logged in any detail can be explained in general terms using a fan model (Mutti & Ricci Lucchi, 1972; Walker, 1978; Normark, 1978). For example, the section at the Clarke River railway bridge shows a coarsening/thickening-up cycle suggestive of a prograding suprafan lobe (Figure 4). However, much more detailed mapping and logging is required to produce anything but a simplistic interpretation of the environments of deposition represented in the Kangaroo Hills Formation. It is possible that the rocks in the northern part of the area (SDk_1) represent basin plain and/or outer fan deposits over which middle and upper fan deposits of the remainder of the unit (SDk_2) prograded.

The arenites in the Kangaroo Hills Formation are generally olive-green to grey, and feldspathic to lithofeldspathic. Angular, strained, monocrystalline grains of quartz are the main framework constituent. In addition, larger grains are commonly composite, consisting of two or more interlocking subgrains. Polycrystalline quartz (chert, metaquartzite, and quartz tectonites) is also present. Feldspar includes both plagioclase and microcline, but plagioclase dominates. Twin lamellae are commonly bent. Composite quartz-feldspar (granitoid clasts) occur in some coarser arenites. Lithic clasts include fine-grained felsic volcanics, granophyre, mica schist, phyllite, siltstone, shale, and limestone (including fossil fragments). Detrital mica flakes are very common, imparting a strong fissility to the finer grained arenite and siltstone. Epidote, allanite, tourmaline, and sphene are common heavy mineral constituents. Shale rip-up-clasts are common locally.

The interbedded shale is generally grey to olive green, and is generally cleaved. Pencil cleavage is common (Plate 7e), where both S_1 and S_2 are developed, or a bedding fissility is present. Calcareous nodules occur locally (Plate 5c), and some preserve burrows.

The polymictic conglomerates are very thick-bedded, poorly sorted, and range from clast to matrix-supported. Bases are commonly channelled, and both normal and reverse grading are common. The conglomerates show a similar range of pebbles to the lithic clasts in the arenites. Most common pebbles are vein quartz, green to black chert, leucogranite, arenite, schist, quartzite, felsic volcanics, limestone, and shale (Plate 4c). The felsic volcanics are generally porphyritic and mainly rhyolitic tuff or ignimbrite. The groundmass in the volcanics is generally recrystallised and some schistose metarhyolite was observed.

Limestone clasts are present, at least in small quantities in most outcrops of conglomerate, and in some beds are the dominant clast type. Clasts range from fine-grained mudstone to bioclastic grainstone and wackestone. Corals and stromatoporoid fragments are common as separate clasts or within clasts. Limestone-rich conglomerates or calcirudites (Plate 4b) are particularly abundant in an area centred about 5 km northwest of Gadara homestead, immediately west of Perry Creek. The rocks there were mapped by White (1962b) as Perry Creek Formation, but are here regarded as part of the Kangaroo Hills Formation, because of the composition of the enclosing arenites.

Olistoliths of limestone up to 100 m long also occur in the Gadara area. Near Limestone Creek at 7960-231027, one olistolith about 50 m long has a breccia of basalt at its base, and another nearby olistolith includes calcareous volcaniclastic arenite and breccia containing *in situ* corals

PLATE 5:

a. **Massive unbedded arenite outcrop. 7960-320043, near Camel Creek, 6 km northeast of Gadara homestead.**

b. **Channelled base to thick-bedded pebbly arenite cutting into amalgamated thin to medium arenite beds. 7959-348740, Clarke River near Clarke River road bridge, Lynd Highway.**

c. **Concretion in laminated mudstone/siltstone. 7959-375752, Clarke River near the railway bridge.**

d. **Fine-grained arenite bed showing convolute laminations. 7959-375752, Clarke River under the railway bridge.**

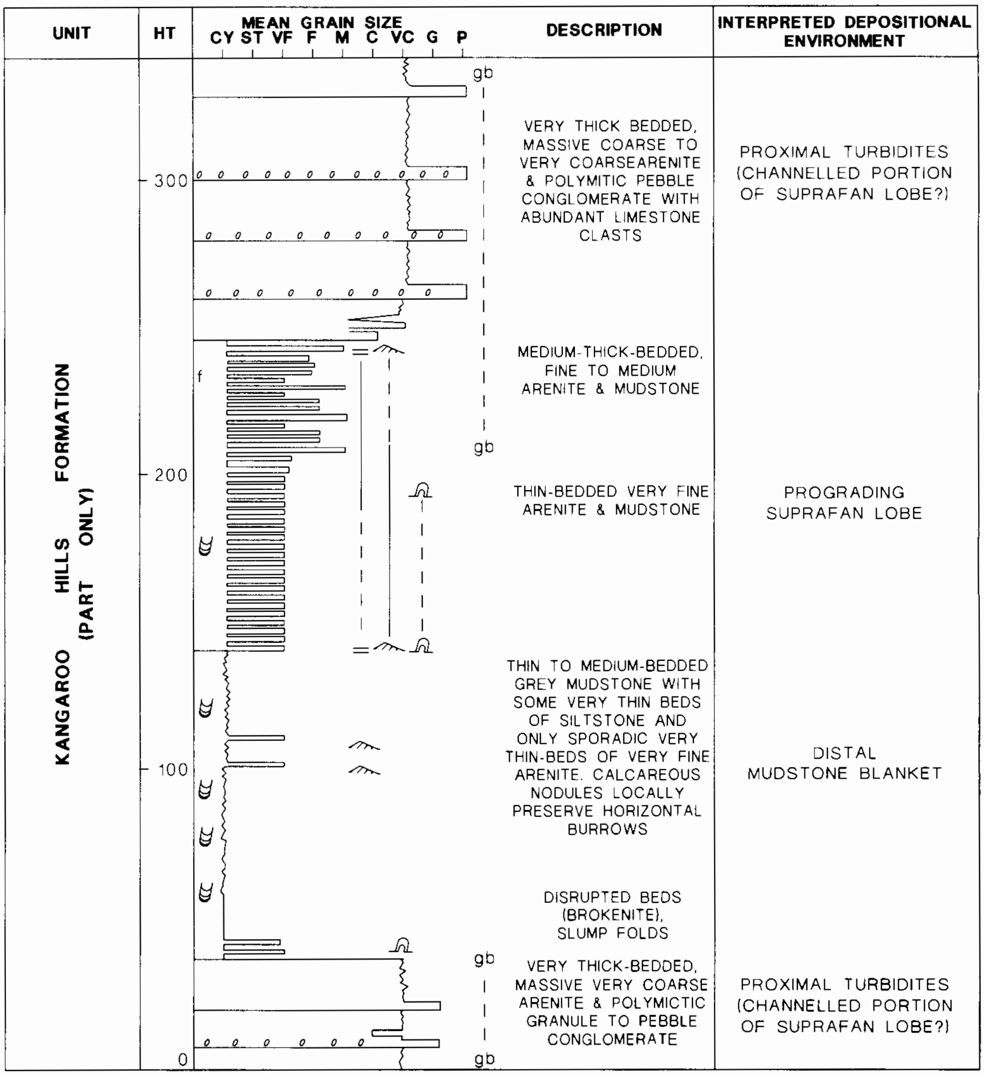


Figure 4. Section showing a prograding turbidite sequence in the Kangaroo Hills Formation in the Clarke River at the Clarke River railway bridge.

(mainly encrusting favositids). The basalt consists of small phenocrysts of plagioclase and clinopyroxene to 1 mm in a very fine-grained groundmass of plagioclase, pyroxene, chlorite, and opaques. Some has abundant calcite-filled amygdales. The association with volcanic rocks suggests that the limestone was originally deposited on seamounts or volcanic islands. About 50 m along strike from one of the olistoliths, a bed of poorly sorted, coarse grained calcarenite, consists largely of angular, broken, crinoid plates and less abundant clasts of recrystallised micrite, quartz, plagioclase and basalt. It is interpreted as a calcareous turbidite and may have been associated with the emplacement of the olistoliths.

An enigmatic limestone crops out at 8059-498840 (J.J. Draper, personal communication, 1987). Although it is surrounded by the Early Carboniferous Ruxton Formation, it is a steeply dipping *Amphipora* packstone similar to those in the Middle Devonian limestones in the Broken River Group, or in the Burdekin Limestone at Mount Podge and Ewan. It could be partly exhumed basement to the Ruxton Formation and really part of the Kangaroo Hills Formation.

The Kangaroo Hills Formation locally contains less lithic, more quartzose arenite towards its western margin with the Perry Creek Formation. Such rocks have been observed in five separate areas from west of 'Gadara' (in the north) to north of the Fullstop Range (in the southeast). Arnold (1975, pp. 69-73) described them from a large exposure in the Burdekin River near the Fullstop airstrip (8059-445762), where lithofeldspathic arenite and polymictic conglomerate also crop out. He regarded the quartz-rich rocks as anomalous, and considered it inconceivable that the two lithofacies could have been deposited together, even though he described a 'transitional facies' at the outcrop. He suggested that the quartz-rich rocks were fault slices emplaced during deposition. Point-counting indicates that they are actually feldspathic and quite distinct from the quartzose arenites of units like the Pelican Range Formation (Figure 5). They are regarded as a lithofacies of the Kangaroo Hills Formation, perhaps reflecting a separate source.

The feldspathic arenites are mainly fine-grained and thin to medium bedded with ABC or BC Bouma cycles. They consist of monocrystalline quartz, lesser feldspar (mainly plagioclase), detrital mica, and epidote. They are interbedded with mudstone. Thick, massive, coarse-grained beds also occur at Fullstop, and north of the Fullstop Range.

In Thatch Creek, the Kangaroo Hills Formation becomes progressively less lithic towards the contact with the Perry Creek Formation. Withnall & others (1985) suggested that this could indicate an upward transition into the Perry Creek Formation. However, the other occurrences of feldspathic arenite, since located, are entirely within the

Kangaroo Hills Formation and flanked on either side by more lithic arenites. Palaeontological evidence also suggests that the Perry Creek Formation is older than the Kangaroo Hills Formation. The feldspathic arenite is likely to form discontinuous lenses at approximately the same level rather than a continuous unit. Although it was observed in Marble Creek and near 'Gadara', a traverse midway between did not intersect it.

Relationships

The Kangaroo Hills Formation is bounded to the west and south by the Perry Creek Formation. The contact is probably faulted. North of the Fullstop Range at 8059-532796, the contact is a melange zone. Both units are intensely disrupted within 20 m of the contact, although less intense disruption is pervasive in the Kangaroo Hills Formation in this area. The contact is placed where quartzose arenite phacoids give way to mainly labile arenite phacoids. The phacoids plunge moderately steeply to the northeast. Elsewhere, the contact is not exposed, but a fault can be inferred. For example, along the Clarke River, the Perry Creek Formation consistently youngs south whereas across the contact the Kangaroo Hills Formation youngs north for several kilometres downstream. In the Christmas Creek area, both units young west, but the Kangaroo Hills Formation is downward-facing with respect to S_1, whereas the Perry Creek Formation is probably upward-facing.

The Kangaroo Hills Formation is unconformably overlain by the Early Carboniferous Ruxton Formation of the Clarke River Group, and by the Late Carboniferous Hells Gate Rhyolite of the Sybil Group. A line of small biotite granite and granodiorite plutons intrude the unit at Rocky Dam, and in the headwaters of Perry and Redbank Creeks. To the east in EWAN and KANGAROO HILLS, the Kangaroo Hills Formation is bounded and intruded by large Carboniferous granite batholiths.

Age

No *in situ* fossils have been found in the Kangaroo Hills Formation, but limestone clasts in conglomerates contain corals, mostly long-ranging tabulates, giving a broad Late Silurian to Early Devonian age. Conodonts from clasts in calcirudites from the Gadara area and near 'Fullstop' indicate a Lochkovian age (B.G. Fordham, personal communication, 1988). This confirms that the unit is at least partly Devonian, although because all material is allochthonous the upper limit is unknown. No Silurian conodont faunas have been obtained, but the unit could be Silurian in part. The *Amphipora?* in the limestone at 8059-498840 could be of Middle Devonian age, but it is uncertain whether the limestone is part of the Kangaroo Hills Formation.

PROVENANCE OF THE CAMEL CREEK SUBPROVINCE

As previously noted, the rocks of the Camel Creek Subprovince can be divided into quartz-rich and quartz-intermediate 'flysch' facies following the terminology of Crook (1974). Compositions of the different units are given in the Appendix and Figure 5, based on point-counted thin sections of arenites using the Gazzi-Dickinson method (Ingersoll & others, 1984).

The Wairuna and Pelican Range Formations and the Tribute Hills Arenite plot in a tight group near the Q-pole of the standard QFL plot and are clearly quartz-rich. Some of the Perry Creek Formation arenites are also quartz-rich on Crook's (1974) scheme, but they are more labile than the aforementioned units. In addition to being compositionally very mature, the quartzose arenites are also very fine-grained in general.

These features suggest subdued relief due to tectonic stability of the source region, allowing chemical breakdown of feldspar, mica, and lithic fragments (for example, Crook, 1974; Dickinson & Suczek, 1979; Johnsson & others, 1988). Alternatively they may be multi-cycle quartzose arenites. Quartzose arenites (also turbidites) characterise the Ordovician of the Lachlan Fold Belt (Powell, *in* Veevers, 1984, p. 293) and these may have had a similar origin, due either to subdued relief, or recycling of older arenites, or both.

The likely source for the arenites is the Georgetown Province. Although the eastern half of the Georgetown Province as now exposed is a high-grade metamorphic/plutonic terrane, this may not have been the case in the Ordovician. The Silurian two-mica granitoids in the eastern Georgetown Province suggest that prior to the Silurian at least, the rocks now exposed there were at a depth of at least 10 to 15 km. Rocks exposed in the Ordovician could therefore have been the low-grade equivalents of the Etheridge Group such as those now exposed farther west. These are fine-grained, generally quartzose to sublabile arenite and mudstone (Withnall, 1984; Withnall & others, 1988a; Bain & others, in press), and could have been a source for the fine-grained quartzose arenites.

The deformation history of the Georgetown Province suggests that it was quiescent for at least 500 Ma and possibly 1000 Ma, before the Ordovician (Black & others, 1979), so it could well have been reduced to a peneplain. Therefore both subdued relief and the nature of the source rocks could have contributed to the characteristics of the Ordovician rocks.

In the Late Ordovician, the emergence of a volcanic arc represented by the Carriers Well Formation and Everetts Creek Volcanics introduced another source, although the Georgetown Province still contributed much of the sediment. Quartzose arenite and quartz-poor volcanilithic arenite are interbedded in the Carriers Well Formation.

This pattern of mixed provenances may explain the apparent interfingering of the Greenvale and Pelican Range Formations. The Greenvale Formation consists largely of lithic arenite. The lithic clasts are mainly of volcanic and high-grade metamorphic origin. The quartz and feldspar are strained and also indicate a metamorphic/plutonic source. The volcanic clasts include both mafic and felsic types, and could be derived from the Carriers Well/Everetts Creek volcanic terrane. The coarser-grained sediment from a plutonic/metamorphic source suggests at least partial uplift of the Georgetown Province or similar rocks, possibly adjacent to the volcanic arc, whereas the remainder of the Georgetown Province continued to supply fine-grained quartzose sediment.

The Silurian Perry Creek Formation as noted is largely quartz-rich in Crook's (1974) scheme, but less so than the Ordovician units discussed above. It is predominantly lithofeldspathic sublabile to labile. The lithic clasts include both schist and felsic volcanics. Mafic volcanic clasts are absent. The quartz is strained, and medium to coarse-grained arenites are much more common than in the Ordovician quartz-rich units. The provenance was thus apparently a plutonic or metamorphic terrain including some felsic volcanics.

The quartz-rich nature could reflect a mainly metamorphic source (largely quartz-rich metapelites) and little or no granitoid. The Halls Reward Metamorphics in the eastern Georgetown Province are largely metapelite (Withnall, 1989b).

The arenites in the Kangaroo Hills Formation by contrast are quartz-intermediate and largely feldspathic arenite with relatively minor volcanic and metamorphic lithic

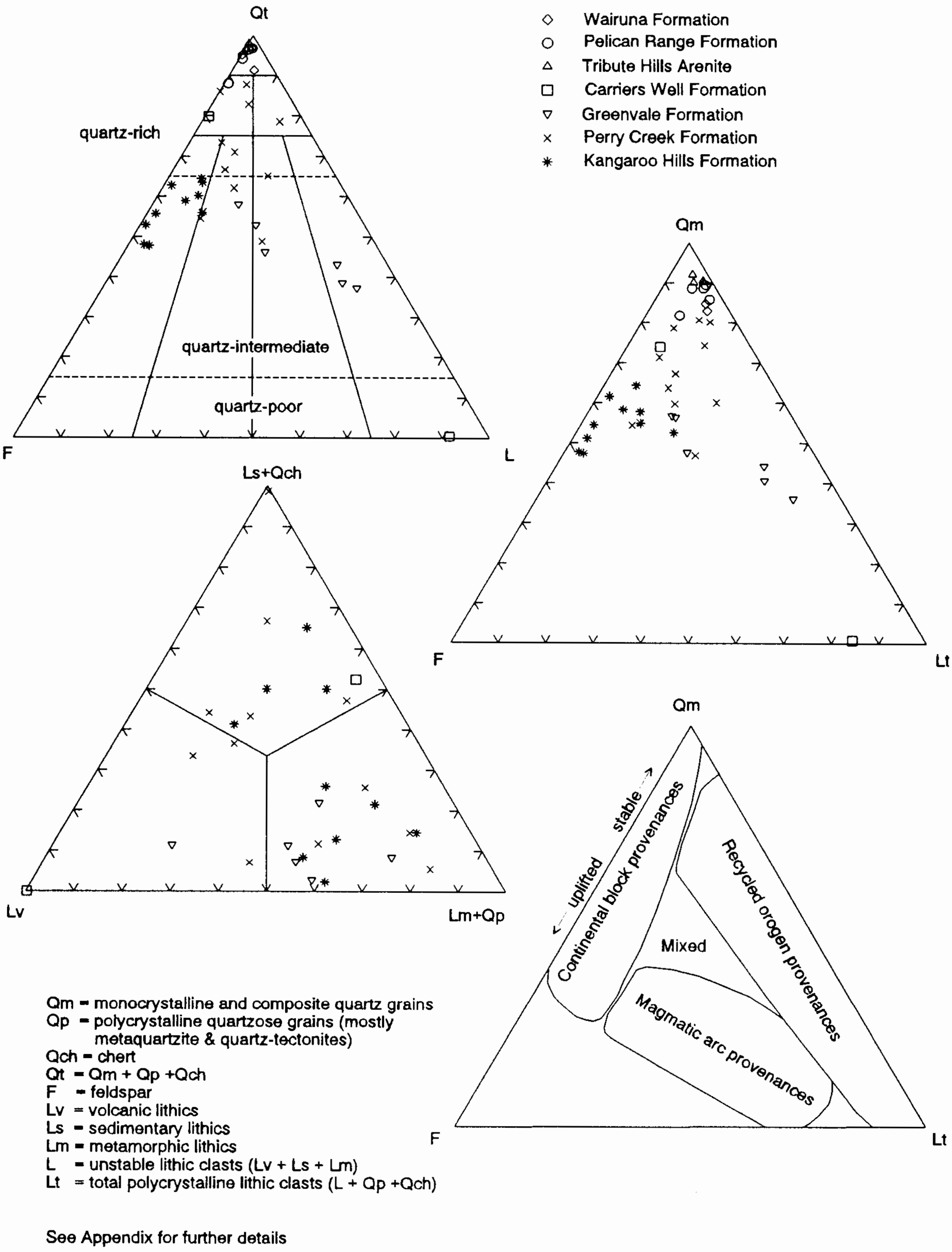


Figure 5. Plots of modal data from arenites in the Camel Creek Subprovince. See Appendix for full analyses and more details. Compositional fields are after Crook (1960, 1974 and inferred provenance fields are after Dickinson & Suczek (1979).

clasts. The source may thus have been a plutonic/high-grade metamorphic terrain. Uplift could have exposed deeper, higher-grade and granitic levels of the Georgetown Province. The volcanic rocks thus appear to have become less abundant from Late Ordovician(?) Greenvale Formation through the Silurian Perry Creek Formation to the Early Devonian Kangaroo Hills Formation. This could be due to progressive erosion of Ordovician volcanics and uplift through the Silurian associated with granitoid emplacement. No systematic palaeocurrent analyses were undertaken in the Camel Creek Subprovince because of the complex deformation. The palaeocurrents observed in the Greenvale and Pelican Range Formations are from the southwest, consistent with the Georgetown Province being a major source.

STRUCTURE OF THE CAMEL CREEK SUBPROVINCE

(I.W. Withnall)

The structure of the Camel Creek Subprovince is complex. The first detailed structural study was by Arnold (1975) who recognised three major deformation events. The second of his events was associated with the development of the main slaty cleavage S_1, and he referred to the supposed earlier, pre-slaty cleavage event as D_s. The third event was also locally associated with slaty cleavage. Hammond (1986) subsequently examined the Camel Creek Subprovince briefly to compare it with the Hodgkinson Province where the major part of his study was concentrated. Hammond concluded that most of the mesoscopic and large-scale effects of Arnold's D_s can be attributed to D_1, which he considered to produce both a slaty cleavage and melange, as in the Hodgkinson Province.

Our study covered a much wider area than Arnold (1975) did, but no detailed structural traverses were attempted. The area is divided into several broad domains (Figure 6) for presentation of the data that were collected. References to the conclusions of Arnold's more detailed studies in localised areas are made where appropriate.

EARLY DEFORMATION AND MELANGE

The D_s event of Arnold (1975)

According to Arnold (1975) an important mesoscopic characteristic of the D_s folds is the lack of an axial plane cleavage except in the hinges of some isoclinal folds. He contrasted this situation with more open F_1 folds which are associated with a pervasive slaty cleavage. However this study has observed that the S_1 slaty cleavage is not everywhere pervasive, so that the presence or absence of cleavage is not always diagnostic of fold generation. Nevertheless, in some areas, it is likely that pre-D_1 folds, possibly due to slumping, are present. For example, road cuttings in the Wairuna Formation east of Greenvale show complex refolded folds. The earliest folds, which are very tight, are refolded by more open folds (probably F_1) with north-trending axial planes and shallow plunges (Plate 7a). The early folds, which locally become dismembered, may correspond to Arnold's D_s generation.

Arnold (1975) suggested that faulting was probably more important than folding during his D_s event. Faults subparallel to bedding are common (Plate 4a). Many are characterised by welded, knife-sharp contacts rather than brecciation. Where faulting is more intense, small-scale duplexes can result (Plate 7b).

Arnold (1975) was uncertain about the large-scale nature of D_s, because of the overprinting by later deformation and lack of marker horizons or faunal control. However, he made a detailed study of S_0/S_1 vergence sense combined with younging evidence. Younging reversals caused by D_1 folding should be accompanied by changes in S_0/S_1 vergence. Arnold found examples of inconsistencies in these relationships. For example, along the Clarke River in the Perry Creek and Kangaroo Hills Formations, he found adjacent zones with different younging senses but constant vergence. Along the Lynd Highway, areas with the same younging senses had different vergence. In Camel Creek downstream of Camel Creek homestead, both situations were found. Our survey also noted anomalous areas. S_0/S_1 vergence and younging indicate areas of downward-facing (Shackleton, 1957) in the Kangaroo Hills Formation (near the 'Fullstop' airstrip in EWAN and along Marble Creek in CLARKE RIVER), and in the Perry Creek Formation (the headwaters of Black Dog Creek in VALLEY OF LAGOONS, although there the main foliation could be S_2). Downward-facing rocks in the Perry Creek and Greenvale Formations were observed locally in the Southern Domain; in some of these outcrops, however, the generation of the cleavage and/or folds is uncertain, and the downward-facing may be due to D_2 refolding of overturned F_1 limbs. The unequivocal cases of rocks which are downward-facing with respect to S_1 suggest large-scale pre-D_1 recumbent folding.

Alternative explanations for inconsistencies between vergence and younging (so-called 'transected folds' - Powell, 1974) have been proposed in other studies. Fergusson (1987) noted local downward-facing F_1 folds in the Benambra Terrane in the southern part of the Lachlan Fold Belt. He suggested that cleavage formed relatively late in the deformation. Progressive deformation involved superimposition of non-coaxial strain increments such that the finite XY plane of strain crosscut early formed fold axial planes. This could give rise to S_0/S_1 vergence being the opposite to that expected from younging evidence.

Anomalous situations as described above are exceptions rather than the rule, and most of the rocks are upward-facing. In addition, although reversals of younging are locally common, our survey has shown an overall large-scale predominant younging sense. To illustrate this, 'younging azimuths' (as opposed to dip azimuths) are plotted as rose diagrams (Figure 7). These illustrate a predominant westward sense in the Western Domain, southwest in the Hinge Domain, and southeast in the Southern Domain. These younging senses are mutually consistent if the effects of the reorientation by the regional F_2 Clarke River Orocline are removed. Younging senses in the domains in the Kangaroo Hills Formation show greater spread and more common reversals, but the distinct west and southeast maxima are still evident.

Melange

Arnold (1975) noted linear zones of 'pseudoconglomerate'. White (1965, p. 45) also described these rocks, which he suggested were 'wildflysch' (Gignoux, 1955) (ie. olistostromes) modified by later shearing. Some tectonised olistostromes may be present, particularly in the Carriers Well Formation, and some 'pebbly mudstones' (rounded arenite or siltstone pebbles in a mudstone matrix) in the Kangaroo Hills and Greenvale Formations could have a similar origin. However, we regard most of these disrupted rocks as having a tectonic origin, and refer to them as 'tectonic melange' (Hsu, 1974), or simply 'melange'. The widespread occurrence of melange (Plate 6) characterises the deformation of the Camel Creek Subprovince.

The melange consists of fragments of arenite or siltstone (and in some cases chert, jasper, or rarely, basalt) from a few millimetres to many metres long in a matrix of mudstone. Terms used for the fragments include:

(a)	clast:	<1 m of any shape
(b)	phacoid:	lensoid or ellipsoidal clasts
(c)	block:	>1 m of any shape
(d)	slab:	flat, parallel-sided blocks, commonly portions of individual thick beds or several beds.

The fragments are generally lenticular (phacoids) and lie parallel to each other. The matrix generally has a pervasively 'sheared' appearance, with dark-coloured, anastomosing cleavage seams which are concentrations of domainal cleavage lamellae and phyllosilicates. The cleavage wraps around the fragments. In many outcrops the phacoids are aligned to produce a linear fabric. Transitions from typical clast-in-matrix melange to coherent rocks range from distances of up to 100 m to relatively sharp fault-like contacts less than 1 m wide. In well-bedded sequences, the transitions pass from clast-in-matrix melange enclosing small blocks or slabs with preserved layering into rocks with increasingly coherent, alternating arenite and mudstone beds. The melange zones themselves can range from a few metres to a kilometre or more wide. Rootless fold hinges are present in many of the melanges, and some incipient melanges contain numerous dismembered folds. The foliation is also chaotically folded in some outcrops; some of this folding may be due to the later regional fold events, but some may have been produced during the melange formation and is similar to F_mm folds in mylonites.

Melange occurs in all of the pre-Carboniferous units in the Camel Creek Subprovince. This contrasts with the Graveyard Creek Subprovince, where melange is restricted to the oldest unit, the Ordovician Judea Formation. Melange is typically well-developed in the units containing abundant quartzose arenite alternating with mudstone, such as the Wairuna, Pelican Range, and Perry Creek Formations. It is not as common in the Tribute Hills Arenite, possibly because the unit is dominated by amalgamated arenite beds, and alternating arenite and mudstone beds are not as common. Melange is also common in the Greenvale Formation.

The Kangaroo Hills Formation is more coherent overall, but incipient melanges are locally present, and two zones of relatively pervasive melanges are known. The largest is a zone, 1 to 2 km wide, in the northeastern part of VALLEY OF LAGOONS. It extends for 13 km from Noname Creek east-northeast to Lincoln Springs homestead, and for an unknown distance into KANGAROO HILLS. The zone is referred to here as the Lincoln Springs 'Shear Zone'. It is well-exposed in Redbank Creek upstream of the Camel Creek-Valley of Lagoons road for about 1 km (Plate 6b), and in Camel Creek 1 to 3 km north of Lincoln Springs homestead. The other area is 10 to 20 km northeast of Fullstop homestead adjacent to the Burdekin River. In this area, most arenite beds are generally at least partly disrupted and boudinaged, with locally more intense melange, particularly along the fault separating the Kangaroo Hills and Perry Creek Formations.

Discussion

Although younging sense of the strata (Figure 7) and individual units is predominantly towards the craton, the overall younging sense from palaeontological evidence is eastwards. The oldest known units are the Late Ordovician Carriers Well Formation and Everetts Creek Volcanics in the west, whereas the youngest rocks (Early Devonian) are in the Kangaroo Hills Formation in the east. The Perry Creek Formation which occupies a medial position in the subprovince has Silurian faunas.

The most plausible explanation for the large-scale structure of the subprovince is therefore one of steeply dipping fault slices subparallel to S_0, with the same predominant younging sense in each slice. The alternating belts of Pelican Range Formation and Greenvale Formation are particularly suggestive of fault imbrication. Although some contacts appear to be stratigraphic, most are probably faults. They are sharp and some are associated with melange and/or truncate bedding trends at low angles. The boundary between the Perry Creek Formation and Kangaroo Hills Formation near 'Christmas Creek' is associated with a change in S_0/S_1 vergence whereas the younging sense is constant (and to the west). Farther south in the Clarke River, the boundary is also marked by a change in S_0/S_1 vergence, but the younging sense is away from the boundary in both formations.

Although the fault slices are now steeply dipping, they may have been originally thrusts which were steepened during ramping and stacking within an imbricate fan or duplex, or by later folding. The melange is probably at least partly related to the thrusting.

Plots of stretching lineations in the Western and Southern Domains (Figure 8) show a predominance of moderate to steep plunges consistent with thrusting from the craton, although some shallow plunges also occur. Shallow plunges are dominant in the Lincoln Springs 'Shear Zone' where a possible dextral shear sense is indicated in some outcrops. Melanges along the fault between the Tribute Hills Arenite and Pelican Range Formation in Black Gin Creek also have subhorizontal lineations. These faults may be transcurrent faults, the latter perhaps related to the Clarke River Fault. Melange in the fault between the Perry Creek and Kangaroo Hills Formations at 8059-532796 has moderately steep lineations. None of these lineations has been adjusted for the local F_1 or F_2 fold plunges. If this were done, a different pattern might emerge. In practice, this is difficult because the local fold plunge is commonly difficult or impossible to determine.

The timing of the melange formation and thrusting is still uncertain in spite of Hammond's (1986) assertion that it was largely syn-D_1, contemporaneous with the slaty-cleavage-related folding, and associated with the formation of a duplex, by thrusting from the west. Arnold (1975, and *in* Arnold & Fawckner, 1980) regarded the melange as subduction-related in an active accretionary margin and contemporaneous with sedimentation; subduction was interpreted as being from the east.

Our evidence suggests that at least some melange did form in the Broken River Province before D_1. For example,

PLATE 6:

a. **Intense melange or 'broken formation', showing lenticular phacoids of fine-grained quartzose arenite, siltstone and chert in a strongly cleaved mudstone matrix. Wairuna Formation. Gray Creek railway bridge, 7959-937966.**

b. **Relatively intense melange or 'broken formation', showing lenticular phacoids of fine-grained arenite in a strongly cleaved mudstone matrix. Kangaroo Hills Formation. 7960-323244 in Redbank Creek, 10.5 km northwest of 'Camel Creek'.**

c. **Pebble to boulder sized, subequant blocks of quartzose arenite in a cleaved mudstone matrix. Carriers Well Formation. 7859-872949 in Gray Creek, 1.2 km downstream of QWRC gauging station.**

d. **Disrupted quartzose arenite beds in mudstone. Judea Formation, on the eastern limb of the Broken River Anticline. 7859-680451, in the Broken River.**

e. **Intense melange or 'broken formation', showing lenticular phacoids and blocks of quartzose arenite in a strongly cleaved mudstone matrix (hammer for scale). Pelican Range Formation. 7959-081899, road cutting on Lynd Highway.**

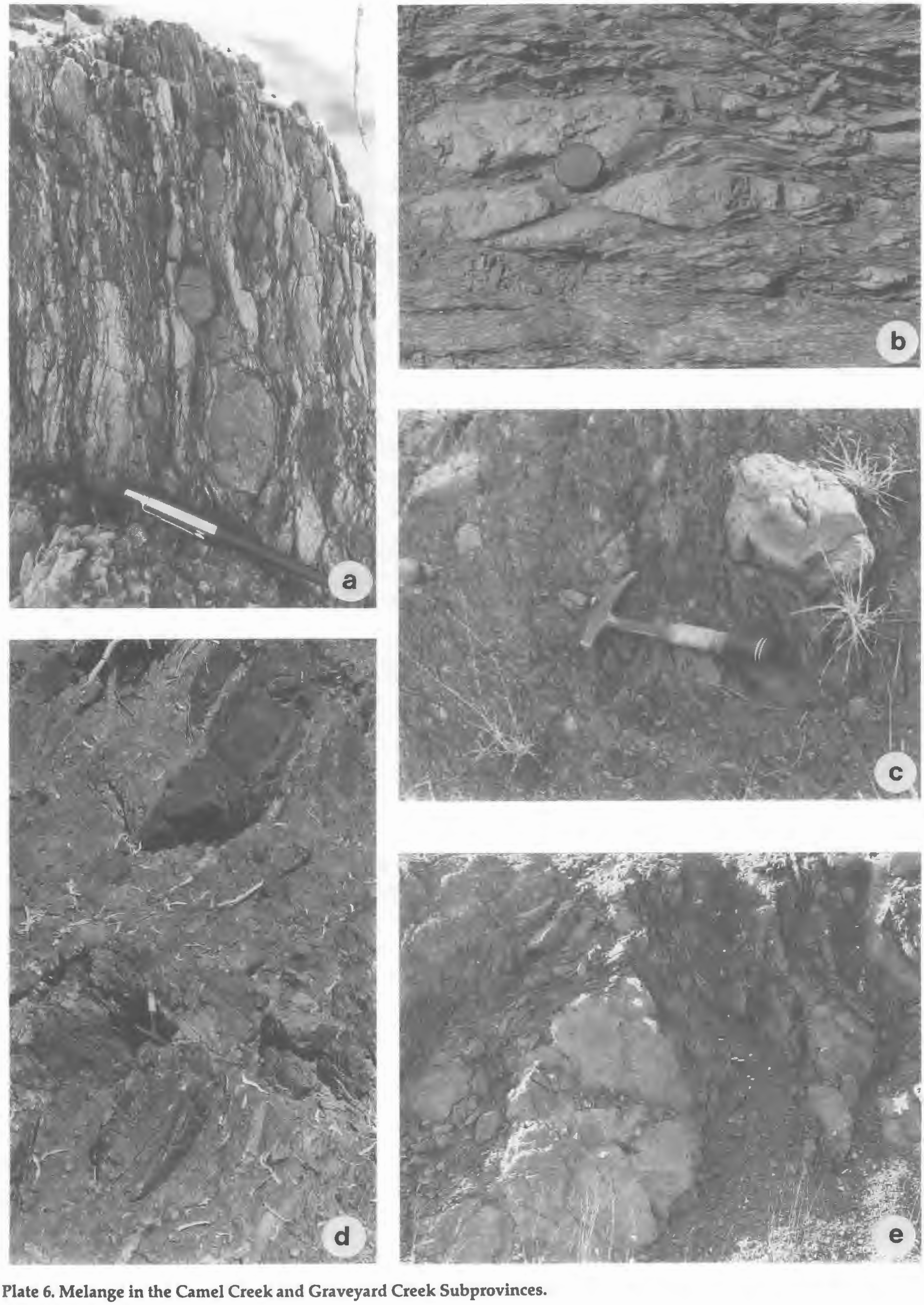


Plate 6. Melange in the Camel Creek and Graveyard Creek Subprovinces.

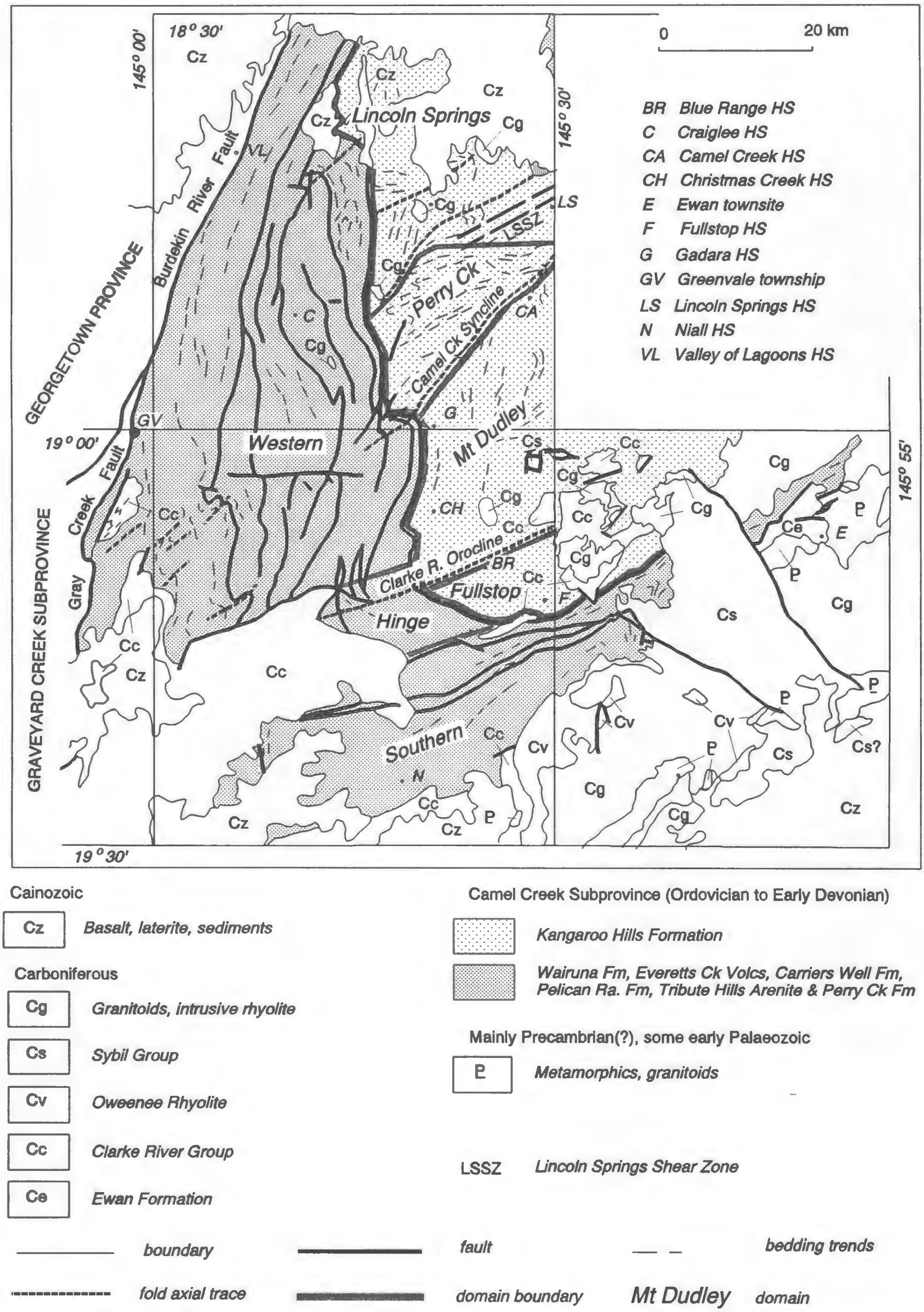


Figure 6. Structural map of the Camel Creek Subprovince, showing main structural elements and domains referred to in the text.

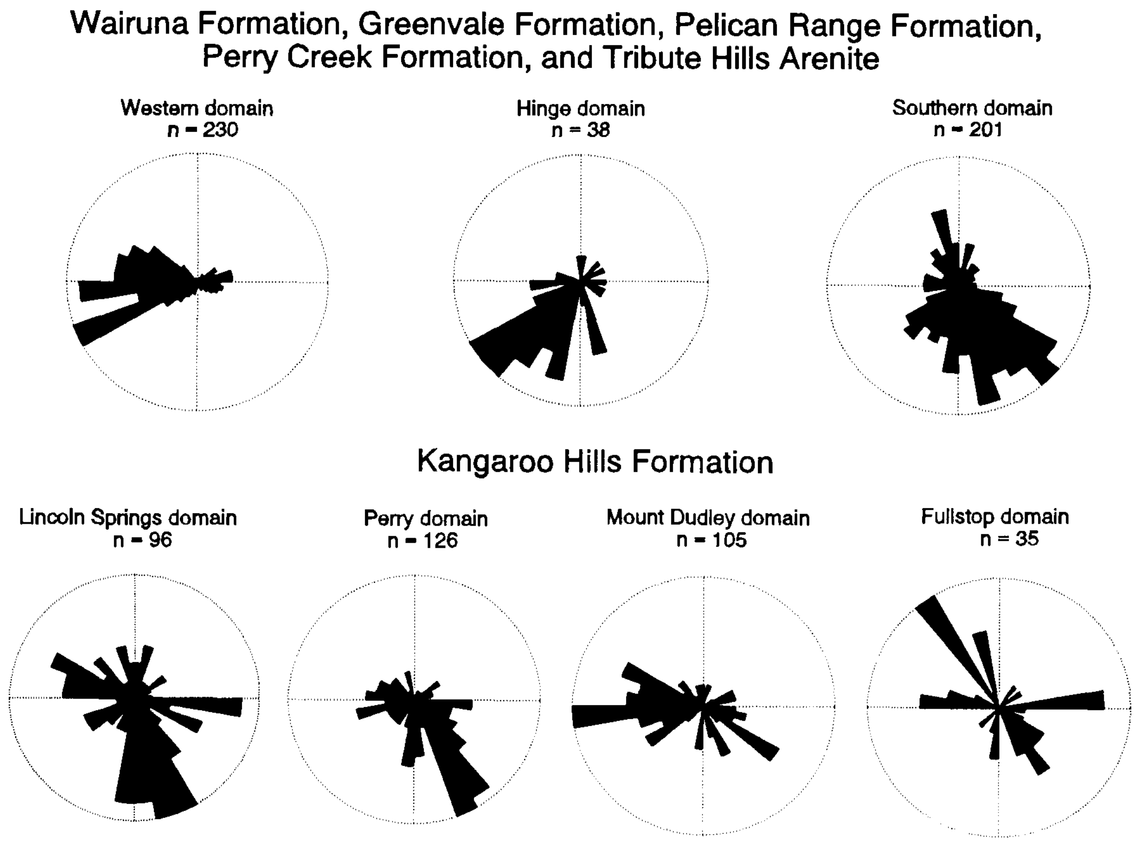


Figure 7. Rose diagrams of younging azimuths from the Camel Creek Subprovince (radius of segment proportional to number of readings). Domains shown in Figure 6.

the Early Ordovician Judea Formation in the Graveyard Creek Subprovince contains well-developed melange that is absent in the overlying Silurian and younger units. This early melange could be related to thrusting of some rocks from the Camel Creek Subprovince onto the Georgetown Province before the Early Silurian. Evidence from the eastern Georgetown Province points to a significant mylonitisation and thrusting event there in the Late Ordovician or earliest Silurian (Withnall, 1989b). However, whether any of the melange in the Camel Creek Subprovince is related to that in the Judea Formation is not known. It is possible that melange formed both intermittently during sedimentation and during D_1. Hammond (1986) suggested that sedimentation in the Hodgkinson Basin may have continued eastwards of an advancing thrust duplex, and a similar situation may have occurred in the Camel Creek Basin. The common arenite clasts in the Kangaroo Hills Formation conglomerates may have been eroded from thrusted and uplifted sediments in the west of the basin.

D_1 FOLDING

This is the most pervasive folding event in the Western and Southern Domains. It was related to the development of a slaty cleavage (Plate 7d) and mesoscopic folds. Larger scale folds, however, are not common. Some are indicated by younging reversals in the Greenvale Formation near Craiglee homestead. Chert beds associated with basalt outline a D_1 anticline about 1 km across in the Perry Creek Formation east of Hopewell Creek. The predominant younging senses discussed above suggest that any major folds are probably asymmetric. The asymmetry could be due to superimposition of the folds on strata which were already dipping steeply west due to thrust imbrication. Alternatively, if both folding and thrusting were synchronous as Hammond (1986) proposed, the shorter, overturned, eastern limbs of the folds may have been dismembered along thrust planes. F_1 folds are more common in the Kangaroo Hills Formation ranging from outcrop scale to about 1 km in wavelength, although the plots of younging azimuths still indicate an overall asymmetry (Figure 7).

Figure 8 shows structural data from all units excluding the Kangaroo Hills Formation. In the Western Domain, F_1 folds trend north to north-northeast as shown by the plot of S_1 and plunge at moderate angles to the north and south. The trend of S_1 is subparallel to that of the foliation in the melange. In the Southern Domain, the fabric elements trend predominantly east-northeast to northeast. In the Hinge Domain the trend is southeast. Beds are commonly overturned. This is indicated by the plot of S_0 for the Western Domain in which poles are relatively evenly distributed between the western and eastern hemispheres even though younging is predominantly to the west. The Southern Domain also shows a symmetrical pattern in spite of the predominant southward younging. Rocks in the Hinge Domain are predominantly overturned.

S_1 is variably developed. In some outcrops it is an intense fissility, but commonly it is weak to absent and much less intense than the bedding fissility. The latter is generally the most pervasive fabric in the shales, particularly in the Pelican Range Formation. In thin section, S_1 is generally defined by very fine-grained chlorite and muscovite flakes, in some cases concentrated in spaced anastomosing, phyllosilicate-rich zones. In some rocks, S_1 is an irregular, spaced crenulation of the bedding fissility. Arnold (1975) noted that in shales in the 'quartz-rich flysch' (Pelican Range Formation), S_1 is characteristically a pervasive, fine, evenly spaced crenulation of the intense bedding fissility. The arenites are generally not cleaved, but in the Southern Domain, many of the quartzose arenites in the

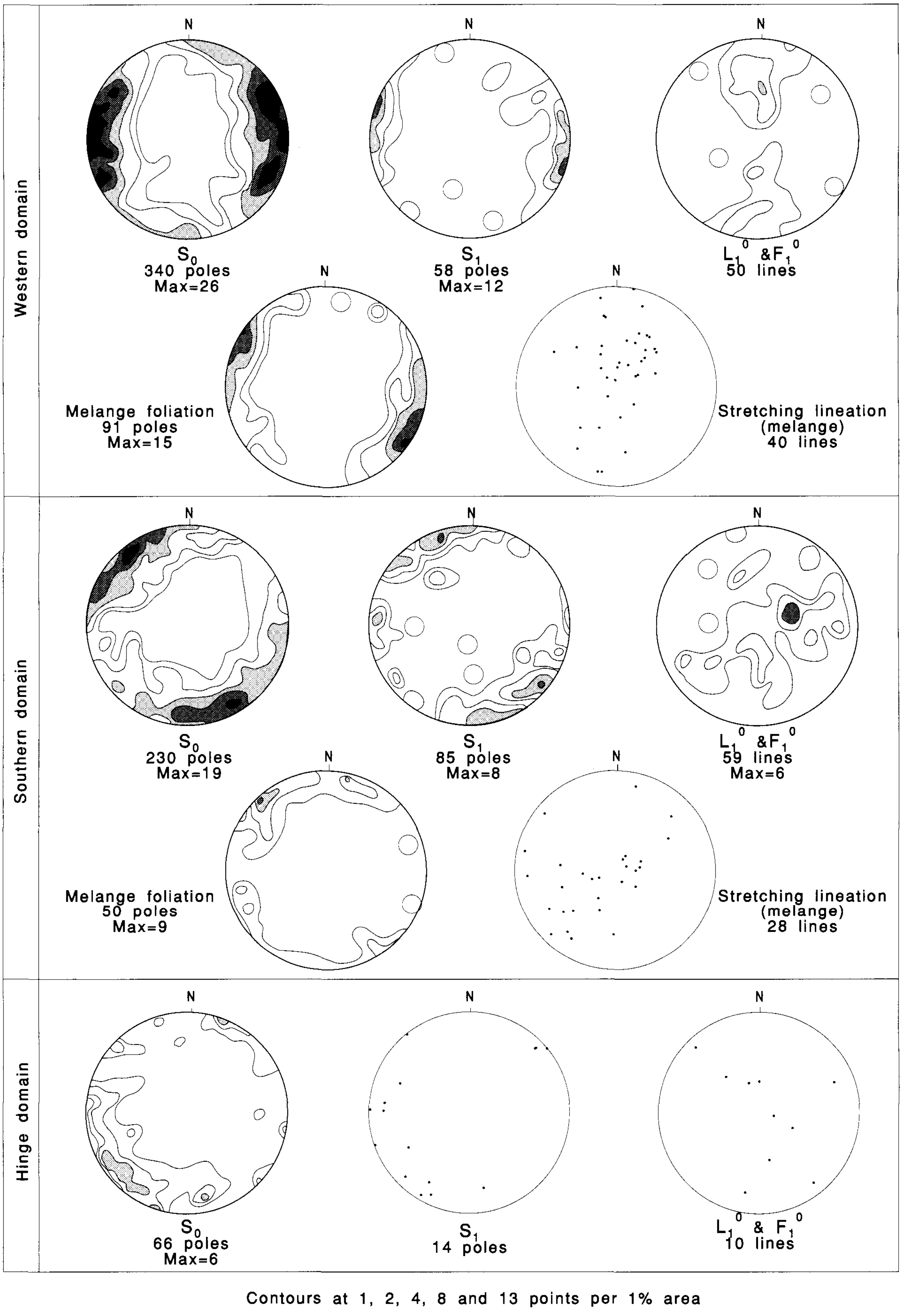
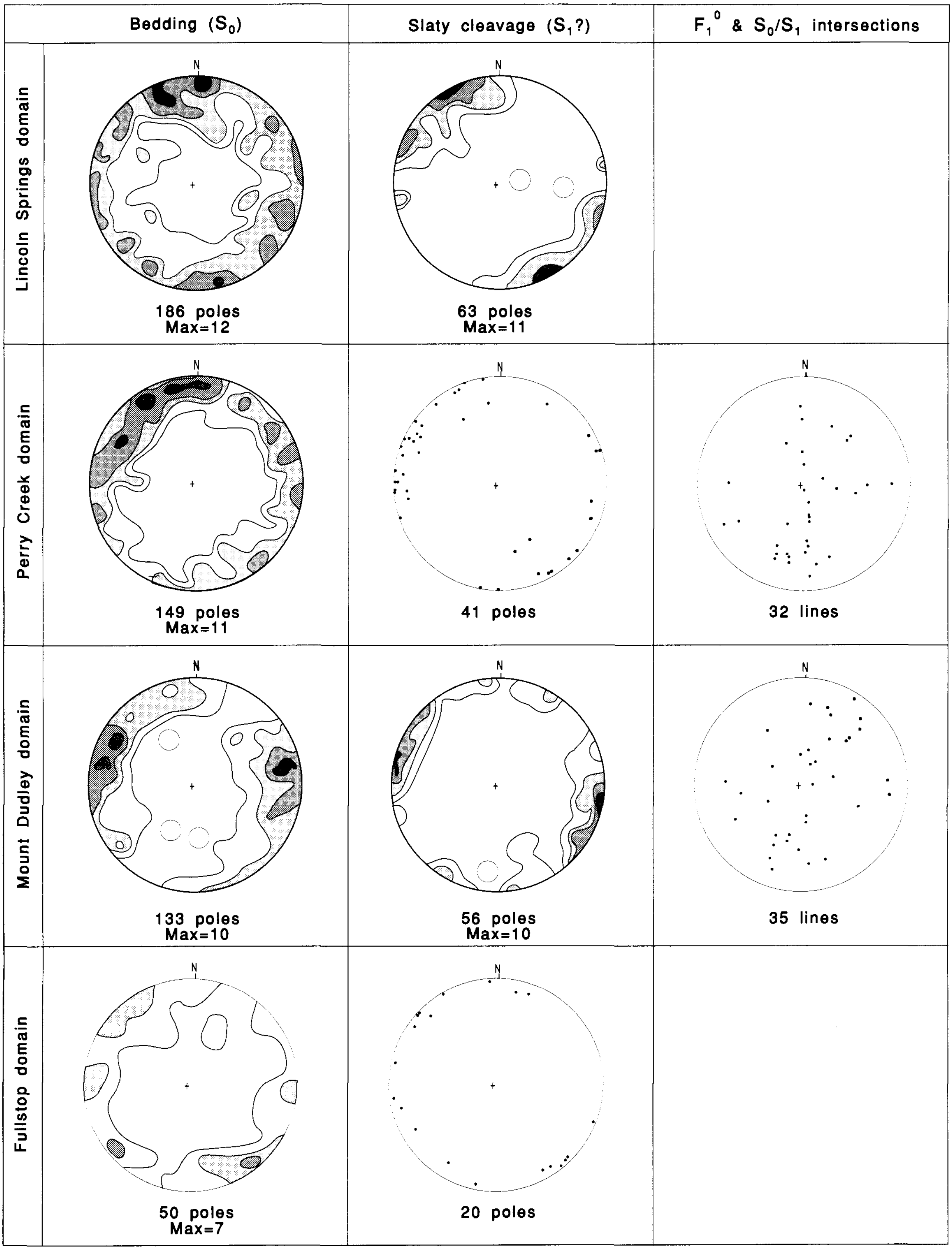


Figure 8. Structural data from the Camel Creek Subprovince, excluding the Kangaroo Hills Formation. Domains shown in Figure 6.



Contours at 1, 2, 4 and 8 points per 1% area

Figure 9. Structural data from the Kangaroo Hills Formation. Domains shown in Figure 6.

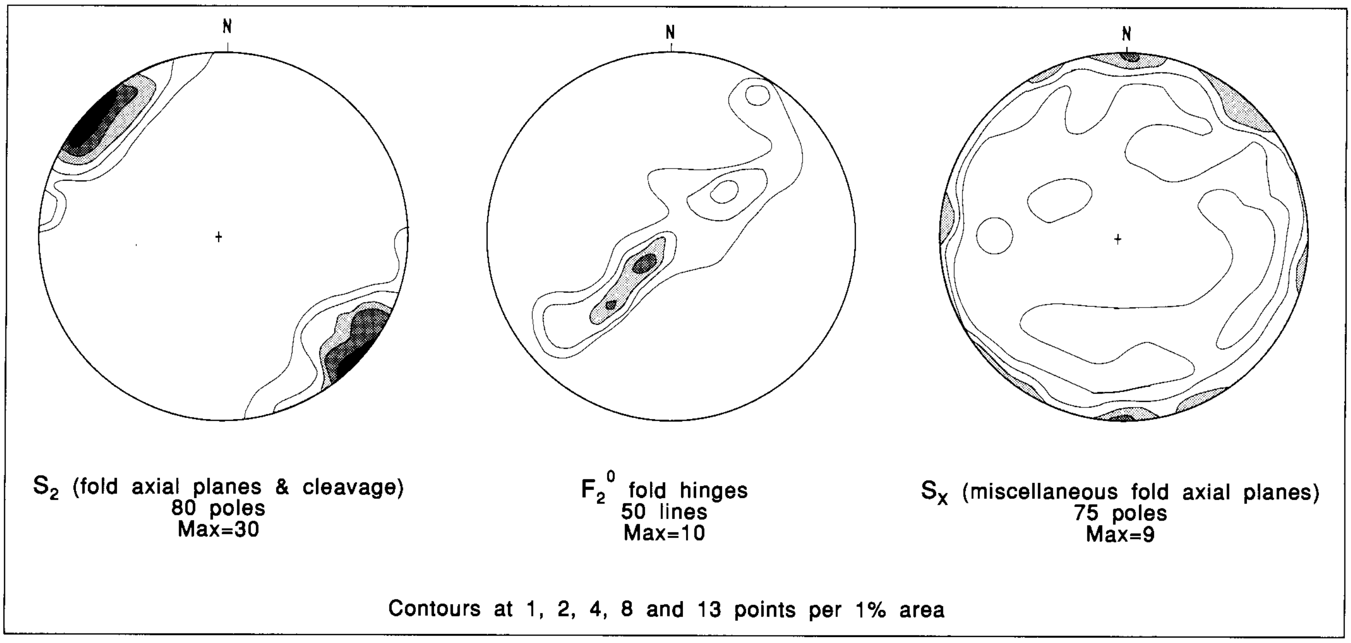


Figure 10. Post-D_1 structural data from the whole Camel Creek Subprovince.

Tribute Hills Arenite and Perry Creek Formation, have widely-spaced (5 to 20 mm) lamellae which cut across S_0 and appear on weathered surfaces as grooves (Plate 7c). They are probably dissolution seams along which phyllosilicates are concentrated. Arenites in the Pelican Range Formation in the Western Domain locally have a similar cleavage, but it is not as well-developed.

Similar 'rough' cleavages have been described from the Ordovician psammitic rocks of southeastern Australia by Gray (1978), and they are also attributed to dissolution. The dissolution is probably best developed in the quartzose arenites rather than the more labile ones, because of the greater solubility of quartz relative to feldspar and lithic grains.

D_2 FOLDING

S_0 and fabrics related to D_1 were reorientated by major, open, regional folds with northeast trending axial planes and wavelengths of 10 to 20 km. The largest of these folds has its axial trace just north of and parallel to the Clarke River; it results in a bending of trends of the major lithological units and mesoscopic fabrics from north in the Western Domain, through southeast in the Hinge Domain, to east-northeast in the Southern Domain (Figure 8). It is referred to here as the Clarke River Orocline. Other folds to the north have been outlined by changes in bedding trends. Another axial trace passes just to the north of 'Gadara' and 'Camel Creek' homesteads. Because of the predominant younging senses on its limbs (Figure 7), it is effectively a syncline and is referred to as the Camel Creek Syncline. The Perry Creek and Mount Dudley Domains represent the western and eastern limbs of the Camel Creek Syncline respectively, and data is plotted in Figure 9. The Perry Creek Domain shows the dominant east-west trend expected for this limb, but there is also significant scatter due to smaller scale folds on the major limb. Data in the Fullstop Domain on the southern limb of the Clarke River Orocline are fewer, but a more complex pattern is apparent, probably due to smaller scale parasitic folds. The Lincoln Springs Domain is also more complex and includes several folds outlined in Figure 3, although the dominant trend is east-west.

A feature of the major F_2 folds is the sharp truncation of their east-trending limbs against the north-trending, fault-bounded belts of Perry Creek and Pelican Range Formations. This suggests that some of the north-trending faults had transcurrent movement, rather than, or as well as, being steepened thrusts. It is possible that the faults acted as vertical decollements during D_2.

Smaller folds ranging from outcrop scale to several kilometres are also common, particularly in the Kangaroo Hills Formation. The intensity of F_2 folds appears to die

PLATE 7:

a. **Reclined isoclinal fold in quartzose arenite and mudstone, refolded by more upright fold. Wairuna Formation. 7859-888975, road cutting on Lynd Highway road, 1 km east of Greenvale township.**

b. **Small-scale thrust duplex in thin-bedded arenite and mudstone. Kangaroo Hills Formation. 7959-375752, Clarke River under the railway bridge.**

c. **Cleavage defined by anastomosing dissolution seams in fine-grained quartzose arenite. Tribute Hills Arenite. 7959-406698, road cutting along Lynd Highway, 3.3 km west of Niall turnoff.**

d. **Thin-bedded arenite and mudstone showing well-developed cross-cutting slaty cleavage. Kangaroo Hills Formation. 7960-403226, Camel Creek.**

e. **Pencil-cleaved mudstone. Kangaroo Hills Formation. 8059-445762, south bank of Burdekin River near Fullstop airstrip.**

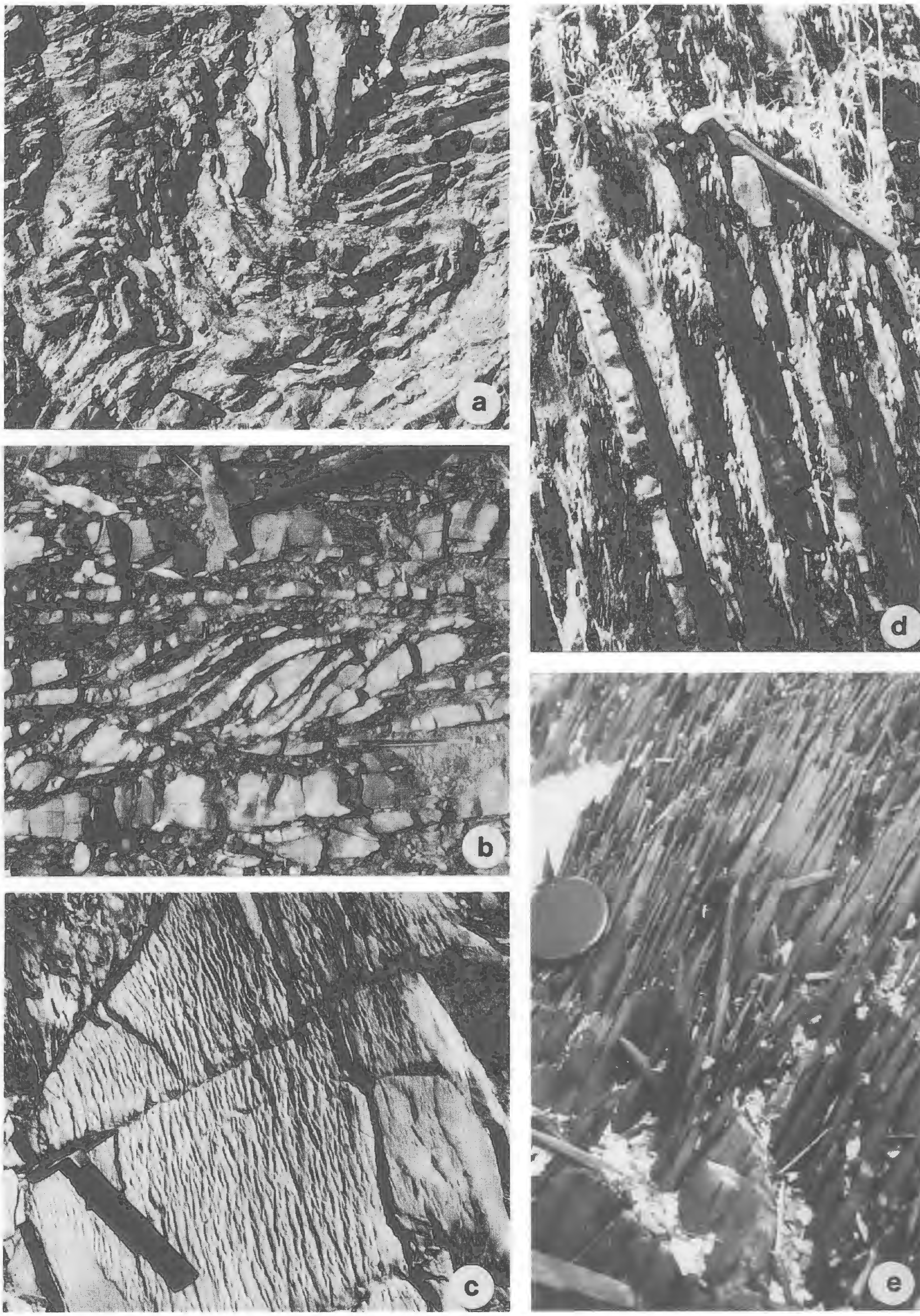


Plate 7. Mesoscopic structures in the Camel Creek Subprovince.

out to the west, although they are present at outcrop scale and a few very open folds trending northeast can be outlined there. Some of these could be related to the main folding event in the adjacent Graveyard Creek Subprovince which is probably unrelated to D_2 in the Camel Creek Subprovince. Plots of S_2 and F_20 from the whole area illustrate the dominant northeast trend (Figure 10).

Distinguishing F_1 from F_2, or S_1 from S_2, is difficult in many areas because both generations are generally not present in the one outcrop. A cleavage at a high angle to S_0 and trending roughly northeast, or an open fold with northeast trend and a high angle to the local prevailing trend of S_0, were generally identified in the field as being D_2 fabrics. However, where S_0 also trends roughly northeast, it is difficult to determine the generation unless overprinting criteria are present; a cleavage or fold axial plane subparallel to S_0 in such outcrops could be S_2 or it could be S_1 reorientated with S_0 by F_2 folds. The cleavage and fold hinges plotted for the Perry Creek Domain (Figure 9) show a dominant north to northeast trend rather than the dominant east to east-northeast trend expected from the plot of S_0. This could be due to the data including both D_1 and D_2 elements. According to Arnold (1975, p. 90 and Fig. 31), S_2 is the dominant cleavage in the areas along Camel Creek north of 'Camel Creek' homestead and along Redbank Creek. These areas correspond largely with our 'Lincoln Springs' Domain. In this survey, some outcrops with two cleavages were observed in this area, for example in the hinge of the Camel Creek Syncline in Camel Creek. Along Camel Creek south of the homestead, Arnold reported that both S_1 and S_2 are present as weakly developed slaty cleavages, and produce coarse rods and blocks at a high angle to bedding.

Petrographic characteristics of S_2 as a slaty cleavage are similar to S_1, the most common expression in shale being spaced, anastomosing, phyllosilicate and opaque-rich zones separated by irregularly crenulated, bedding-parallel micas (Arnold, 1975).

YOUNGER FOLDS

Apart from these two main folding events, other generations of folds are apparent in outcrop. Folds with approximately east to east-southeast-trending axial planes are common, but folds with numerous other orientations have been recorded (Figure 10). East-trending folds overprint the main generation of folds in the Graveyard Creek Subprovince and they are also known from the Hodgkinson Province (Hammond, 1986; Halfpenny & others, 1987; Bultitude & Domagala, 1988), and eastern Georgetown Province (Withnall, 1989b). Some north-trending folds are apparent in the Kangaroo Hills Formation, where the prevailing trend of S_0 is easterly, and on the southern limb of the Clarke River Orocline. Also present are folds with axial planes dipping at moderate to shallow angles with no dominant strike direction. These are also common in the eastern Georgetown Province (Withnall, 1989b) and in the Argentine Metamorphics to the east of the Broken River Province (Withnall & McLennan, 1991).

AGES OF DEFORMATION

The ages of D_1 and D_2 are imprecisely known but both occurred during the Devonian. They are constrained by the Early Devonian conodonts in the Kangaroo Hills Formation (B.G. Fordham, personal communication, 1987) and the Late Devonian to Early Carboniferous age of the Clarke River Group (Jell & Playford, 1985; Playford, 1988). D_1 may be Early Devonian and is generally correlated with a tectonic event in the Georgetown Province dated isotopically at about 400 Ma (Black & others, 1979; Bell, 1980). However, the nature of that event is uncertain (Withnall, 1989b), and the isotopic ages may largely reflect uplift rather than folding. If the thrusting model of Hammond (1986) is correct, such uplift could be related to the thrusting of the Georgetown Inlier over the Camel Creek Subprovince. A 400 Ma age would correspond to the possible Pragian hiatus between the Graveyard Creek Group and Shield Creek Formation of the Graveyard Creek Subprovince. Apart from this rather tenuous correlation with the 400 Ma event, other evidence for the age of D_1 comes from the Ewan area where the Early Devonian equivalents of the Fanning River Group overlying the Precambrian basement adjacent to deformed Perry Creek Formation are only weakly folded. The Perry Creek Formation is steeply dipping with a strong slaty cleavage and common melange. However, the Fanning River Group does not directly overlie the Perry Creek Formation. No rocks younger than Lochkovian are known in the Camel Creek Subprovince.

Earlier thrusting of quartz-rich turbidites (represented by the Judea Formation) onto the Georgetown Province in the Ordovician to Early Silurian may have been related to some melange formation in the Camel Creek Subprovince. As already discussed, it is uncertain whether melange formed synchronously with sedimentation, culminating in D_1, or whether it was solely related to D_1.

D_2 could correspond with the slight Frasnian unconformity between the Broken River and Bundock Creek Groups in the Graveyard Creek Subprovince. This would have allowed sufficient time for erosion before deposition of the basal fluviatile to marine sediments of the Clarke River Group in the Late Famennian.

Neither D_1 nor D_2 in the Camel Creek Subprovince had much effect on the Graveyard Creek Subprovince. In turn, the main Carboniferous folding event in the latter had little effect on the Camel Creek Subprovince, because the Clarke River Group is only very weakly folded. The younger east-trending folds possibly reflect the continent-wide north-south compressional event postulated for the Middle Carboniferous by Powell & others (1985); major effects of this event are supposedly the Alice Springs Orogeny and mega-kinks in the Lachlan Fold Belt.

Other more northerly trends apparent in Figure 10 could be related to Permian to Triassic folding in the New England Fold Belt and Bowen Basin, as well as deformation in the eastern part of the Hodgkinson Province (Bell, 1980; Hammond, 1986). Local folds with this orientation occur in the southeastern part of the Graveyard Creek Subprovince and also in the Georgetown Inlier (Duncan, 1983; Withnall, 1984; Bain & others, in press).

INTRUSIONS AND CONTACT METAMORPHISM

A line of five small intrusions of biotite granite and granodiorite crop out in VALLEY OF LAGOONS. The line trends northeast from the Camel Creek-Greenvale road near Frasers Creek to the headwaters of Redbank Creek. The intrusions are associated with tin and tungsten mineralisation. Tungsten occurs as scheelite in a quartz reef at 7960-214278 in the headwaters of Perry Creek, and as wolframite in quartz at Wolfram Hill (218216). At the latter locality the host rocks are hornfelsed mudstone and the presumed intrusion is "blind". However, it lies on the same trend as the exposed plutons. Alluvial tin occurs in the headwaters of Perry Creek, and also in the headwaters or Redbank Creek near the northernmost pluton. The tin at Perry Creek, is very coarse and obviously locally derived. Zones of altered muscovite granite in the biotite granite pluton may be related to the primary mineralisation.

The intrusions are all associated with wide contact metamorphic aureoles. Spotted shales crop out up to 2 km from the intrusions which are themselves no more than 3 km wide. Areas of spotted shale between the exposed plutons are presumably related to other "blind" intrusions. Near the head of Black Dog Creek in VALLEY OF LAGOONS, an extensive area of hornfels several kilometres in diameter surrounds a small porphyry intrusion less than 100 m across.

Arnold (1975) suggested that the intrusions were intruded pre- or syn-D_1; the foliation, which he interpreted as S_1, is defined by muscovite and biotite and wraps around the spots (retrogressed aluminosilicates). The fact that biotite defined the foliation suggests that the metamorphism was syn-tectonic. However a syn-D_1 age conflicts with the K/Ar ages obtained for the plutons by Richards & others (1966), namely 357 Ma (GA 449 from Rocky Dam) and 322 Ma (GA 450 from Perry Creek). Ages have been corrected using the decay constants of Steiger & Jager (1977). An age of about 400 Ma might be expected for a syn-D_1 granitoid, if that is the age of D_1 in the Camel Creek Province as discussed in the previous section. The younger of the two ages almost certainly reflects argon loss, and some loss may also have affected the older age, which is close to the Devonian-Carboniferous boundary of 353 ± 4 Ma (Clauoe-Long & others, 1992). The marked northeast alignment suggests some structural control which might not have been preserved if the plutons were emplaced pre-D_2. The northeast trend is approximately parallel to S_2, and therefore it is possible that emplacement was syn-D_2. This would be more consistent with the K/Ar age, allowing for slight argon loss. As noted previously, D_2 may be Late Devonian. The foliation in the hornfels may therefore be the regional S_2 and not S_1. As noted above, it is difficult to distinguish S_1 and S_2 in places, and Arnold (1975) considered S_2 to be the main cleavage north of Camel Creek. If the intrusions are of Late Devonian age, they are significantly older than the main Carboniferous to Permian tin-tungsten granites in northeast Queensland.

In CLARKE RIVER, a small biotite granite pluton intrudes the Kangaroo Hills Formation, 7 km east of Christmas Creek homestead, and a quartz diorite pluton surrounded by cordierite hornfels intrudes the Tribute Hills Arenite, 5 km southwest of Fullstop homestead.

PRE-SILURIAN GEOLOGY OF THE GRAVEYARD CREEK SUBPROVINCE

(I.W. Withnall)

The oldest rocks exposed in the Graveyard Creek Subprovince are in the Gray Creek Complex which, as discussed below, is probably of Precambrian age. It is overlain by, or possibly overthrust by, the Judea Formation, which is strongly deformed, and intruded by small tonalite plutons. The Judea Formation is similar to quartz-rich units of the Camel Creek Subprovince such as the Wairuna and Pelican Range Formations. We suggest that the Judea Formation may be a slice of one of these units, thrust onto the Georgetown Province (of which the Gray Creek Complex is thought to be a part) in the Late Ordovician or Early Silurian, prior to formation of the Graveyard Creek Subprovince. A significant angular unconformity occurs between the Judea Formation and Graveyard Creek Group, but no major angular breaks have been recognised above it. Therefore the Judea Formation is best regarded as basement to the Graveyard Creek Subprovince or Basin.

GRAY CREEK COMPLEX

Introduction

The Gray Creek Complex, which consists mainly of metamorphosed mafic and ultramafic rocks, crops out mainly as an elongate, triangular-shaped body about 20 km long on the western side of Gray Creek (Figure 11); it is about 5 km wide at its southern end, tapering to a point about 1 km west of Greenvale township. A smaller belt of ultramafic and metamorphosed mafic rocks, about 1 km wide and disrupted by faulting, extends for about 8 km farther south on the eastern side of Gray Creek, and is a continuation of the Gray Creek Complex. Possible equivalents crop out east of Jessey Springs Hut, in the core of the Wade Anticline.

The Complex was first described in detail by Green (1958) and White (1965). They considered the complex (and the Boiler Gully Complex in the adjacent Georgetown Inlier) to be of Devonian age; the Gray Creek Complex was thought to be intrusive into the Wairuna Formation and probably even the Graveyard Creek Formation. Arnold (1975) and Arnold & Rubenach (1976) re-examined the complexes and showed that they had the same metamorphic and deformation history as the Precambrian Halls Reward Metamorphics which host the Boiler Gully Complex. A Precambrian age was therefore considered likely for both complexes, and they were regarded as basement to the Palaeozoic rocks and not Early Palaeozoic ophiolites. They interpreted the Gray Creek Complex as an isolated part of the Georgetown Inlier, and therefore basement to the Judea Formation. The exact relationship between the Boiler Gully Complex and the Halls Reward Metamorphics, in which it occurs, is not known. It is possible that the Halls Reward Metamorphics represent pelitic metasedimentary rocks deposited on oceanic crust represented by the ultramafic/mafic complex, although some tabular mafic bodies interlayered with the mica schist may have been sills or lava flows. The oceanic crust may have occurred at the edge of the craton or may have formed at a spreading centre. The only vestige of sedimentary rocks in the Gray Creek Complex is a small area of mica schist in its southeastern extension.

Corroborative evidence for the Precambrian age was provided by Ar^{39}-Ar^{40} dating of hornblende from the complexes. D_1 ages of 1111 and 1316 Ma, and D_2 ages of 457 to 762 Ma were reported by Black & others (1979, Table 3). These are probably minimum ages. However, Rubenach (1982), although accepting the ages tentatively, pointed out that excess argon, derived by degassing of K-rich mica schists during a later metamorphism, could have made the ages too old.

Arnold & Rubenach (1976) stated that the mode of emplacement of the complexes, whether tectonic or by *in situ* crystallisation was unknown, but suggested as a possibility that "the complexes were emplaced during interaction between simatic crust and the cratonic terrain by a process similar to the emplacement of Phanerozoic ophiolites". Subsequent Precambrian deformation and metamorphism resulted in interfolding of the complexes with the metamorphic rocks.

Rubenach (1982) further discussed the origin of the complexes on the basis of detailed mineral chemistry and whole-rock geochemistry. The relatively immobile trace elements (Ti, Zr, Nb and Cr) are similar to both island arc and ocean-floor tholeiites, like the mafic volcanic and intrusive rocks of the Georgetown Inlier (Withnall, 1984, 1985). Amphibole chemistry from the amphibolites supports structural information that the complexes were metamorphosed during D_1 and D_2 at relatively shallow levels of the crust with the schists of the Halls Reward Metamorphics; very low levels of Na in the M4 sites suggests that metamorphism took place at low to intermediate pressures. The amphiboles are normal hornblende, and not pargasitic or kaersutitic amphiboles, such as occur in ophiolites or peridotites metamorphosed at relatively deep crustal levels or in the upper mantle. No obvious differences between amphiboles from the two complexes are apparent.

In spite of the mineral chemistry, Rubenach (1982) still favoured an ophiolitic origin for the complexes. Similar mafic and ultramafic rocks occur along the faulted margin of the Proterozoic craton at least as far north as Chillagoe. Rubenach suggested that this margin represents a Proterozoic suture reactivated in the Palaeozoic as the Palmerville and Burdekin Fault zones.

Lithology

Towards its northern end, the complex has a core-zone, up to 500 m wide, of serpentinite derived from dunite, enstatite olivinite, and peridotite. In the Spring Creek area, the serpentinite is flanked by clinopyroxenite which is medium to coarse-grained, and consists predominantly of clinopyroxene (commonly diallage), usually partly replaced along grain margins and cleavage planes by pale green or colourless tremolite. A narrow belt of clinopyroxenite has been mapped farther south between Dinner Creek and the southern end of the main outcrop area. Wehrlite and metagabbro are interlayered with the clinopyroxenite in Spring Creek. Metamorphism affected the metagabbro more strongly than the clinopyroxenite; in the metagabbro, clinopyroxene occurs mainly as relict cores within pale green amphibole, and the plagioclase is saussuritised. According to Arnold & Rubenach (1976), the layering and texture of these rocks indicates a cumulative origin; they agreed therefore with the suggestion of Green (1958) and White (1965) that the complex originated as a layered complex with a basal zone of dunite and wehrlite grading up into clinopyroxenite, in turn overlain by layered gabbro.

Metagabbro (as described above) and amphibolite form the largest area within the complex. The amphibolite is foliated or lineated and consists of hornblende, plagioclase (commonly altered), and accessory sphene. According to Arnold & Rubenach (1976), although some of the amphibolite was clearly derived from gabbro, much of it was apparently derived from strongly deformed, amphibolitised mafic dykes, suggesting that a large part of the complex may have been mafic dyke swarms. They described clinopyroxenite cores and boudins crosscut by amphibolitised, pre-S_1 mafic dykes in a matrix of amphibolite. Cross-cutting relationships between amphibolites showing slightly different textures have been observed in the northern part of the complex.

Mylonitised mica schist, probably equivalent to the Halls Reward Metamorphics, crops out along the eastern margin of the southern extension of the complex adjacent to the Gray Creek Fault and is the only occurrence of metasedimentary rocks within the complex. This contrasts with the situation west of the Halls Reward Fault in which the Boiler Gully complex is part of an assemblage of metamorphic rocks in which metasedimentary rocks of the Halls Reward metamorphics predominate.

In the southwestern part of the main outcrop area, Arnold & Rubenach (1976) described dykes characterised by large hornblende and clinozoisite porphyroblasts (which pseudomorph ferromagnesian and plagioclase phenocrysts) in a matrix of hornblende, plagioclase, and epidote. Similar dykes north of Spring Creek grade into irregular amphibolitised quartz diorite intrusions. Dykes of this suite supposedly crosscut S_1 but predate S_2. Arnold & Rubenach (1976) therefore assigned them to a younger "interkinematic igneous suite".

Some of the serpentinite along with lenses of metagabbro was probably mobilised in the solid state during movement on the Gray Creek Fault or later folding. It was emplaced along the fault, and also within the Wairuna Formation up to 4 km east of the fault. Minor serpentinite also intrudes the Judea Formation and Jack Formation in the Poley Cow Creek and Jessey Springs areas. Serpentinite intrudes the Wairuna Formation at several localities in the Craigie area near the Clarke River Fault and a possible extension of the Gray Creek Fault (McLennan, 1986).

Structure and metamorphism

As Arnold & Rubenach (1976) showed, the amphibolite in the northern part of the complex has an intense pervasive foliation, S_2, defined by an amphibolite facies assemblage, mainly hornblende and plagioclase. Amphibole chemistry

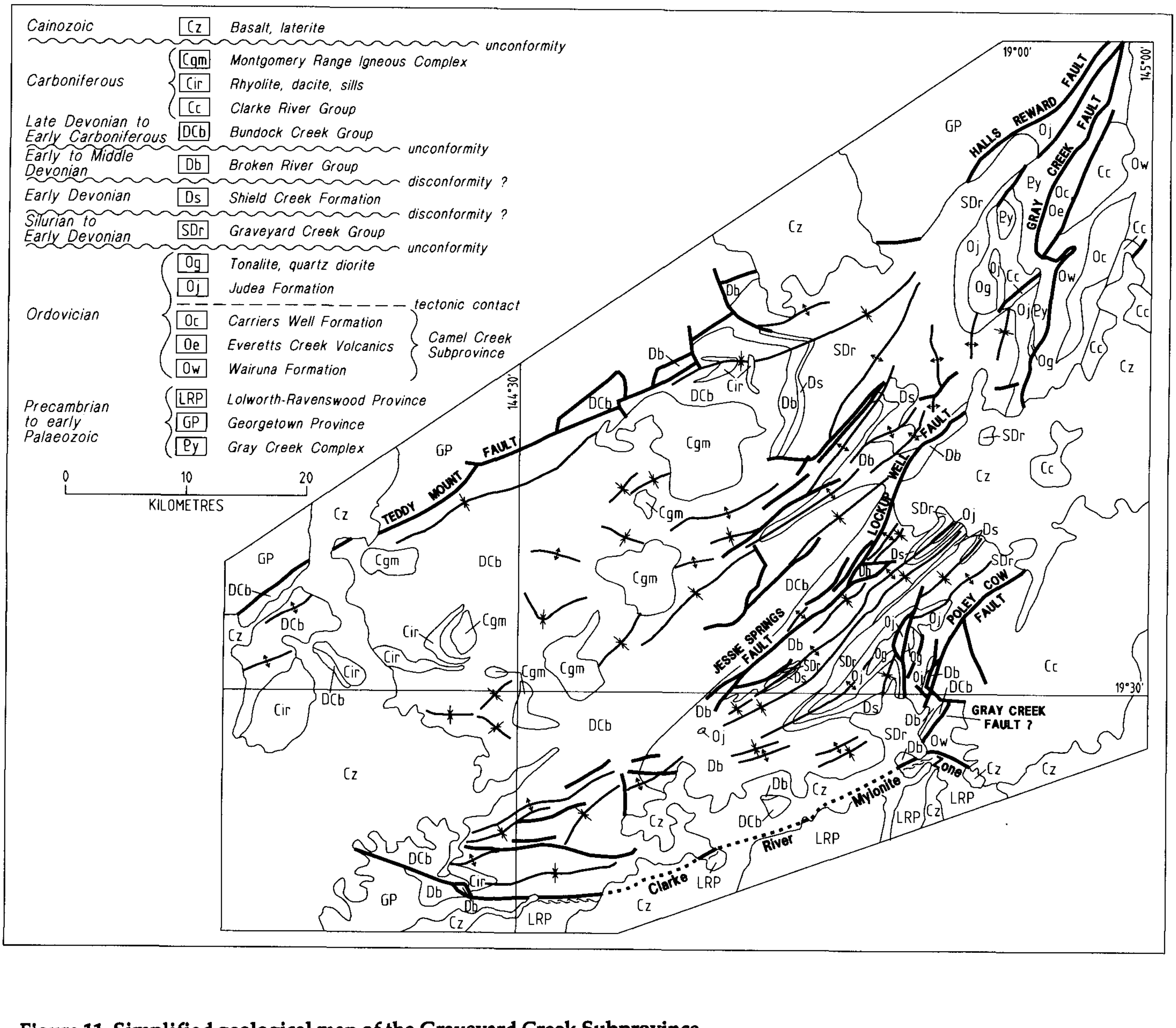


Figure 11. Simplified geological map of the Graveyard Creek Subprovince.

(Rubenach, 1982) indicates that the metamorphism took place at low to intermediate pressures. S_1, which is defined by a similar assemblage, can be recognised in the hinges of intrafolial, isoclinal folds. Farther south towards Dinner Creek, the structural history is similar, but S_2 is variably developed and Arnold & Rubenach (1976) suggested "a diminution in metamorphic grade and strain associated with D_2 from north to south in the complex".

Metamorphic fabrics are generally not developed in the clinopyroxenite, which retains its coarse igneous texture (except near margins of the bodies or in irregular cross cutting zones). However, the clinopyroxenite is inferred to have had the same deformation history to that described above, because it locally occurs as boudins in amphibolite showing evidence of that history. Differences in lithology therefore appear to have resulted in variable metamorphic reconstitution of mineralogy and intensity of foliation development.

Serpentinisation of the dunite and peridotite probably post-dated the metamorphism because lizardite is the main serpentine polymorph. Amphibolite facies metamorphism should have produced antigorite.

The eastern margin of the Gray Creek Complex is the Gray Creek Fault, marked by a zone of mylonitised amphibolite up to 200 m wide. The mylonitic schistosity post-dates S_2, which is preserved in less deformed cores within anastomosing schistose zones. Complex mesoscopic folds and refolds occur within the zone. The mylonite consists of acicular actinolite and clinozoisite. A subhorizontal mineral elongation is developed in the mylonitised amphibolite suggesting that movement was transcurrent. The foliation in the Carriers Well Formation on the other side of the fault is much less intense and lower in metamorphic grade. Therefore the mylonitised amphibolite formed at a deeper crustal level under ductile conditions, and was juxtaposed against the lower grade rocks during movement on the Gray Creek Fault, either in the same event, or much later if the fault results from reactivation of an older mylonite zone. If the fault is a thrust formed by reactivation of an older shallowly dipping mylonite zone, as suggested by Hammond (1986), the subhorizontal lineation may be unrelated to the younger movement. NNE-SSW stretching lineations are common in shallow-dipping mylonite zones of unknown age in the Halls Reward Metamorphics (Withnall, 1989b). If the mylonites along the Gray Creek Fault are related to those in the Halls Reward Metamorphics, north-northeast folding during D_1 in the Camel Creek and eastern Graveyard Creek Subprovinces could have steepened them to near vertical, but allowed the NNE-SSW stretching lineation to remain subhorizontal.

Although no later mesoscopic folds have been identified within the Gray Creek Complex, it has presumably been folded with the Ordovician-Silurian rocks which surround it. The complex is flanked to the west by a syncline and the main part of the complex probably represents the core of a doubly plunging anticline, although no mylonite zone has been recognised on the western contact of the complex. The Palaeozoic rocks wrap around the southern end of the main area of the complex and are folded into another syncline to the east; the smaller belt of Gray Creek Complex to the southeast occurs on the eastern limb of this syncline.

Relationships

The southern part of the Gray Creek Complex is intruded by the Saddington Tonalite, which also intrudes the Ordovician Donaldsons Well Volcanic Member of the Judea Formation. The tonalite was previously considered to be part of the complex, and Arnold & Rubenach (1976) regarded it as one of their "interkinematic suites". In this report it is regarded as post-dating the deformation and metamorphism of the Gray Creek Complex.

The Gray Creek Complex is in fault contact with the Judea Formation; this has been interpreted as a thrust contact by T. Bell (personal communication, 1982), but it may simply be a faulted unconformity, and the complex would thus be basement to the Judea Formation. The latter interpretation was favoured by Arnold & Rubenach (1976). This is discussed in more detail below. Along its eastern margin, as noted above, the complex is faulted against the Carriers Well Formation and Wairuna Formation. The Crooked Creek Conglomerate of the Silurian Graveyard Creek Group lies directly on the Gray Creek Complex about 6 km southwest of Lucky Springs homestead.

JUDEA FORMATION

Introduction

The Judea Formation crops out in a narrow strip up to 2 km wide west of the Gray Creek Complex between Greenvale and Tomcat Creek, and in cores of anticlines in the Broken River area. The unit was named and defined by Arnold & Henderson (1976) as the Judea Beds. Prior to this, the rocks were included in the Wairuna Formation (White, 1959, 1962a, b, 1965). As mapped by White, the Wairuna Formation contained a heterogeneous assemblage of strongly deformed strata in which stratigraphic relationships are uncertain. The Wairuna Formation as now mapped and the Judea Beds are actually lithologically similar. However, the Judea Beds are retained as a separate unit, because their stratigraphic relationships are reasonably clear, and they are separated from the Wairuna Formation by a major suture, the Gray Creek Fault. Withnall (1989a) redefined the unit as the Judea Formation.

Arnold & Henderson (1976), also included a sequence of spilitic volcanic rocks in the Judea Beds. These rocks occur consistently at the base of the formation as exposed, and

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PLATE 8:

a. **Sole markings (flute casts) in quartzose arenite. Judea Formation. 7859-662442, Broken River, 1.1 km downstream of Jack Hills Gorge.**

b. **Basaltic pillow lava. Donaldsons Well Volcanic Member. 7859-666442, Broken River, about 2 km downstream of Jack Hills Gorge.**

c. **Unconformity between the Judea Formation and Poley Cow Formation. Hammer handle lies along unconformity surface which separates thick-bedded, fine-grained quartzose arenite and mudstone of the Judea Formation (to left) from an angular, basal conglomerate of the Poley Cow Formation. 7859-662442, Broken River, 1.1 km downstream of Jack Hills Gorge.**

d. **Disrupted thin-bedded fine-grained quartzose arenite and mudstone. Judea Formation. 7859-856972, Lynd Highway, 2 km west of turnoff to Greenvale township.**

e. **Coherent, folded, thin to medium-bedded, fine-grained quartzose arenite and mudstone. Judea Formation. Same locality as d.**

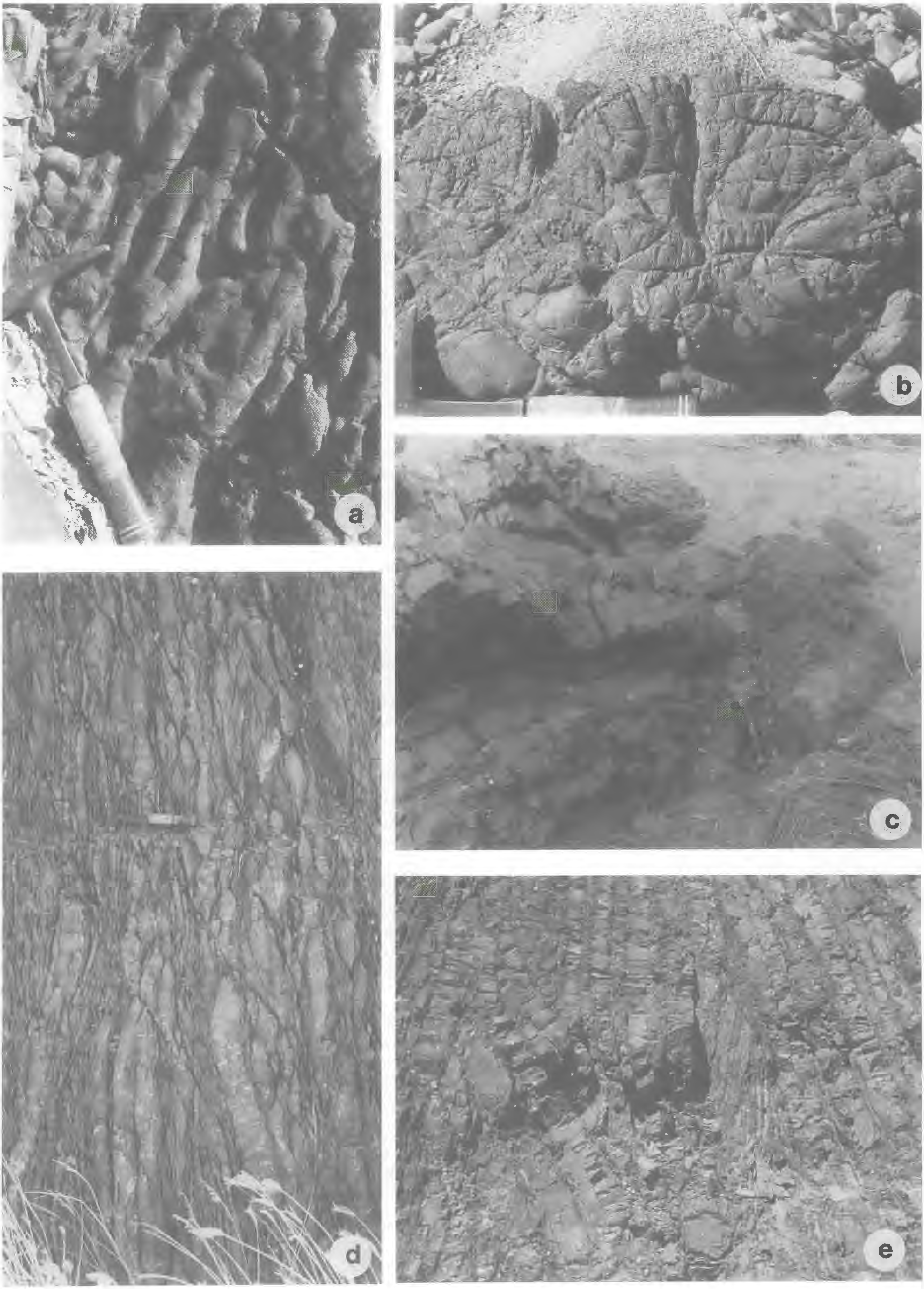

Plate 8. Judea Formation.

are now mapped as the Donaldsons Well Volcanic Member, which was also defined by Withnall (1989a).

The thickness is unknown because of structural complexity. The outcrop area of the Judea Formation is rarely more than 1500 m wide except near Greenvale where it occupies the core of a synclinorium.

Repetition by small-scale folding is common, suggesting that the unit is considerably less than 1500 m thick. The upper sedimentary part probably comprises about 500 m of this or less.

Donaldsons Well Volcanic Member

The Donaldsons Well Volcanic Member consists predominantly of green, aphyric lava ranging from basalt to dacite in composition. Pillow structures have been observed locally, for example in the Broken River (Plate 8b), but generally the rocks are massive. The lavas are fine-grained, generally 0.1 mm or less.

The basalt consists of randomly oriented plagioclase laths (zoned from andesine to albite) and subophitic clinopyroxene, commonly extensively uralitised. In some rocks the pyroxene forms acicular prisms in a felted intergrowth with plagioclase laths.

Dacite or low-K rhyolite is difficult to distinguish from the basalt in hand specimen, although it is generally slightly paler in colour particularly on weathered surfaces. However in thin section, it consists predominantly of randomly orientated laths or radiating clusters of plagioclase (probably now mainly albite), interstitial quartz, and up to 30% interstitial chlorite as irregular pale green flakes less than 0.1 mm.

Although the rocks are predominantly aphyric, porphyritic rocks do occur locally, particularly in the strip south from the junction of Horse and Gray Creeks. These rocks contain up to 30% plagioclase (oligoclase to andesine) laths, up to 3 mm long, in a groundmass of plagioclase and chlorite. Interstitial quartz in some rocks suggests that they are dacite, but others, in which it is not apparent, may be andesite. Amygdales filled with chlorite, quartz, and calcite are also common in this area. Quartz phenocrysts are rare, but 5 km east of Top Hut yards, porphyritic dacite contains about 15% subhedral, partly embayed quartz phenocrysts up to 2.5 mm across, as well as andesine laths, in a microcrystalline groundmass of quartz and feldspar. Dacite (and possibly andesite) containing plagioclase phenocrysts crop out between the Halls Reward Metamorphics and Graveyard Creek Group north of Dinner Creek, and locally in the Broken River section.

Chemical analyses of the volcanic rocks confirm the compositional range from basalt through andesite to low-K rhyolite. The basalts are low-K tholeiites or ocean-floor basalts (see later).

'Blows' of red, locally manganiferous jasper are common in the Donaldsons Well Volcanic Member. These range from thin irregular patches, possibly filling interstices of pillows, to large outcrops several metres across and up to 100 m long. The jasper is usually massive and only rarely bedded.

Sedimentary rocks

The upper sedimentary part of the Judea Formation consists typically of alternating beds of quartzose arenite and cleaved mudstone, generally less than 30 cm thick (Plate 8d, e). The arenite is mainly fine to very fine-grained and in places grades into siltstone. Deformation has obliterated the primary structures in some places, particularly in the north, but where preserved, they indicate a turbiditic origin. The thicker arenite beds are locally graded, and sole markings (Plate 8a) and partial Bouma cycles are present (generally ABC and BC). Mudstone may separate the arenites, but in places the arenite beds are amalgamated. Rare pebbly beds contain quartz and chert clasts less than 1 cm diameter.

Clasts in the arenites are predominantly quartz (generally 90% or greater) (Figure 13) and minor albite and lithic clasts of phyllite and felsic volcanics. The larger quartz grains are commonly composite and strained, with sutured internal grain boundaries, suggesting derivation from a deformed plutonic or metamorphic terrane. They are commonly elongate and aligned parallel to bedding. In some areas, this could be due to deformation, but in most cases it is probably due to their derivation from foliated rocks, and the alignment is a sedimentary feature. Detrital mica (muscovite, biotite, and chlorite) rarely exceeds a few per cent. The arenites are poorly sorted, containing up to 40% matrix of silt-sized quartz, and phyllosilicates less than 0.01 mm. Detrital tourmaline and zircon are common.

Purple to green, volcaniclastic arenite and rudite and purple mudstone locally occur just above the Donaldsons Well Volcanic Member.

The mudstone generally has a strong fissility parallel to bedding, but in some areas, a crosscutting slaty cleavage is present. Near Greenvale, the bedding-parallel fissility is very strong and probably enhanced by tectonic processes. Metamorphic grade is also higher near Greenvale (chlorite zone, and possibly locally biotite zone, of the greenschist facies), and the phyllosilicates in both the mudstone and arenite matrix are coarser (up to 0.05 mm); a slightly differentiated crenulation cleavage is locally superimposed on the bedding-parallel cleavage.

West of the Gray Creek Complex at 7859-753820, deformed, stylolitised, fine-grained limestone crops out for about 100 m along strike at the boundary with the Donaldsons Well Volcanic Member. Limestone also occurs at 7859-697485 along a tributary of Diggers Creek. The blocks of limestone are up to 2 m across, and occur with mudstone and arenite. The exact relationships of the limestones at both localities to the rocks with which they occur is not certain. They could be olistoliths.

Environment of deposition and provenance

The lack of volcaniclastic deposits associated with the Donaldsons Well Volcanic Member, particularly the more felsic lavas, may suggest that the rocks were erupted in relatively deep water such that the hydrostatic head prevented explosive vesiculation in the vents. At depths greater than 3 km, explosive fragmentation of magmas is not possible (Cas & Wright, 1987, p 39). Alternatively, the magmas may have had low volatile contents. The absence of vesicles in most of the lavas could indicate a low volatile content, or it also could be due to the hydrostatic head. Sedimentary structures indicate that the arenites in the Judea Formation were deposited by turbidity currents. Like the quartzose arenite units in the Camel Creek Subprovince, the relative maturity and fine grain size of the Judea Formation suggests subdued relief due to tectonic stability in the source region, and this allowed chemical breakdown of labile minerals such as feldspar, mica, and lithic fragments (for example, Crook, 1974; Dickinson & Suczek, 1979; Johnsson & others, 1988). Alternatively they may be multi-cycle quartzose arenites, and this possibility has been discussed previously in relation to the quartzose units in the Camel Creek Subprovince.

Relationships

The Judea Formation is intruded by the Netherwood Tonalite, and unconformably overlain by the Graveyard Creek Group. The Saddington Tonalite intrudes the Donaldsons Well Volcanic Member. The unconformity is exposed in the Broken River at 7859-662442 (Plate 8c) and 683440. At both of these localities a basal conglomerate containing pebbles and cobbles of quartz-veined quartzose arenite rests on the unconformity. Although a clear angular discordance occurs at these outcrops, such discordance is difficult to demonstrate elsewhere, and the outcrop patterns indicate a gross regional concordance.

Apart from the local angular discordance and basal conglomerate, other evidence for an unconformity can be cited: (a) no boudinage or broken formation occurs in the Graveyard Creek Group (except for minor disruption in mudstones near the base, probably due to slumping); (b) clasts of quartzose arenite in the basal conglomerates are commonly quartz-veined indicating induration and veining prior to erosion; and (c) the Netherwood Tonalite, intrudes the Judea Formation, but is overlain nonconformably by the Graveyard Creek Group.

The relationships to the Proterozoic rocks of the Georgetown Inlier and Gray Creek Complex are less clear. Near Greenvale the Judea Formation is in contact with the Proterozoic Halls Rewards Metamorphics to the west, and the Gray Creek Complex to the east. The western contact is marked by a 200 m-wide mylonite zone, the Halls Reward Fault. The mylonite is a finely laminated phyllitic rock, which probably includes both phyllonite, derived by grain-size reduction of the coarse mica schist of the Halls Reward Metamorphics, and mylonitised Judea Formation. The mylonitic foliation is subvertical and trends 010$, but has not been studied in sufficient detail to determine movement sense.

T.H. Bell (personal communication, 1982) has interpreted the mylonite zone as a thrust, on which the Judea Formation was thrust over the Halls Reward Metamorphics. Furthermore, because the overlying Graveyard Creek Group farther south towards the Dinner Creek occupies a synclinal hinge, he interpreted the contact between the Judea Formation and the Gray Creek Complex to the east as the same thrust repeated on the eastern limb of the syncline.

The latter interpretation has at least two problems. No obvious mylonite zone occurs between the Judea Formation and the Gray Creek Complex, although this could be explained by later faulting. Another problem is that the Saddington Tonalite intrudes both the Gray Creek Complex and Donaldsons Well Volcanic Member. Because it is itself intruded by dolerite dykes, which could be feeders to some of the volcanic rocks, Arnold & Rubenach (1976) interpreted the tonalite as being contemporaneous with the volcanism, and therefore it should have predated the thrusting. However, if the Judea Formation was thrust over the Gray Creek Complex, the tonalite must postdate the thrusting, and is not related to the volcanic rocks.

A further interpretation of Bell's is that the Gray Creek Fault (which is a mylonite zone) also represents the thrust, repeated again on the eastern limb of an antiform, the core of which is the Gray Creek Complex. If this interpretation is correct, the Gray Creek Fault should close around the northern end of the complex rather than continuing north to join the Burdekin Fault as presently mapped. The Judea Formation and Wairuna Formation would then merge into each other; the Everetts Creek Volcanics and Carriers Well Formation on the eastern limb would also be equivalent to the Judea Formation. Younging directions in the Everetts Creek Volcanics and Carriers Well Formation should therefore be to the east. No clear predominant younging direction has been determined, although westward younging is at least as common as eastward younging.

Age

The limestone in the Donaldsons Well Volcanic Member at 753820 contains poorly preserved favositid and heliolitid corals. These suggest a Middle Ordovician or younger age for at least part of the Judea Formation. Palmieri (1984) found poorly preserved panderodiform and falodiform conodont elements in a limestone sample from this locality. However, the discovery of a tetragraptid in shales underlying the Poley Cow Formation near Diggers Creek Gorge (Withnall & others, 1988b), indicates that the sedimentary part of the Judea Formation is Early Ordovician. If the limestone is part of the Donaldsons Well Volcanic Member, and not infaulted Graveyard Creek Group, the younger age suggested by the corals is not consistent with the volcanics apparently underlying the sedimentary rocks. It may suggest that this apparent stratigraphic position is the result of thrusting.

The overlying Graveyard Creek Group is partly of Early Silurian (Llandoverian) age. Therefore the age of the Judea Formation is in the range Early Ordovician to Early Silurian.

TONALITE PLUTONS

Introduction

White (1962a) originally mapped a small body of "granodiorite" in the Broken River as Craigie Granodiorite. Later work (Arnold, 1975; Arnold & Henderson, 1976) showed that such rocks are more extensive in the area. Our mapping has shown that they are distinct from the Craigie Granodiorite in its type area near Craigie homestead and are separated from it by the Clarke River Fault; they were named and defined as the Netherwood Tonalite by Withnall (1989a).

Small intrusions of "granodiorite" were originally mapped as part of the Gray Creek Complex by White (1962a) and Green (1958), and correlated with the Craigie Granodiorite by White (1959). Arnold & Rubenach (1976) later referred to gabbro, tonalite and trondhjemite at the southern end of the Gray Creek Complex as part of their "interkinematic igneous suites". They were named and defined as the Saddington Tonalite and excluded from the complex by Withnall (1989a).

Netherwood Tonalite

The Netherwood Tonalite forms two small plutons, partly dismembered by faulting, and totalling about 5 km^2 in the Broken River area. In the type area in the Broken River (between 7859-675443 and 679442), the Netherwood Tonalite consists of greenish grey, fine to medium-grained, equigranular biotite-hornblende tonalite to quartz diorite. The western contact with the Donaldsons Well Volcanics Member is complex and may be partly faulted as interpreted by Arnold & Henderson (1976). However, abundant enclaves of green aphyric volcanic rocks from a few centimetres to 20 m long are present, and indicate that the tonalite intrudes the volcanic rocks. Near the eastern contact, breccia or pebble dykes of quartzose arenite clasts occur in the Judea Formation. A chilled margin of brecciated porphyritic dacite has also been observed in several places. The tonalite is commonly strongly jointed, and incipiently sheared and brecciated, but is otherwise unfoliated.

The tonalite consists of subhedral laths, 1 to 3 mm long, of plagioclase (60 to 70%) and interstitial quartz (20 to 25%). The plagioclase has cores of andesine or oligoclase and more sodic rims, and is generally slightly sericitised or saussuritised. Biotite (about 5%) is largely chloritised and forms ragged flakes up to 2 mm across. Up to 10% brownish green hornblende is present as subhedral, subequant to prismatic grains, 0.5 to 2 mm long, although some outcrops are devoid of hornblende.

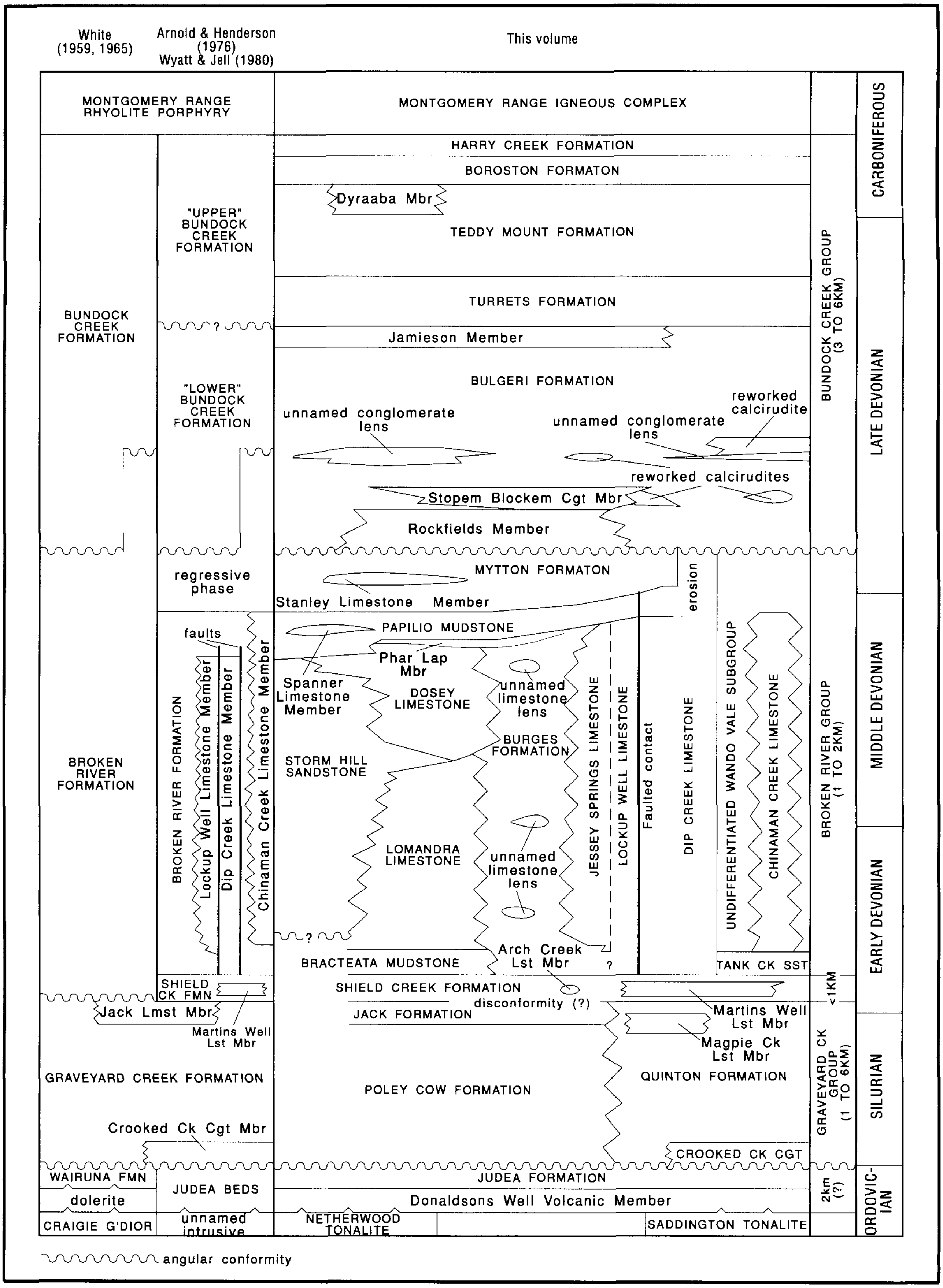

Figure 12. Stratigraphic nomenclature of the Graveyard Creek Subprovince.

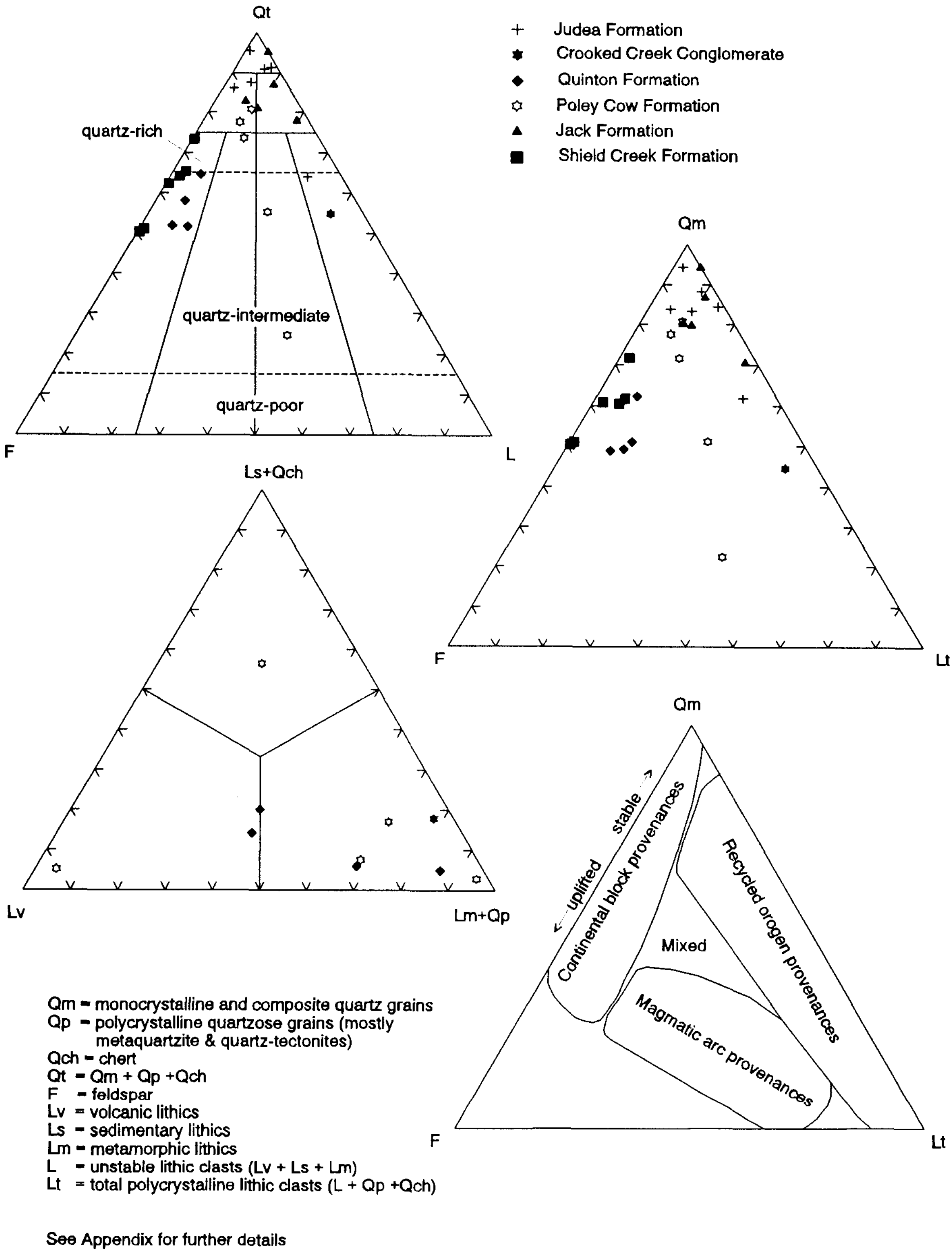

Figure 13. Plots of modal data from arenites in the Graveyard Creek Group and Shield Creek Formation. See Appendix for full analyses and more details. Compositional fields are after Crook (1960, 1974) and inferred provenance fields are after Dickinson & Suczek (1979).

The Netherwood Tonalite intrudes the Judea Formation and is nonconformably overlain by the Graveyard Creek Group. At 7859-709473 and 707455 basal conglomerate of the Poley Cow Formation containing clasts of tonalite cops out adjacent to *in situ* tonalite. The relationships at these outcrops appear unequivocal; Arnold & Henderson (1976, figures 2 and 5) also examined the first locality and interpreted it in the same way. However, near the junction of Diggers Creek and the Broken River the relationship is less clear and could be interpreted as intrusive (C. Fielding, personal communication). Arnold & Henderson (1976, figure 2), interpreted it as a fault, and this interpretation is followed on the Broken River Special (Plate 1).

Saddington Tonalite

The Saddington Tonalite forms an irregular pluton about 20 km^2 in area, cropping out mainly between Crooked and Horse Creeks and straddling the Greenvale-Pandanus Creek road. Tonalite or quartz diorite in a small north-trending fault slice about 3 km long and a few hundred metres wide crops out east of Gray Creek, about 5 km east of Top Hut yards. The unit consists mainly of grey, medium-grained, equigranular hornblende tonalite, quartz diorite, and diorite. The rocks are locally weakly foliated and in some outcrops the quartz grains are bluish due to strain. Xenoliths are generally rare, except near some contacts with the Gray Creek Complex. The type area is at 7859-780770 at the head of a small tributary of Horse Creek.

The rocks contain 10 to 30% quartz as strongly strained grains commonly with mortar texture. Plagioclase (40 to 50%) forms subhedral, normally zoned laths with generally turbid cores (An_{50}) and clearer rims (An_{0-20}). Some laths are poikilitically enclosed by ragged, brownish green, subequant prismatic hornblende grains up to 4 mm long. Minor biotite as aggregates of small flakes partly replace hornblende in some rocks. The small slice of Saddington Tonalite east of Gray Creek is commonly cataclastic, probably due to movement on the nearby Gray Creek Fault. Strongly strained quartz occurs in a dark green matrix of "rock flour".

The rocks are mainly tonalite using the IUGS classification (Streckeisen, 1976). Arnold & Henderson (1976) described them as trondhjemite, but the more general term, tonalite, is preferred here.

The Saddington Tonalite intrudes the Gray Creek Complex. The mapped outcrop pattern suggests that the Saddington Tonalite also intrudes the Donaldsons Well Volcanic Member, and a large "septum" of volcanics almost divides the pluton into two. However, because of the poor outcrop, no actual contacts have been observed. Arnold & Rubenach (1976) described locally abundant basaltic xenoliths within the tonalite and also suggested an intrusive relationship with the volcanic rocks. They also pointed out the similarities between the Saddington Tonalite and the "trondhjemite" in the Broken River (now Netherwood Tonalite) which is known to intrude the volcanic rocks.

Abundant, aphyric, fine-grained mafic dykes and some rare feldsparphyric mafic dykes intrude the Saddington Tonalite. Arnold & Rubenach (1976) suggested that the mafic dyke swarms were feeders to the Donaldsons Well Volcanic Member. Similar dykes also intrude the Gray Creek Complex.

Age

The Netherwood Tonalite is Early Ordovician to Early Silurian in age because it intrudes the Judea Formation and as described above is nonconformably overlain by the Poley Cow Formation.

The Saddington Tonalite is probably similar in age. It may have been intruded contemporaneously with the eruption of the Donaldsons Well Volcanic Member; it intrudes the volcanic rocks, but is itself intruded by mafic dykes, which may have been feeders to some of the volcanic rocks.

STRATIGRAPHY AND SEDIMENTOLOGY OF THE SILURIAN TO EARLY DEVONIAN GRAVEYARD CREEK GROUP AND SHIELD CREEK FORMATION

(I.W. Withnall, C.R. Fielding, S.C. Lang & P.J.G. Fleming)

The Graveyard Creek Group crops out in two areas separated by the large laterite plateau in central BURGES. The larger, about 250 km^2, extends from near Pandanus Creek Homestead east to Lockup Well, and north to the middle reaches of Dinner Creek. The other area forms a belt about 4 km wide extending for about 25 km southwest from the headwaters of Back Creek to south of the Broken River; in this area the formation is interfolded with the Judea Formation.

The unit was originally defined as the Graveyard Creek Formation by White (1959, 1962a, 1965). As a result of our remapping, the unit has been subdivided into several formations and is given group status (Withnall & others, 1988b; Withnall, 1989a; see Figure 12).

The constituent formations are described under separate headings below. The Crooked Creek Conglomerate (originally a named member of the Graveyard Creek Formation) and Quinton Formation lie to the north of the laterite plateau. The Magpie Creek Limestone Member is a prominent limestone lens in the Quinton Formation. The Poley Cow Formation and the Jack Formation (originally the Jack Limestone Member) are to the south.

CROOKED CREEK CONGLOMERATE

(I.W. Withnall)

Introduction

The Crooked Creek Conglomerate is a thick basal unit to the Graveyard Creek Group, cropping out in a southwest-trending belt between Dinner Creek and Gray Creek. Conglomerate near Top Hut yards is also equated with the unit.

The Crooked Creek Conglomerate unconformably overlies the Judea Formation and Gray Creek Complex. Its relationship with the Halls Reward Metamorphics and Boiler Gully Complex is uncertain and may be faulted, but it could be locally unconformable. The unit is conformably overlain by the Quinton Formation.

White (1959) gave a type area for the unit in Dinner and Crooked Creeks. In both of these creeks the unit is exposed in the core of a synclinorium and the top is not exposed. Withnall (1989a) redefined the unit and designated the section exposed in Dinner Creek between 7859-784867 and 754870 as the type section, and the section in Crooked Creek between 725842 and 760837 as a reference section. These sections include both limbs of the fold and numerous smaller-scale folds, which prevent calculation of the thickness.

The thickness of the Crooked Creek Conglomerate is difficult to determine because of repetition by folding in most sections, but at least 300 m is exposed beneath the Quinton Formation in Chinaman Creek where the base is not exposed. It thins to the southeast. South of the junction of Horse and Gray Creeks towards Lockup Well, basal conglomerates overlying the Judea Formation are thin (less than 50 m) to absent.

Lithology

The Crooked Creek Conglomerate consists mostly of polymictic, boulder to pebble conglomerate. It is commonly massive with no internal structures other than imbrication of tabular and elongate clasts. Bedding where present is defined by stringers of arenite, alignment of tabular clasts, or variations in clast size and abundance (Plate 9a). Basal scours up to 3 m deep are present in some beds. Normal and inverse grading, and rare large-scale cross-stratification are present locally. The rocks are generally bimodal and range from clast-supported conglomerate to pebbly or bouldery arenite. The pebbles and boulders are subangular to rounded. The matrix is poorly sorted lithofeldspathic arenite.

On the western limb of the synclinorium in Dinner and Crooked Creeks, and in the core of the Black Wattle Anticline, the unit is characterised by a predominance of amphibolite and metagabbro clasts (Plate 9b), presumably derived from the Boiler Gully Complex in the adjacent part of the Georgetown Inlier or the Gray Creek Complex. The matrix to such conglomerates consists of coarse, quartz-poor arenite composed of plagioclase and amphibole. Many of the amphibolite clasts have a mylonitic foliation. Other clast types include black chert, aphyric mafic volcanics, limestone, and serpentinite. Some of the clasts are boulders up to several metres. Outcrops of metamorphic rocks, originally mapped by Jell (1967), about 7 km northeast of Pandanus Creek Homestead, consist of blocks of amphibolite and metagabbro at least 30 m across; they are probably olistoliths rather than local occurrences of basement as suggested by Jell. North of Dinner Creek, near the contact with the Halls Reward Metamorphics, very poorly sorted conglomerates are composed almost entirely of mica schist clasts, ranging from a few millimetres to a metre. Outcrops of quartz up to 5 m long may be veins in large schist blocks. Rare conglomerates are composed almost entirely of serpentinite clasts in a serpentine matrix (Plate 9c). Arnold & Henderson (1976) also described diamictite consisting of clasts of various sizes in a mudstone matrix.

On the eastern limb of the synclinorium in Dinner Creek, the conglomerates show a much greater variety of clast type. They include biotite granitoids, quartzite, quartzose arenite (from the Judea Formation), mafic volcanic rocks, felsic porphyry, vein quartz, and schist, as well as amphibolite, metagabbro, and serpentinite.

About 17 km northeast of 'Pandanus Creek' matrix-supported cobble and boulder conglomerate (Plate 9d) also contains a wide assortment of clasts, the most common of which are felsic volcanic rocks, as well as biotite granitoid, leucogranite, mica schist, amphibolite, and felsic mylonite. The felsic volcanic rocks include mildly metamorphosed and deformed flow-banded rhyolite and lithic-crystal tuff; quartz phenocrysts are strained and some rocks have a foliation.

Cropping out within this conglomerate are two large limestone lenses consisting predominantly of massive fine-grained limestone (calcilutite) with local crinoidal calcarenite and calcirudite. The largest of the lenses is 2 km long and 150 m wide, and both terminate abruptly along strike against conglomerate. They may be allochthonous blocks (olistoliths) transported downslope from a neighbouring shelf. Sporadic limestone clasts have also been observed in the amphibolite conglomerate between Dinner and Crooked Creek.

Farther east near Top Hut Yards, the Crooked Creek Conglomerate contains a predominance of clasts derived from the underlying Judea Formation. These include fine-grained quartzose arenite and siltstone, phyllitic shale or mudstone, and vein quartz; additional clasts include mica schist and phyllite, probably from the Halls Reward Metamorphics.

Although the unit consists predominantly of conglomerate and arenite, mudstone also crops out locally, generally as thin discontinuous beds. However, thicker beds showing internal disruption crop out in the Black Wattle Anticline. The mudstone is strongly fractured and thin arenite beds within it are disrupted by both cross-faulting and boudinage. The disruption in the mudstone may be due to submarine slumping and sliding, consistent with the presence of diamictites and olistoliths.

Environment of deposition

The Crooked Creek Conglomerate was probably deposited as short headed fans adjacent to a faulted margin when subsidence of the Graveyard Creek Subprovince was initiated. This is suggested by the common lack of mixing of clasts from the different lithologies within the adjacent Georgetown Province, the main provenance of the unit. Significant relief (probably an active fault scarp) is suggested by the extremely large blocks and olistoliths of metamorphic rocks within the conglomerate in places. Mass flow processes were probably significant depositional mechanisms to transport such material.

Age

The Crooked Creek Conglomerate is probably of Early Silurian age, because of the Llandovery fossils in the overlying Quinton Formation. Faunas in the limestone blocks have not been studied in detail. V. Palmieri (written communication, 1983) suggested a Late Ordovician age for a sparse conodont fauna from the large allochthonous blocks northeast of Pandanus Creek homestead.

QUINTON FORMATION

(I.W. Withnall)

Introduction

The Quinton Formation, defined by Withnall (1989a), is that part of the Graveyard Creek Group north of the laterite plateau in the Basalt Yards area. It is a predominantly a turbidite sequence. The Quinton Formation conformably overlies the Crooked Creek Conglomerate and is laterally equivalent to the Poley Cow Formation from which it is separated by the laterite plateau. Near Jessey Springs, just south of the laterite plateau, an inferred basement high, on which the Poley Cow Formation is very thin or absent, also separates the two units.

The unit is overlain by the Shield Creek Formation with apparent conformity, although a time-break is possible. The type section is in Chinaman Creek between 7859-665696 (base) and 610696 (top) (Figure 15).

Lithology

Western area

In the type section and adjacent area west of the Black Wattle Anticline, the formation is about 5000 m thick, and is an arenite-dominated proximal facies. In most of this area, medium to very thick-bedded, coarse to very coarse-grained, lithofeldspathic arenites predominate. However, intervals up to 200 m thick, in which mudstone or shale predominate or alternate with thin to medium-bedded, medium to coarse-grained arenite, are also present, particularly in the lower half of the section. Some shaley intervals which form distinct photopatterns can be traced for up to 5 km. A few intervals also contain conglomerate. The top 650 m of the type section consists of very thick- bedded (4 to 5 m, but up to 30 m), coarse to very coarse-grained, pebbly arenite. This very thick-bedded sequence persists for at least 10 km from near Pandanus Creek Homestead to at least the hinge of the Six Mile Syncline.

In some parts of the section, the beds are predominantly massive internally and Bouma divisions are rarely developed. However, in many places, the thicker, coarser arenite beds pass upwards from a massive or graded basal part to planar laminae, and less commonly, cross-laminae or convolute laminae (the ABC Bouma divisions - Plate 10a, c). Such arenite beds may be separated by thin mudstone layers, but commonly they are in contact with other thick arenite beds. Contacts are commonly parallel-sided, although channelled bases are also present. Shale clasts up to 10 cm long occur in some arenites.

Sporadic pebble and cobble conglomerate beds are also intercalated with, and locally grade upwards into, the thick arenite beds (Plate 10b). Clasts are generally quartz, black chert, and mylonitised amphibolite, but aphyric mafic volcanics, quartz-feldspar porphyry, leucogranite, pegmatite, biotite granitoid, schist, phyllite, quartz arenite, and rare coralline limestone also occur.

The thinner-bedded, medium to coarse arenites, intercalated with mudstone, are commonly laminated and locally have cross-laminae, and, together with the mudstone, represent the BCE Bouma divisions. Grading is locally present, but is not common. Truncated, open, convolute folds are common in the upper laminated parts of the arenite beds, and some thin beds show pinch-and-swell.

Limestone in blocks from a few metres up to 200 m long occur sporadically in the lower part of the sequence on both limbs of the anticline. The blocks occur in an interval 100 to 500 m above the Crooked Creek Conglomerate in very thick-bedded coarse-grained arenite and conglomerate, and are probably olistoliths. Thin-bedded, fine-grained, impure limestone beds also crop out in a few places, for example 640676. They are graded and laminated and may be turbidites.

The arenites throughout the area are lithofeldspathic to feldspathic (Figure 13). They range from poorly to moderately sorted, although they contain little actual clay or

PLATE 9:

a. **Thick-bedded, polymictic conglomerate composed largely of amphibolite clasts with lesser granitoid and quartz supported by a feldspatholithic arenite matrix; also medium-bedded feldspatholithic arenite lenses. 7859-770867, Dinner Creek, 6 km south-southeast of Burges Dam.**

b. **Pebble to boulder conglomerate composed almost entirely of amphibolite and metagabbro clasts in a quartz-poor matrix of plagioclase and hornblende. 7859-730844, 8 km south-southwest of Burges Dam.**

c. **Cobble conglomerate composed entirely of serpentinite clasts in a matrix of altered serpentine and magnesite. 7859-759868, Dinner Creek, 6 km south of Burges Dam.**

d. **Boulder of granitoid and cobble of felsic volcanic (ignimbrite?) in coarse-grained lithofeldspathic arenite. 7859-686800, 10 km northwest of Top Hut Yards.**

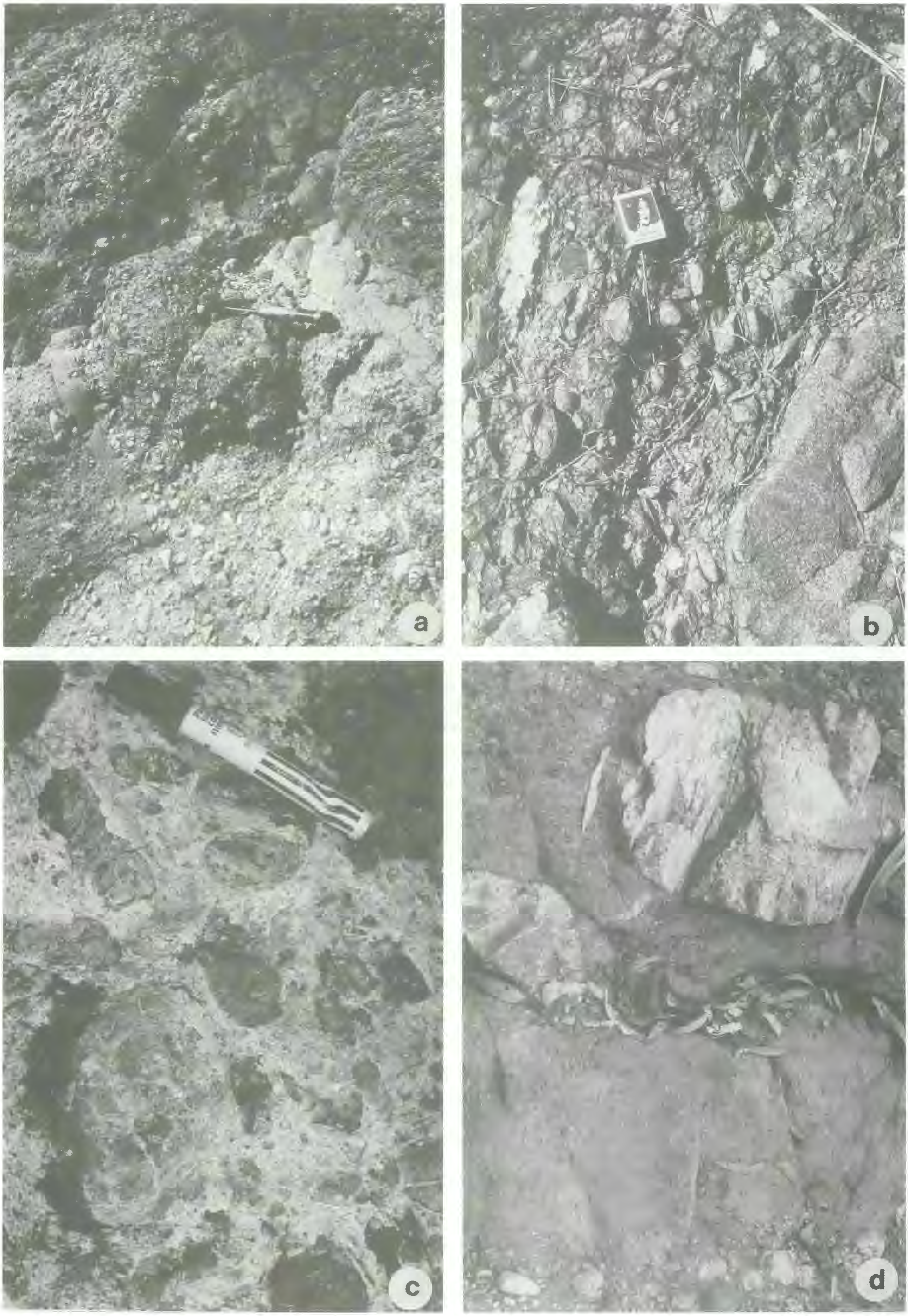

Plate 9. Crooked Creek Conglomerate.

silt-sized matrix (less than 5%). Clasts are commonly subangular. Quartz (40 to 60%) is generally strained (commonly very strongly mylonitic), and grains are usually composite; rare unstrained grains may be of volcanic origin. Feldspar (20 to 40%) is predominantly plagioclase, but microcline is generally also present. Mica (up to 10%), including both muscovite and chloritised biotite flakes, is a common constituent; muscovite is also present as fine aggregates which may be phyllite clasts or retrogressed alumino-silicates from high-grade metamorphic rocks. Lithic clasts (up to 10%) include mica schist, phyllite, micaceous quartzite, fine-grained aphyric felsic volcanics, and leucogranite.

Eastern area

East of the Black Wattle Anticline, between Martins Well and the old Pandanus Creek airstrip, the arenite-dominated facies passes into a more distal facies (Plate 10d), in which shale or massive mudstone generally predominates over arenite. Arenite beds are generally thin to medium-bedded, fine to medium-grained, and have well-developed Bouma divisions generally ABCE and BCE). Sporadic, thicker, coarse-grained arenites are generally graded. The overall thickness of the formation is difficult to determine because of the complex folding which ranges from outcrop scale to folds with wavelengths of several kilometres. However, it is probably of the order of 2000 m or less in the Turtle Creek area.

Thin to medium-bedded calcarenite and calcilutite are relatively common in the top half of the sequence in the Turtle Creek area. They are graded, laminated, contain rip-up clasts of mudstone, and have load casts; they probably represent calcareous turbidites or debris flows from a neighbouring shelf, possibly on a postulated palaeo-high to the south between Lockup Well and Jessey Springs.

Minor limestone, possibly *in situ*, occurs in Gray Creek at 759716 near Top Hut Yards towards the base of the formation. A large limestone lens (the **Magpie Creek Limestone Member**) crops out towards the top of the Quinton Formation in the headwaters of Turtle and Magpie Creeks. The lens is about 5 km long and between 300 m and 500 m thick. It consists predominantly of massive calcilutite and fine calcarenite, with a few discontinuous mudstone intervals up to 50 m thick. It is locally brecciated with angular clasts ranging from a few millimetres to large boulders. According to T. Munson (personal communication, 1984) breccia is common throughout the lens, which he interprets as a large olistolith. In our survey, the lens was only studied along the road to Basalt Yards and towards the western end; in these areas the limestone appears to be mainly unbrecciated except towards the base and locally near the top. The breccias appear to be zones of shattering or brittle deformation, or are possibly due to dissolution, rather than being debris flows. The turbiditic nature of the surrounding sediments is consistent with the lens being allochthonous, although the immediately adjacent sediments are mudstone, and no thick, chaotic debris flows which might be expected in an olistostrome have been observed. The relationships of the lens need further study. Overlying the lens, mudstone and thin-bedded arenite crop out, together with some thin to medium, graded beds of coarse-grained calcarenite and calcirudite, which may be turbidites. The Magpie Creek Limestone Member may be equivalent to the limestones in the Jack Formation.

Quartz-poor arenite containing over 90% felsic volcanic clasts was described by Arnold & Henderson (1976) from the eastern part of the area. Spring (1979), and our survey have further delineated the extent of the volcaniclastic rocks. They occur in an interval up to 100 m thick which can be traced from the Turtle Creek area (around 735700) across Gray Creek towards the junction of Horse and Gray Creeks and thence south along Tomcat Creek. In the latter area they occur about 100 m above the base of the formation, and above the basal conglomerates. Such quartz-poor volcaniclastic rocks appear to be restricted to the area described, and none have been observed in the equivalent Poley Cow Formation to the south, or west of the Black Wattle Anticline.

In outcrop, the volcaniclastic rocks have a distinctive, cream, bleached appearance (Plate 10e). They range from thin-bedded, locally laminated, cherty siltstone to pebble conglomerate (Plate 10f), but generally they are medium to thick-bedded, fine to medium-grained arenite, which are commonly graded. The conglomerates tend to be lenticular and have channelled bases. Mudstone and normal lithofeldspathic arenite are interbedded with the volcaniclastic rocks, which consist of two main types. The first type contains a cryptocrystalline or microcrystalline matrix, and up to 60% angular crystals of volcanic quartz and sericitised albite, generally less than 1 mm. Minor, very fine-grained felsite and rare, non-volcanic, lithic clasts (quartzite and phyllite) are also present. Some of these rocks are graded. The other type comprises poorly sorted arenites consisting of angular quartz, albite, and mostly aphyric, felsite clasts in a silty to very fine sandy matrix of quartz and feldspar. These grade into granule and pebble conglomerate, and also include non-volcanic detritus. Staining with sodium cobaltinitrite indicates little, if any, K-feldspar.

Arnold & Henderson (1976) compared the volcaniclastic rocks with submarine pyroclastic rocks described by Fiske & Matsuda (1964), and suggested that the rocks with the

PLATE 10:

a. **Medium bed of coarse-grained lithofeldspathic arenite showing grading and interbedded with fine-grained arenite showing planar laminae and minor soft-sediment deformation and load casts. 7859-629692. Chinaman Creek, 5 km north-northeast of Pandanus Creek homestead.**

b. **Very thick bed showing grading from polymictic conglomerate at its base to coarse grained lithofeldspathic arenite. 7859-045769, 13 km north-northeast of Pandanus Creek homestead.**

c. **Soft-sediment folds and planar laminae in medium-grained, lithofeldspathic arenite. 7859-642742, 10 km north-northeast of Pandanus Creek homestead.**

d. **Typical thin-bedded arenite and mudstone of the 'distal' facies of the Quinton Formation. 7859-716694, 3.5 km east-southeast of Martins Well.**

e. **Bed of fine-grained, volcaniclastic arenite or siltstone, showing its characteristic white, bleached appearance in outcrop, and interbedded with 'normal' lithofeldspathic arenite and mudstone. 7859-743715, Gray Creek crossing, Greenvale-Broken River track.**

f. **Detail of volcaniclastic granule conglomerate, showing abundant white, subangular aphyric dacite clasts in a matrix of finer volcanic clasts plus 'normal' quartz, feldspar, and sedimentary lithic sand grains. Same locality as e.**

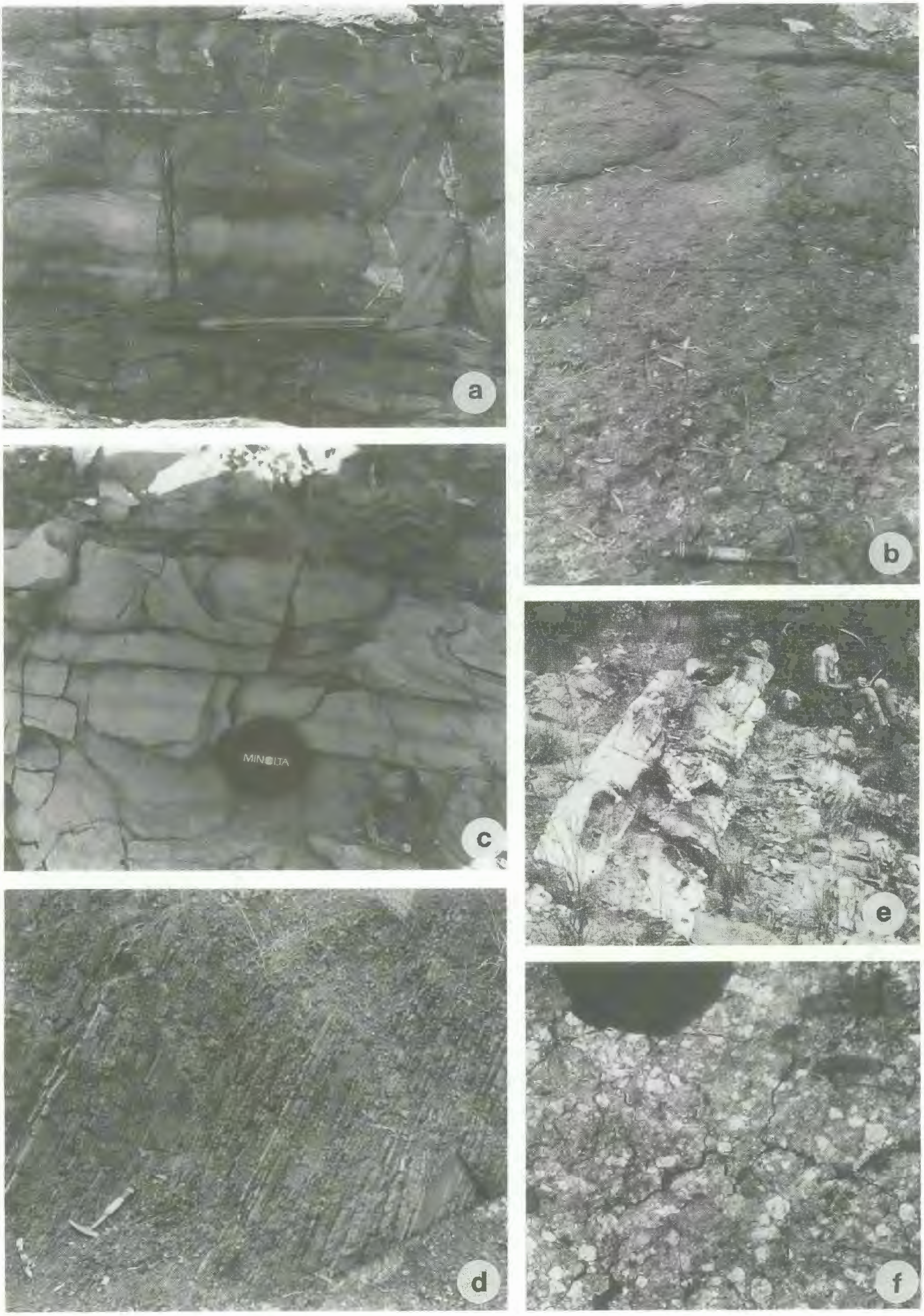

Plate 10. Quinton Formation.

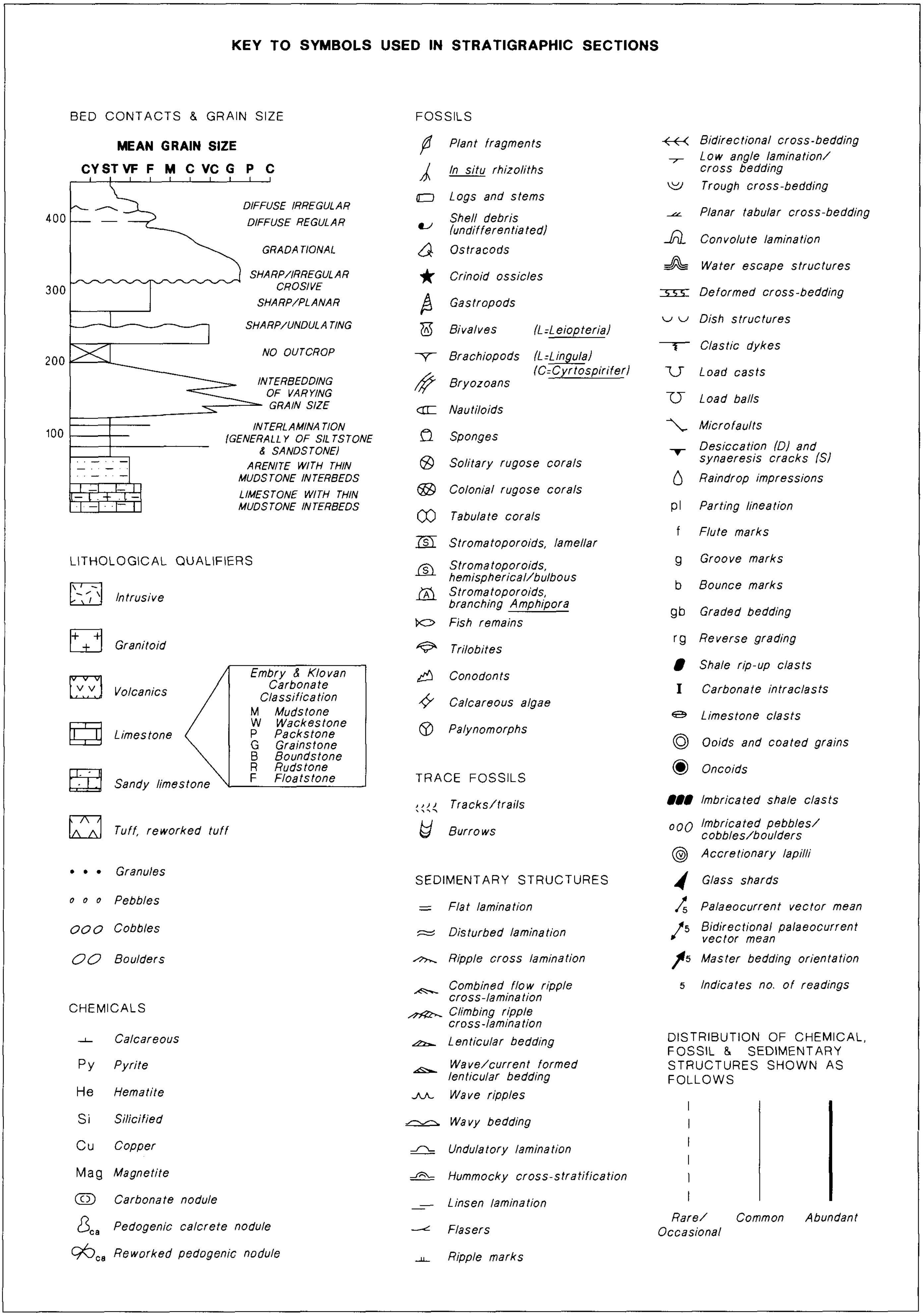

Figure 14. Legend to stratigraphic sections throughout report.

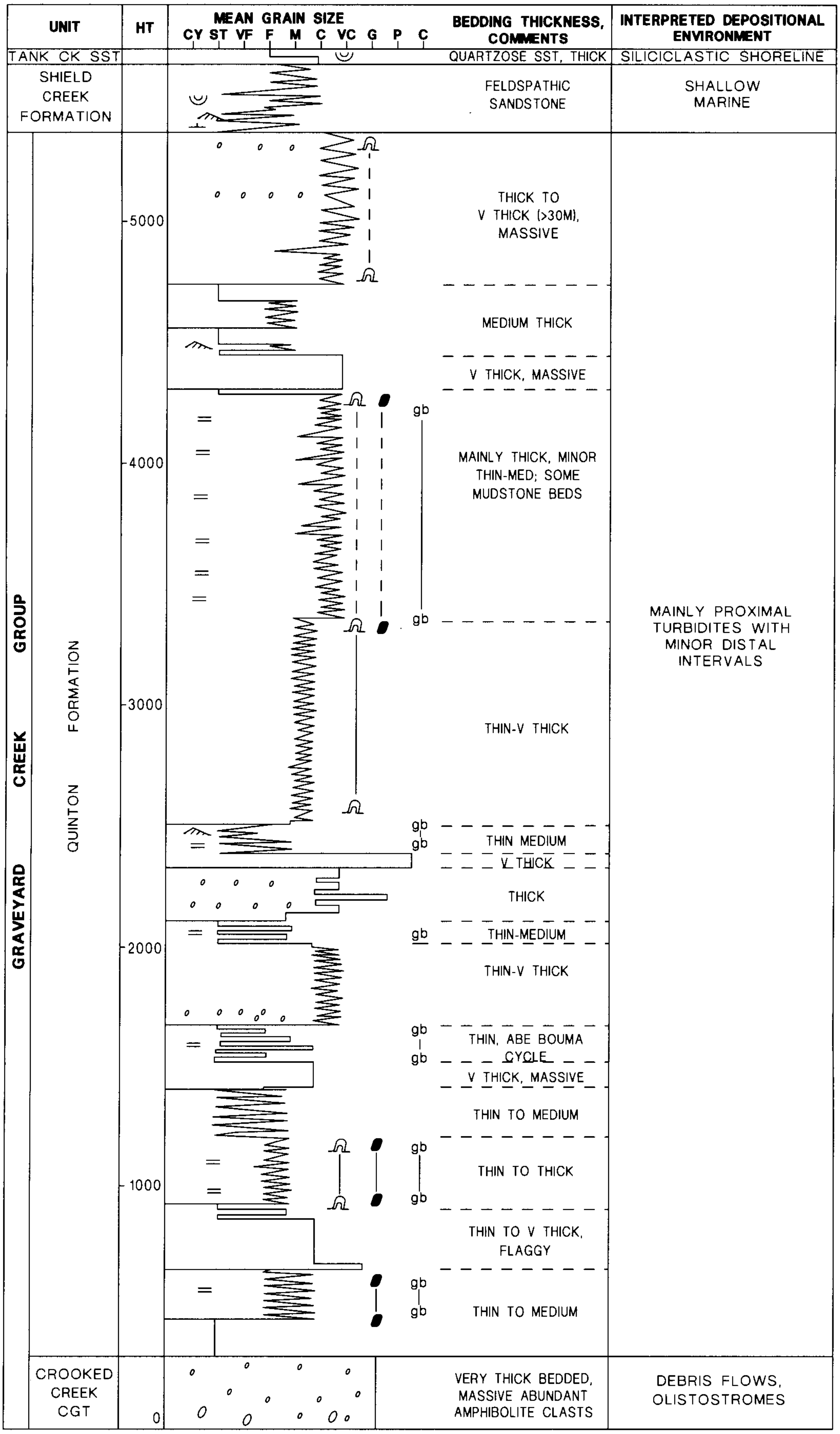

Figure 15. Type section of the Quinton Formation in Chinaman Creek. See Figure 14 for reference.

microcrystalline matrix were originally pyroclastic turbidites; the matrix was probably originally fine-grained glassy ash, and clastic textures were obliterated by devitrification and submarine alteration, except where crystal and other lithic clasts are present. Clastic textures in the matrix have been obliterated by devitrification. The arenites and conglomerates may be partly pyroclastic turbidites, from which the finer ash and dust were winnowed before or during transport. The lack of mixing with non-volcanic detritus in many of the beds suggests a local source and can be best explained by minor, relatively short-lived, contemporaneous volcanism during deposition of the Graveyard Creek Group in the northeastern part of the Graveyard Creek Subprovince.

Environment of deposition

Detailed sedimentological studies of the Quinton Formation are yet to be done. However, the most likely environment of deposition is a submarine fan system adjacent to an actively subsiding faulted margin to the Georgetown Province, which was the main provenance, consisting of Proterozoic granite and metamorphic rocks, and probably some Early Palaeozoic volcanic rocks. Some shelf deposition may have occurred on the Georgetown Province beyond the faulted margin, and this was possibly the source of the limestone and perhaps the black chert clasts common in the west.

East of Martins Well, the Quinton Formation is much thinner (less than 2 km) and more distal in appearance. This trend is consistent with the source being mainly to the west or northwest. Continuous more rapid subsidence in the west allowed a thicker accumulation of sediments (up to 5 km) there and prevented progradation of the proximal facies farther east. The Shield Creek Fault coincides approximately with the eastern extent of the proximal facies, and it or a precursor may have been active during deposition. The proximal facies could thus have been deposited in a narrow trough between the Teddy Mount and Shield Creek Faults.

Some sediments in the east may have been derived from the basement high which separates the Quinton and Poley Cow Formations, and which may have been a site of non-deposition in the Early Silurian. The Lockup Well/Jessey Springs Fault system may also have been a long-lived structure and may coincide with the northwestern margin of this high.

Age

White (1965) listed a fauna which included trilobites and brachiopods from Gray Creek at 7859-791748. White incorrectly assigned this locality to the Wairuna Formation (now Judea Formation), but the locality is actually just above the unconformity in the Quinton Formation. A Late Llandovery or Wenlock age was assigned to the fauna which also contains corals. Arnold (1975), Arnold & Henderson (1976), and Lane & Thomas (1978) assigned the same age range to a similar fauna from a locality at 785738, about 1.5 km upstream of White's locality, but about 600 m above the unconformity; a conodont fauna from the locality (Aldridge *in* Lane & Thomas, 1978) suggests a late Llandovery age. Llandovery graptolites have also been found in Gray Creek at 7859-753715 by R.A. Henderson (JCUNQ). The fauna is dominated by *Monograptus exiguus* indicating a slightly younger age than the faunas in the Poley Cow Formation.

Limestone cropping out in Gray Creek near Top Hut at 759715 has yielded a Llandovery conodont fauna (Simpson, 1983) and also contains corals which suggest a similar age (Munson, 1987). A rich coral fauna in the Magpie Creek Limestone Member has yet to be studied in detail, but is possibly of Ludlow to Pridoli age.

POLEY COW FORMATION

(C.R. Fielding)

Introduction

The Poley Cow Formation crops out south of the large laterite plateau and consists of mudstone and arenite, and common large lenses of polymictic pebble conglomerate, which distinguish it from the eastern distal facies of the Quinton Formation. The two units are equivalent in age. The Poley Cow Formation unconformably overlies the Judea Formation and Netherwood Tonalite, and is conformably overlain by the Jack Formation. It was defined by Withnall (1989a) who designated a type section in the Broken River between 7859-662442 (base) and 660453 (top) (Figure 16).

Lithology and sequence

The Poley Cow Formation comprises up to at least 680 m of interbedded siltstones, sandstones, pebbly sandstones and conglomerates. The typical vertical sequence, exemplified by the type section (Figure 16), comprises a basal conglomerate 5-15 m thick, succeeded by a 200-250 m thick interval of mainly thin-bedded sandstone-siltstone, in turn overlain by an upper 200-400 m conglomerate-sandstone package with minor sandstone-siltstone interbeds. Downstream of the Broken River crossing, in the lower reaches of Diggers Creek, and along Poley Cow Creek and its tributaries, the more complex faulting and folding cause difficulties in unravelling the sequence or determining its thickness.

East of Jessie Springs Hut, the Graveyard Creek Group crops out in the core of the Wade Anticline. Only about 100 m of clastic sedimentary rocks (including quartzose arenite) crop out between the Judea Formation and limestone of the Jack Formation. The Poley Cow Formation may be partly represented in this interval, or the interval could be part of the Jack Formation, the Poley Cow Formation being entirely absent. This could be due to either uplift and erosion prior to the deposition of the Jack Formation, or the presence of a basement high on which only minor deposition occurred.

South of the Broken River, around the hinge of the Broken River Anticline, the Graveyard Creek Group is only 150 m thick. The Poley Cow Formation is represented only by a basal conglomerate and is overlain by medium-bedded, fine to medium-grained micaceous labile arenite, micaceous siltstone and minor conglomerate equated with the Jack Formation. Farther west, near Storm Dam, the entire Graveyard Creek Group, Shield Creek Formation, and lower part of the Wando Vale Subgroup are missing, and the Judea Formation is overlain directly by the Storm Hill sandstone. The smaller-scale vertical arrangement of lithologies varies from locality to locality.

Arenites are typically quartzose with significant feldspar, although a few samples are markedly volcanolithic in composition (Appendix and Figure 13). Conglomerates are dominated in their coarse fraction by clasts of metasedimentary lithologies reminiscent of the underlying Judea Formation, and vein quartz, with generally trace proportions of a variety of high-grade metamorphic and igneous lithologies, chert, limestone and intraformational siltstone. The mainly sand-grade matrix of conglomerates shows similar composition to the arenites. All lithologies are affected by the effects of incipient regional metamorphism.

Seven lithofacies have been recognised from exposures along the Broken River and tributary creeks (Table 1). These occur in two broad associations comprising Facies A-C (thin-bedded association - Plate 11a-c) and Facies D-G (conglomeratic association), although interfingering occurs, particularly of conglomerate beds within thinly bedded arenite-siltstone sections (Figure 16). Lithofacies A and B are transitional into one another, as are Facies D, E and F.

The basal conglomerate (Facies D or E) generally shows a crude normal grading, and passes upward via interbedding into the overlying thin-bedded arenite-siltstone association (Facies A and B). No overall grain-size trend has been observed within the lower, thin-bedded interval, although thickening/coarsening upward trends occur over 5-10 m intervals (Figure 17). Possible wave-generated structures and hummocky cross-stratification have been noted within such intervals. Scattered through the thin-bedded section or occurring in groups are thin, sharp-bounded arenite beds of volcanic lithic composition (Facies C).

The boundary between the lower thin-bedded interval and the overlying conglomerate-arenite-dominated section is always sharp and erosive where exposed, there being no coarsening-upward trend from one association to the other (Figure 17). The upper half of the formation thus comprises a series of thick conglomerate-arenite packages, separated by shorter intervals of the thin-bedded association (Figure 18). Within some conglomeratic intervals, systematic fining-upward trends have been noted from maximum particle size measurements (for example, Figure 18, 0-8 m).

The uppermost part of the Poley Cow Formation is poorly exposed, but in the type section comprises a thick interval of arenite (Facies G), becoming progressively more calcareous towards the base of the Jack Limestone.

Sedimentology and Environment of Deposition

A marine environment of deposition for the Poley Cow Formation is suggested by the available fossil evidence. The unit bears superficial similarity to sequences deposited in modern and ancient deep marine environments, and has been interpreted as such and termed "flysch" by previous workers (for example, Arnold & Henderson, 1976).

Despite this superficial similarity, the Poley Cow Formation displays a variety of features inconsistent with a deep-water origin and suggestive of accumulation in shallow water environments. With the exception of graptolites which are widely regarded as pelagic organisms, the fossil record from the Poley Cow Formation represents marine shelf and shoreline environments. Trace fossils (Plate 11d), which are unequivocally *in situ*, are reminiscent of the *Zoophycos* ichnofacies of Seilacher (1967) which typifies relatively quiet-water, offshore marine environments of unspecified water depth (Frey & Pemberton, 1984).

The thin-bedded association bears some resemblance to "distal" turbidites, but there are numerous differences. In addition to the fossils mentioned above, the arenites show probable wave-formed structures (Plate 11c)and hummocky cross-stratification, a combined current-wave flow structure restricted to shallow water, wave-affected settings. The thicker arenite beds, which contain this structure, are markedly lensoid in cross-section unlike distal turbidites. Well-developed Bouma sequences, which are diagnostic of rhythmically bedded distal turbidites, are absent. Instead, individual arenite beds show abundant evidence of waning flow, indicative only of deposition from decelerating currents.

Nelson (1982) has demonstrated the capacity of storm-generated sand layers to mimic turbidites in terms of their preserved vertical sequence. The thin-bedded association of the Poley Cow Formation is similar in all respects to descriptions of modern, offshore, storm-dominated marine shelves (for example, Aigner & Reineck, 1982), and accounts of ancient sequences interpreted or reinterpreted in this way (for example, Hurst & Pickerill, 1986; Tyler & Woodcock, 1987; Xia & Lu, 1988). Accordingly, the thin-bedded association of the Poley Cow Formation is interpreted here as storm- and fair-weather deposits of a shallow, offshore, marine shelf.

The conglomeratic association comprises arenites, pebbly arenites and conglomerates of various types, the only fossils recorded being the trace *Zoophycos* and *Lingula* brachiopods from Facies G (arenite). The conglomerates have previously been interpreted as originating at the base of a submarine slope (Arnold & Henderson, 1976) and as submarine debris flows (Arnold & Henderson, 1976; Savory, 1987; Withnall & others, 1988b). A deep marine interpretation is inconsistent with the presence of the brachiopod *Lingula*, typically an intertidal or shallow marine indicator fossil.

The conglomerates show some similarity to debris flow and high-density turbidity flow deposits (thick, internally unorganised beds, presence of normal and reverse grading). The occurrence of small- to large-scale cross-bedding at numerous horizons and the common evidence of deep scouring at bed bases, however, imply at least intermittently the action of true stream flows in depositing gravels. The common vertical and lateral transitions between Facies D, E and F also imply variability in formative process. Clast imbrication is of both A- and B-axis varieties.

Many of the Poley Cow conglomerates resemble the deposits of 'hyperconcentrated flows' of Beverage & Culbertson (1964) or 'fluidal flows' of Nemec & Steel (1984). Such flows are transitional between ordinary stream flow and sediment gravity flow, and arise when stream flows become choked with sediment. Other conglomerate beds, however, are evidently deposits of fluidal debris flows (Nemec & Steel, 1984) or true stream flow.

The available fossil evidence, abundance of cross-bedding, occurrence of possible wave-generated structures in arenites, and the interbedding of conglomerates with thin-bedded sediments established as shelfal storm beds, suggest that the conglomeratic association was deposited in shallow water. Gravels were laid down mainly by sediment-choked aqueous flows transitional to turbulent debris flows. At times when the total sediment load was reduced, stream flows operated, leading to the formation of dune bedforms and avalanche cross-bedding. During peak discharge periods, gravels were laid down in a disorganised fashion from decelerating flows of various types. Sequences of conglomerates and associated arenites similar to the Poley Cow Formation are described by Nemec & others (1984), Kleinspehn & others (1984) and Marzo & Anadon (1988), and interpreted as the deposits of subaqueous portions of fan deltas.

The coarseness of the gravels, and their textural and mineralogical immaturity, suggest derivation from a nearby exposed source. Both palaeocurrent and thickness data indicate a proximal-distal relationship from west to east. Palaeocurrent data from both the thin-bedded and conglomeratic associations indicate ENE-directed palaeoflows throughout the deposition of the Poley Cow Formation (Figure 19). To the southwest the unit thins and ultimately onlaps the Judea Formation basement surface.

To the north, the Poley Cow Formation may pass laterally into the much thicker Quinton Formation, although there is some evidence that it thins and may onlap the Judea

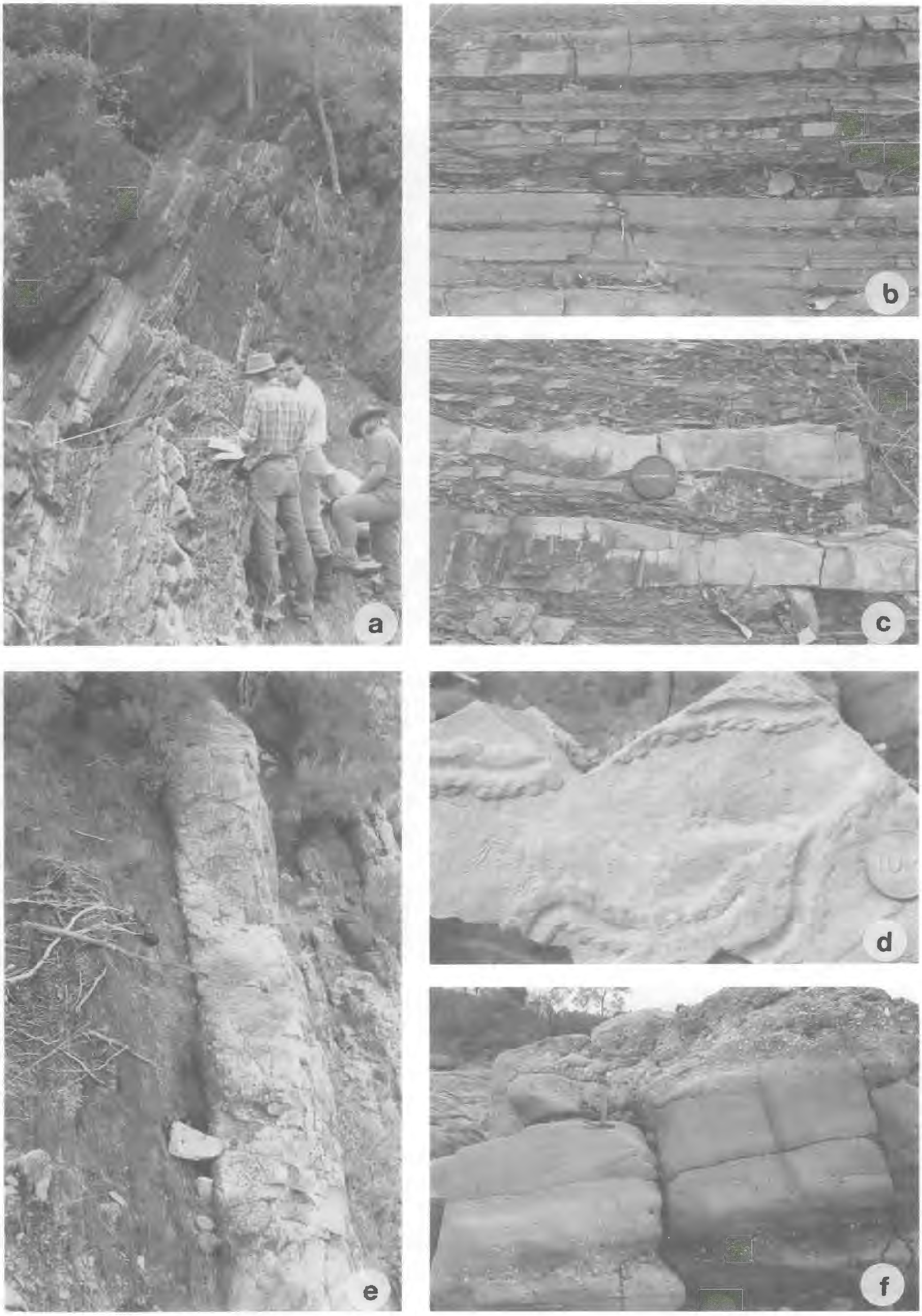

Plate 11. Poley Cow Formation.

Formation basement northeast of Jessey Springs. The SSE-directed palaeocurrents indicated by pebble imbrication may be from this basement high.

The abundance of metasedimentary clasts characteristic of Judea Formation lithologies, together with the westerly pinchout of the Poley Cow Formation against that unit, strongly suggest derivation from an exposed and tectonically uplifted Judea Formation to the immediate west of the Broken River-Dosey Creek area.

The Poley Cow Formation is here interpreted as the deposits of coarse-grained fan or braid deltas (*sensu* McPherson & others, 1987, represented by Facies D-G) which issued eastwards onto a storm/wave-influenced marine shelf (Facies A-C). There was only minimal wave reworking of coarse gravels supplied to the fan deltas, resulting in thick deposits of often chaotic conglomerates. Facies G, which preserves possible wave-formed sedimentary structures, may represent modest wave reworking of sand on the delta front. The fans evidently drained an elevated landscape to the immediate west of the study area, composed dominantly (or locally) of Judea Formation metasediments.

Fossils and age

Graptolites from the Poley Cow Formation in the Broken River area were first described by White & Stewart (1959) and Thomas (1960), although they were incorrectly assigned to the Wairuna Formation. The two localities have been recollected, and three additional localities have been found. The five localities are all within the lower thin-bedded interval and are of late Llandovery age (Jell & others *in* Withnall & others, 1988b). Most of the faunas are from the *turriculatus* Biozone, although one of Thomas's (1960) localities (BRS101, in the headwaters of Poley Cow Creek) is slightly younger (*greistoniensis* Biozone). A trilobite/brachiopod fauna also indicating a Llandovery age was recovered from a similar stratigraphic level at one locality.

A locally abundant but taxonomically restricted suite of trace fossils is known from the thin-bedded association (Plate 11d; also Munson, 1987; Savory, 1987), as are rare reworked favositid coral heads. The trace fossil *Zoophycos* and a small number of *Lingula* brachiopods have been found in arenites of Facies G.

JACK FORMATION

(I.W. Withnall & P.J.G. Fleming)

Introduction

The Jack Formation is the uppermost unit of the Graveyard Creek Group south of the laterite plateau. The unit overlies and may interfinger with the Poley Cow Formation. It was previously defined as the Jack Limestone Member by White (1959), and as such it consisted of two main limestone units separated by a siliciclastic sequence in a narrow belt extending for about 10 km northeast of the Jack Hills Gorge. Withnall & others (1988b) raised the unit to formation status, and extended it to include lateral equivalents of the siliciclastic rocks in the Poley Cow Creek and Dosey areas where the limestones are absent. Withnall (1989a) formally redefined the formation. The type section in the Jack Hills Gorge on the Broken River between 7859-660453 (base) and 655455 (top) is 580 m thick (Figure 20). Its thickness in the Poley Cow Creek area is difficult to determine because of the folding there.

Lithology

The base of the Jack Formation in the type section (Figure 20) is the base of the lowermost limestone, which is 120 m thick and consists of massive to thick-bedded, fine grained, dark-grey to black, muddy limestone, locally containing large pelecypods and sparse solitary rugose corals (Plate 12). Dolomitisation is evident and stylolites are abundant. Discontinuities in some beds are probably due to pressure solution, and most bedding planes may actually be large stylolites.

This lower limestone is overlain by about 240 m of thick-bedded, red to purple, medium to coarse-grained, micaceous quartzose arenite (Plate 13a) and shale and minor limestone lenses. This is overlain by a thin-bedded sequence of siltstone and fine-grained labile, micaceous arenite containing abundant *in situ* coral heads (Plate 13b-d). The corals include favositids, heliolitids and solitary rugosans; brachiopods and encrinurid trilobites are also present. This sequence immediately underlies the upper limestone and is about 75 m thick. Workers in the area refer to it colloquially as the "Coral Gardens", and it can be recognised in the same stratigraphic position over much of the outcrop area of the Jack Formation. Oncolitic and oolitic limestones occur towards the top of the interval (Plate 13e, f).

The upper limestone is 220 m thick in the type section and is massive to thick-bedded and fine-grained. Some beds have irregular chert nodules (Plate 13g, h). Abundant large stromatoporoids and some corals occur towards the top of the unit. The limestone thins to the northeast; the lower limestone disappears completely probably due to a facies change, and only the upper limestone with its underlying "Coral Gardens" sequence appears to crop out northeast of Diggers Creek and in the core of the Wade Anticline northeast of Jessie Springs Hut. The limestone extends along strike from Diggers Creek to 729526 where it is represented by a 15 m-thick interval of small discontinuous bioclastic calcarenite lenses in mudstone. About 25 m beneath this interval, pebbly quartzose arenite and quartz-pebble conglomerate form a prominent ridge. They are taken as the base of the unit in this area, because they can

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PLATE 11:

a. General view of thin-bedded association (Facies A & B). Along the Broken River (27-33 m in Figure 16).

b. Detail of thin-bedded sandstone-siltstone (Facies B). Along the Broken River (40 m in Figure 16).

c. Detail of thin-bedded sandstone-siltstone (Facies B), showing lensoid geometry of thicker sandstone beds and symmetrical ripple forms on bed tops. Along the Broken River (42 m in Figure 16).

d. Detail of locomotion trace (*Scalarituba*) from thin-bedded association. 7859-718438 (5 m in Figure 17).

e. View of contact between lower, thin-bedded interval and upper conglomeratic interval. Prominent sheet-like conglomerate unit is 2.8 m thick. Stratigraphic younging is to right. In the type section along the Broken River (255 m in Figure 16).

f. Detail of relationships between clast and matrix-supported conglomerates (Facies E & D) and cross-bedded pebbly sandstone (Facies F). 7859-702445 (8 m in Figure 18). Hammer 0.25 m long.

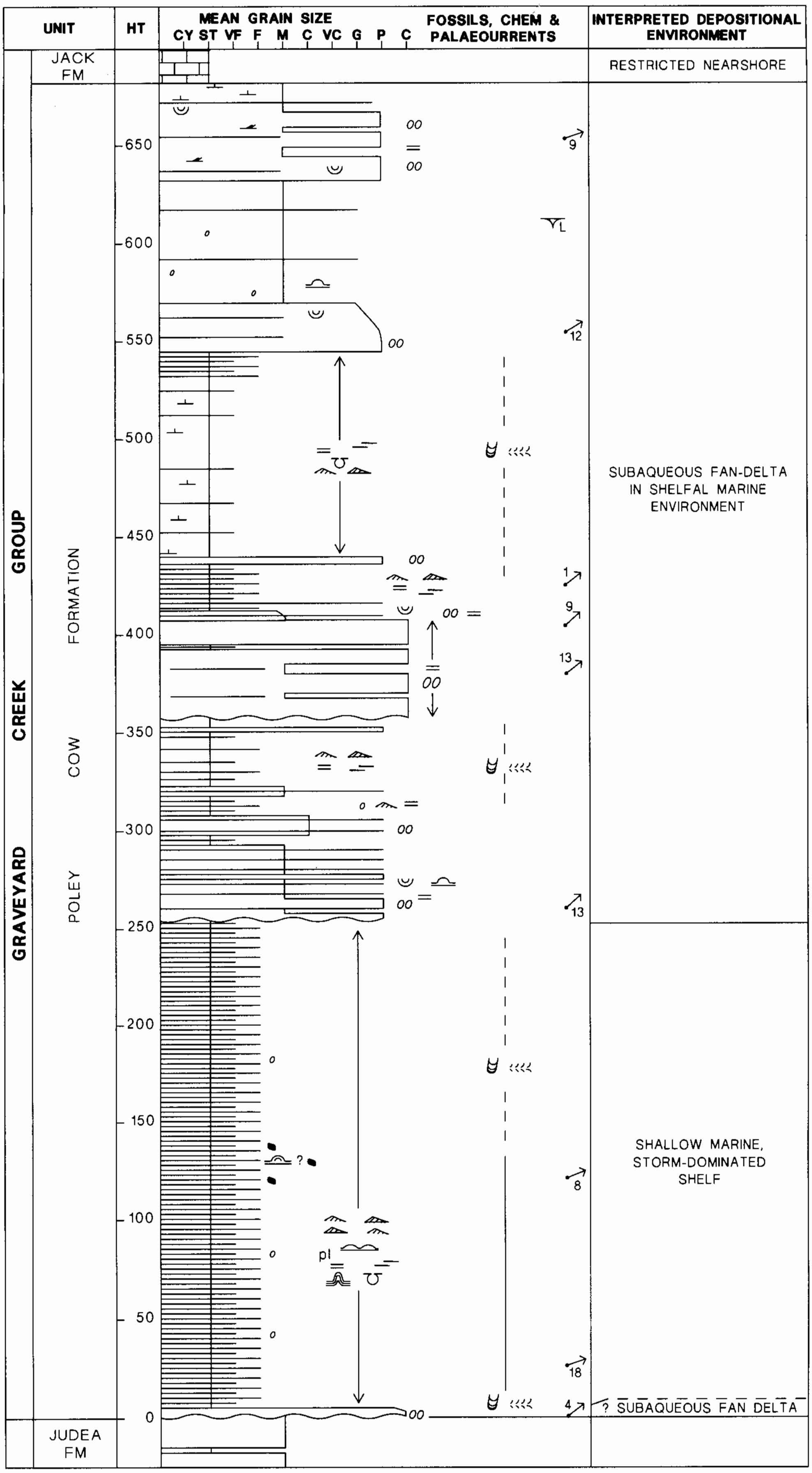


Figure 16. Generalised graphic log of the Poley Cow Formation type section, showing the gross subdivision of the unit into a lower, predominantly thin-bedded interval and an upper conglomeratic interval. See Figure 14 for reference.

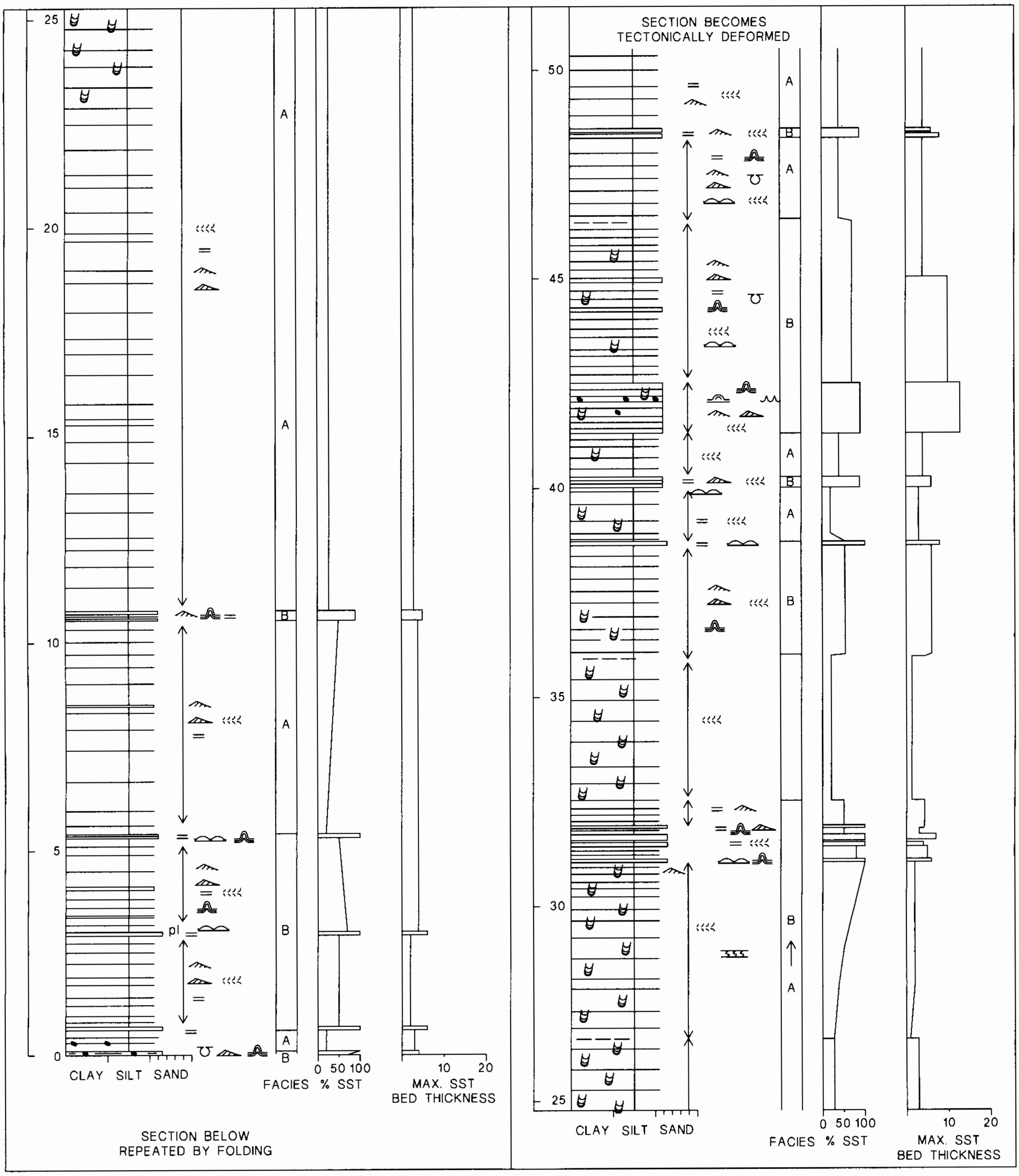


Figure 17. Detailed graphic log of part of the lower, thin-bedded interval of the Poley Cow Formation at 7859-718438. See Figure 14 for reference.

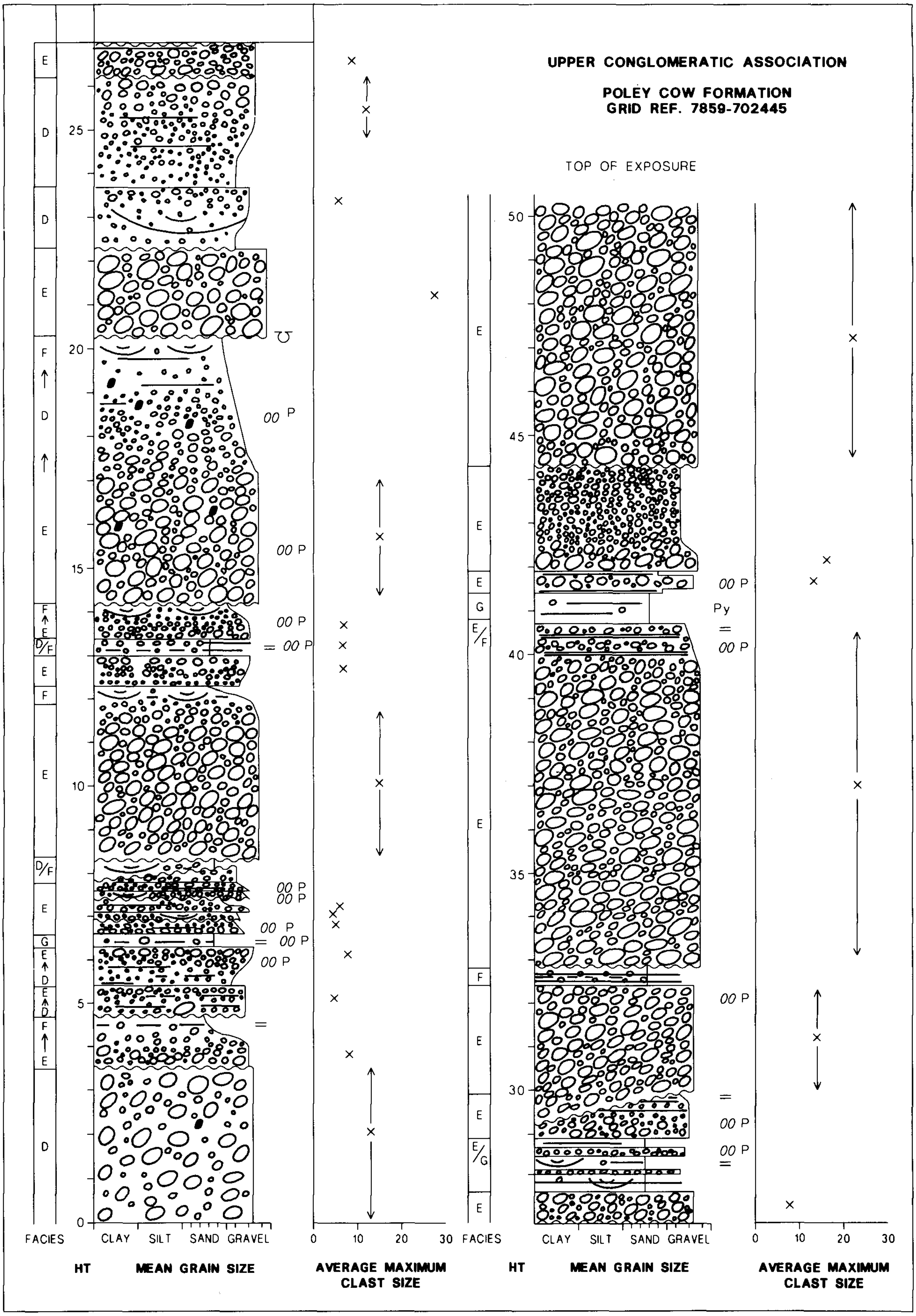
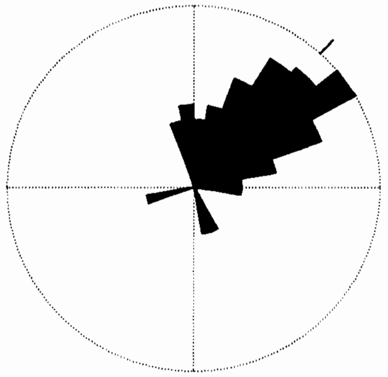
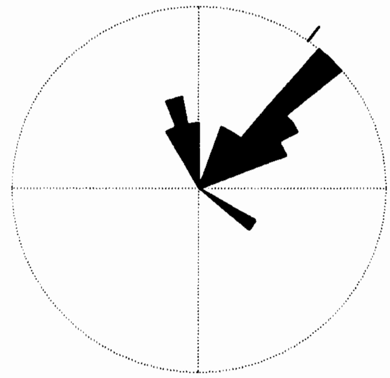


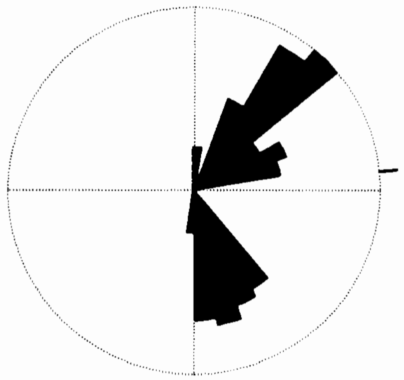
Figure 18. Detailed graphic log of part of the upper conglomeratic interval of the Poley Cow Formation at 7859-702445. See Figure 14 for reference.



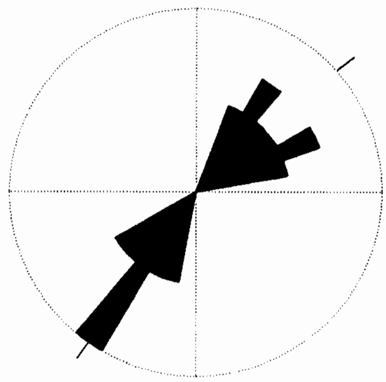
(a) Ripple cross-lamination, thin-bedded interval (Facies A-C), Poley Cow Formation. n = 69, mean azimuth = 043°



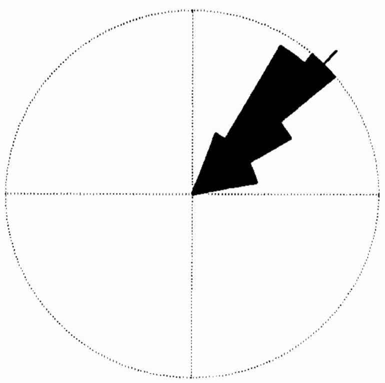
(b) Cross-bedding, upper conglomeratic interval (Facies D-G), Poley Cow Formation. n = 21, mean azimuth = 036°



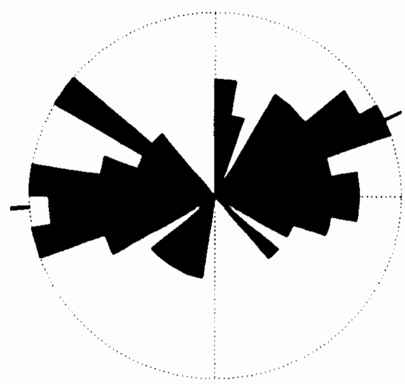
(c) Imbrication, basal conglomerate (Facies D-E) and upper conglomeratic interval (Facies D-G), Poley Cow Formation. n = 87, mean azimuth = 084



(d) Trough cross-bedding, middle part of Jack Formation, from gully just SW of type section in Jack Hills Gorge n = 16, mean azimuths = 048° and 215°



(e) Trough cross-bedding, Shield Creek Formation near the Dosey Creek - Broken River junction n = 22, mean azimuth = 045°



(f) Trough cross-bedding, Phar Lap Member n = 57, mean azimuths = 065° and 266°

Figure 19. Palaeocurrent distribution for the Poley Cow Formation, Jack Formation, Shield Creek Formation and Phar Lap Member (plotting by 10° intervals - area of segment proportional to number of readings).

TABLE 1: LITHOFACIES SCHEME FOR THE POLEY COW FORMATION

Facies	Interpretation	Lithology	Texture	Sedimentary Structures	Fossils	Geometry
A	Storm/wave-Influenced Offshore Marine Shelf	Thinly interbedded, very fine to fine-grained quartzose sandstone and medium grey siltstone; siltstone dominant	Sandstones, poorly to moderately sorted	Interlamination structures (linsen-lenticular bedding etc.), ripple cross-lamination, flat and undulatory lamination, load casts, water escape structures	Various tracks/ trails including *Scalarituba* and *Helminthopsis*; *Chondrites* burrows in sandier sections; rare graptolites, brachiopods, trilobites	Thick sequence and individual beds, sheet-like; sandstone beds ≤8cm thick
B	Storm/wave-Influenced Offshore Marine Shelf	Thinly interbedded, very fine to fine-grained quartzose, sandstone and medium grey siltstone; sandstone dominant	Sandstones poorly to moderately sorted	As per Facies A; ?wave-rippled bed tops hummocky cross-stratification, shale clast conglomerate layers	Tracks/trails/ burrows as per Facies A; rare (reworked) favositid coral heads	Sequences appear laterally extensive; thin beds also sheet-like; thicker sandstone beds markedly lensoid
C	Reworked Volcanic Shelf Storm Layers	Medium to coarse-grained volcanic lithic and feldspathic sandstone, sharp-bounded beds up to 0.3m; calcareous cement	Poorly to moderately sorted, grains angular to sub-rounded	Crude flat lamination; possible rare, low-angle cross-bedding; shale clasts; some beds normally graded	Tracks/trails on bed tops	Thinner beds sheet-like; thicker beds markedly lensoid
D	Subaqueous Fan Delta - deposition from fluvial flows and debris flows	Matrix-supported, pebble to boulder conglomerate, units up to 2m thick	Clasts ≤50cm, most ≤9cm, subangular to rounded, poorly to well sorted; silt to very coarse sand matrix	Some beds show no internal organisation; others show clast imbrication, crude flat stratification, normal and reverse size and distribution grading; rare cross-bedding	None	Highly variable - some beds pass laterally or vertically into Facies E or F
E	Subaqueous Fan Delta - deposition from stream flows to debris flows	Clast-supported, pebble to boulder conglomerate, units up to 6m thick	Clasts ≤86cm, most ≤20cm, subangular to very well rounded, poorly to well sorted; fine to coarse sand matrix	Some beds show no internal organisation; others show clast imbrication, normal grading, crude flat stratification; trough cross-bedding	None	Highly variable - some beds pass laterally or vertically up into Facies D or F; some beds show channelised base
F	Subaqueous Fan Delta - deposition from stream flows to debris flows	Pebbly/cobbly sandstone, units up to 2m thick	Clasts ≤8cm, most ≤5cm, subangular to very well rounded, poorly to well sorted; coarse to very coarse sand matrix	Crude flat stratification, trough cross-bedding, some clast imbrication	None	Highly variable - some beds pass laterally or vertically into Facies D or E; some beds show channelised base
G	Subaqueous Fan Delta - ?wave and current-reworked sands	Thick-bedded, fine to coarse-grained quartzose sandstone, with minor siltstone partings, units up to 22m thick	Sandstones moderately to well sorted	Flat lamination, some trough cross-bedding, possible hummocky cross-stratification and wave ripples; rare shale clasts and small pebbles	*Zoophycos* and indeterminate bioturbation; *Lingula*	?Laterally extensive

be traced to the east where the limestone is absent, and are thus a useful marker.

In the type section, the limestone is directly overlain by about 20 m of feldspathic arenite equated with the Shield Creek Formation. However, about 7 km northeast, and in the Wade Anticline, the Shield Creek Formation is separated from the limestone by an interval of poor exposure up to 200 m thick in which some mudstone crops out. This interval is regarded as part of the Jack Formation.

In the headwaters of Poley Cow Creek, limestone is virtually absent. Quartzose arenite and quartz-pebble conglomerate, probably at about the same stratigraphic level (locally containing abundant, poorly preserved brachiopods and crinoid fragments) crop out on the opposite limb of the anticline to the limestone, and to the east around the hinge of the adjacent syncline, where they form Jesseys Lookout, a prominent hill at 727511. East of here, ridge-forming pebbly quartz arenite units crop out at least two stratigraphic levels. They are separated by poorly exposed mudstone and micaceous sublabile to quartzose arenite. As noted above, the lowermost quartzose arenite/conglomerate is taken as the base of the Jack Formation in this area. A thin isolated crinoidal limestone bed, interbedded with sublabile micaceous arenite containing moulds of crinoid stems, occurs at 760500 within this sequence. Limestone is also absent to the south of the Broken River around the hinge of the Broken River Anticline and in several anticlinal hinges west of Dosey Creek, but the thin sequence of micaceous arenite between the Judea Formation and Shield Creek Formation is equated with the Jack Formation.

Environment of deposition

Fleming (*in* Withnall & others, 1988b, pp. 152-156) interpreted the depositional system that gave rise to the Jack Formation in the Broken River/Diggers Creek area as a near-shore shallow-water complex of fans, bars, restricted lagoons, and marine tongues or bays. The limestones represent deposition in restricted, shallow to very shallow lagoons.

In the restricted lagoons represented by the limestones, the fauna typically consisted of favositids, small stromatoporoids, beds of solitary rugose corals (mainly *Tryplasma*), pentamerid brachiopods, and, in the lowermost limestone, very large unidentifiable, mud-dwelling pelecypods (Plate 12c). Also present were crinoids and ostracodes.

The lowermost limestone, as a whole, represents a less oxygen-depleted environment, particularly towards the top. In the top 20 m, oxygenation was high, and agitation was sufficient to uproot the large pelecypods and overturn coral and stromatoporoid colonies. A very rich (but not diverse) fauna of corals, stromatoporoids, crinoids, pelecypods, ostracodes and a few brachiopods is present. In addition, the algae *Wetheredella* occurs as oncolites (Plate 12g), and sporadic ooids were transported in.

Toward the top of the upper limestone, the number and size of stromatoporoid colonies increases dramatically. Chert replaces many of the corals and stromatoporoids. The top few metres consist of very large stromatoporoid colonies with interstitial feldspathic arenite, and a small number of other faunal elements, including corals, crinoids, and shell fragments.

The siliciclastic sequence between the limestones is interpreted as being deposited in a marine bay. Bipolar cross-bedding is abundant suggesting deposition in tidal channels (Figure 19). The reddening of the sandstones may not be primary, but could be associated with strike faulting and possible hydrothermal activity. The fauna of corals, stromatoporoids, bryozoans, crinoids, brachiopods, and pelecypods gradually increases upwards in richness and diversity to about 360 m (the top of the "Coral Gardens"). The sandy facies above it represents a shoaling environment. The laminated micaceous quartzose arenite contains trilobites and rhynchonellid brachiopods that must have been adapted to the shifting sand environment. The oolitic calcarenite overlying this facies contains mainly sand-sized skeletal detritus.

Diagenesis

Where the large pelecypods are in growth position, especially in the lower part of the lower limestone, they consist of drusy calcite (Plate 12c). Their shells are irregularly reduced in thickness by solution/compaction prior to calcite precipitation. They are filled by black carbonate mud containing small fossils and faecal pellets. The central part of this infilling contains patches of dolomite, usually with silica.

The sequence of events was as follows:

1. Large aragonitic pelecypods lived umbo down, partly buried in black carbonate mud.
2. After death, very fine carbonate sediment accumulated in the shell cavity; other animals settled on the black infilling and faeces accumulated.
3. After the shells were buried, the sediment began to dewater, and the entrapped, very wet shell cavity infilling became micro-porous; SiO_2 and Mg migrated, accumulating in places with porosity or low pressure; aragonite dissolved; compaction stress increased; cavities left by solution of aragonite collapsed; calcite infilled remaining shell moulds.

A similar process of migration of Mg^{++} and SiO_2 into low pressure/porous sites and deposition there has given rise to the white-cored load structures in the black limestones (Plate 12d), most noticeably present in the 70-102 m interval above the base of the type section. Comparison with similar material known (by PJGF) from the Cambrian Beetle Creek Formation of the Lawn Hill area of the Georgina Basin suggests that porosity in load structures can be very great, as compaction is accompanied by dewatering.

Chert nodules which form chert bands in the upper part of the upper limestone in the Jack Hills Gorge (Plate 13g,h), consist of silica and dolomite intimately associated with colonial corals and stromatoporoids. SiO_2 and Mg^{++}, deposited with the lime mud, again probably migrated during compaction and dewatering, and were redeposited in places protected from compaction stress. Silica, as usual, replaced much of the skeletal material.

Stylolitisation is abundant in the limestones in the type section, and its cross-cutting relationships with calcite veins are important. The bedding is exaggerated by the stylolite residuum that resembles thin mud interbeds (Plates 12a, d, f). Some patches of stylolitisation stand out because of the bright red-brown outlines of their iron-rich residuum. Even at their most severe, stylolites rarely cut across the relatively pure calcite of fossil skeletons (Plate 12a). Numerous smaller stylolites through the limestone are generally parallel to bedding. However, in places, especially in massive grey limestone beds around 90 m above the base, stylolitisation is so intense that stylolite planes have been irregularly reduced in spacing, and cross-cutting stylolites have also developed to such a degree that rotation of stylolite-bounded blocks has occurred. As a result, the rock now resembles a limestone breccia (Plate 12e).

The general preferred orientation of the stylolites parallel to bedding, which is sub-parallel to the axial plane of the

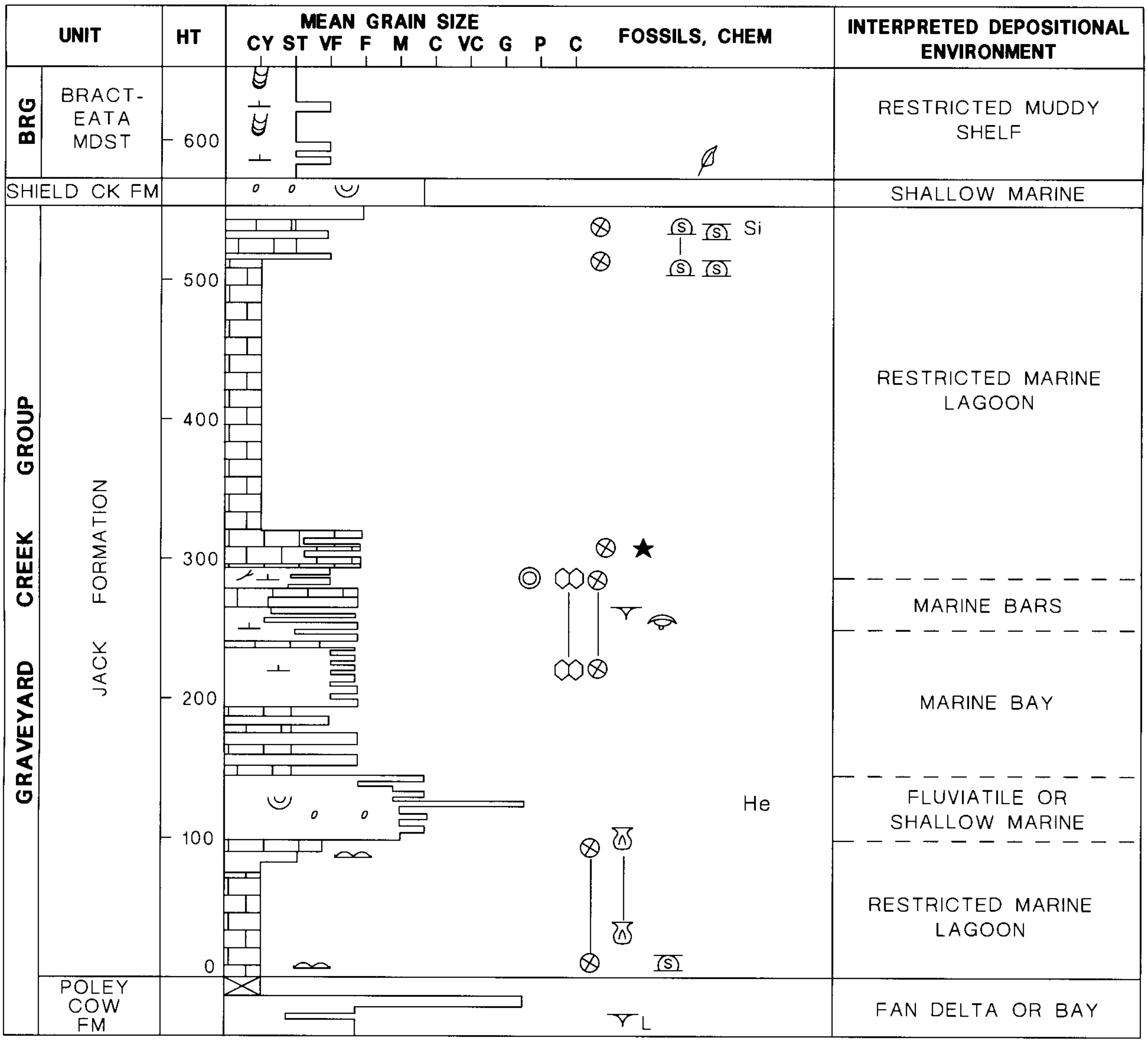


Figure 20. Type section of the Jack Formation along the Broken River in Jack Hills Gorge. See Figure 14 for reference.

PLATE 12:

a. **Etched slab, X1, of stylolitised carbonate from about 45 m, containing algae, stromatoporoids, corals, gastropods, and ostracods in carbonate mud. Blocks in styloresiduum are chiefly skeletal.**

b. **Etched slab, X1, of carbonate mud from about 50 m, containing well-preserved coral, stromatoporoid, algal, ostracod, mollusc, unidentified skeletal remains, and pelloids.**

c. **Etched slab, X1, of section through unidentified pelecypod from about 60 m. The shell is in its life position (umbo down) and was replaced by drusy porosity. It is infilled by black carbonate mud with faecal pellets, a solitary coral, and probably stromatoporoid fragments. The dewatered infilling is host to intense dolomitisation.**

d. **Etched slab, X1, of black, dolomitised, pelloidal carbonate mudstone from about 55 m, containing a very poor fauna and compaction structure with concentrations of dolomite in areas of expansion where pressure was relieved.**

e. **Horizontal outcrop (matchbox scale) of nearly vertical, thin to medium bedded carbonate so heavily and irregularly stylolitised that it resembles carbonate breccia. Parts of some beds are reduced to fragments and blocks from some beds are rotated. Some of the white calcite tension veins follow stylolites.**

f. **Outcrop of load-casted medium-bedded lime mudstone from about 70 m. Matchbox scale. Determining whether the siliciclastic interlayers are interbeds or styloresiduum is usually not possible in such beds in the field.**

g. **Etched slab, X1, of algal carbonate from about 125 m near top of lower limestone. Crinoid plates overgrown by the algae *Wetheredella*, which has bound the carbonate mud.**

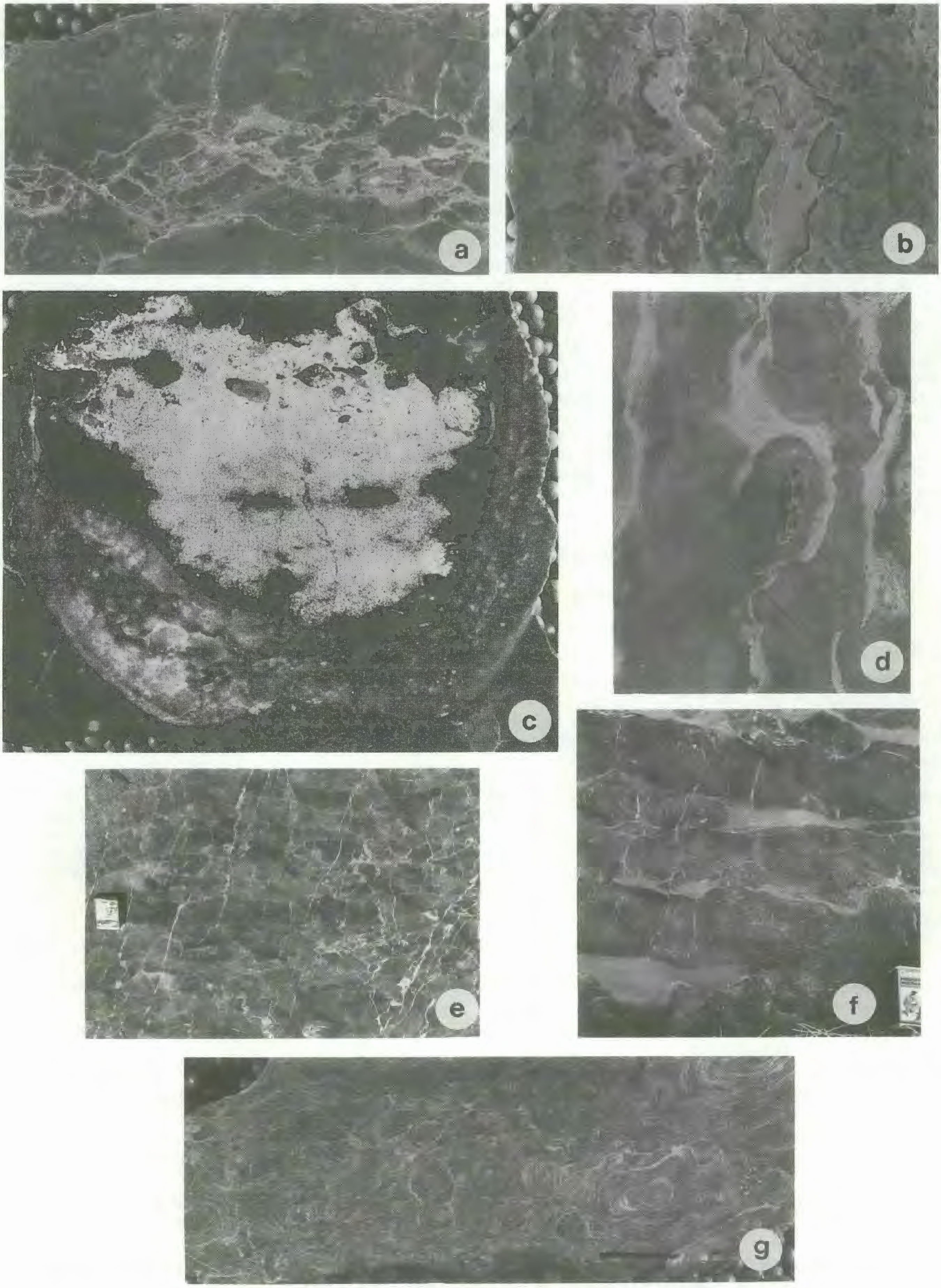


Plate 12. Detail of diagenetic and depositional structures in the lower part of the Jack Formation type section.

folding, suggests that the stylolitisation is structural. White and black calcite tensional veins occur throughout. The black is due to included carbon, mostly derived from stylolite residuum in the dark limestones. The veins commonly follow the stylolites, which were opened during post-folding release of stress. The basal quartzose arenite and conglomerate and similar lenses higher in the sequence in the Poley Cow Creek headwaters were probably deposited in extremely shallow water or on a beach. The lack of fine fractions and labile components suggests a high energy environment.

Age

The Jack Formation contains Ludlovian conodont faunas in the upper limestone at the Broken River crossing, some 4 km downstream from the Jack Hills Gorge ('Broken River Gorge'), and its top is probably Pridolian or Early Devonian (Simpson, 1983). It is not certain that the carbonates of the Jack Formation at the Broken River crossing are exact age equivalents of those at the gorge, and attempts at recovering diagnostic conodonts at the gorge have so far been unsuccessful (A.G. Simpson, personal communication, 1992). However the 'Coral Gardens' fauna indicates a Ludlovian age. As noted above, the base of the Poley Cow Formation is Llandovery in age. It is possible that (i) clastics in the Poley Cow Formation below the lower limestone interval of the Jack Formation, (ii) the lower limestone itself, (iii) the reddish arenites above the lower limestone, or all three, may be Wenlockian.

SHIELD CREEK FORMATION

(I.W. Withnall, J.S. Jell, S.C. Lang & C.R. Fielding)

Introduction

The Shield Creek Formation was first named and described by Wyatt & Jell (1980). The unit crops out as a continuous folded belt from the hinge of the Six Mile Syncline, north of 'Pandanus Creek', to the head of Magpie Creek on the northern edge of the laterite plateau. South of the plateau, it continues to Dosey Creek, although near the Broken River it becomes too thin to map. It also occurs in several anticlinal cores between Storm Dam and the Broken River. A composite type section (Figure 21) was defined by Withnall & others (1988b) and Lang & others (1989a). The basal part is in a small tributary of Turtle Creek from 7859-702665 (base) to 694661 (base of Martins Well Limestone Member). The middle part is the type section of the Martins Well Limestone Member, between 7859-682684 (base) and 683683 (top), as originally defined by Jell (1968). The top part is in a gully between 7859-680640 (top of the member) to 679635 (base of Dip Creek Limestone).

Lithology

In the lower part of the composite type section in the Turtle Creek area, the formation contrasts markedly with the underlying Quinton Formation, which there consists of mudstone-dominated distal flysch. The Shield Creek Formation in this area is 850 m thick. The lower part is 300 m thick and begins with thick to very thick bedded, medium to large-scale, trough and low-angle tabular cross-stratified, coarse to very coarse-grained, feldspathic and locally quartzose arenite and minor conglomerate. These pass upwards through finer arenite, siltstone and mudstone to the Martins Well Limestone Member. Bi-polar cross-beds occur in places (Plate 14a). This member was originally defined by Jell (1968) as part of the Broken River Formation.

The **Martins Well Limestone Member** (Jell, 1968) is a low, rubbly ridge-forming unit (Plate 14c) which extends from the headwaters of Magpie Creek to Martins Well. The type section is 85 m thick, but elsewhere the unit is up to 150 m thick. The type section consists of three lithological units. The lowermost unit consists of 15 m of mainly bioclastic calcarenite. The calcarenites are packstones and wackestones with bioclastic detritus ranging from 0.2 mm to 20 cm with a mean of 0.4-1 mm. The larger detritus includes clasts of tabulate and rugose corals and stromatoporoids; other detritus in order of importance are crinoids, algae, brachiopods, gastropods, pelecypods, ostracodes, and sponge spicules. Algal material, in particular broken thalli of *Lancicula*, makes up a considerable fraction of the rock. Biohermal mounds of coralline limestone occur in places. They are up to 3 m across and 0.25 to 2 m high. They consist of thickets of massive colonial rugose corals (mainly *Hexagonaria*) and locally massive tabulate corals. Small colonies of rugose and tabulate corals in growth position are common between these mounds. Sporadic shale interbeds form less than 2% of the section.

The middle unit is 44 m thick, and consists of well-bedded muddy calcarenite similar to that in the lower interval, except that coral and stromatoporoid colonies in growth position are less common. Thin calcareous mudstone beds constitute up to 30% of the section. The bioclastic material

PLATE 13:

- **a.** **Quartz and intraclast pebbles in cross-bedded, brown, poorly sorted, non-marine sandstone, at about 180 m (matchbox scale).**
- **b.** **Tabulate coral colonies and small lenses of fossiliferous carbonate in micaceous, quartzose sandstone, at about 350 m (matchbox scale).**
- **c.** **Head of *Favosites* and flatter colonies of *Heliolites* in growth positions in fine-grained, micaceous quartzose sandstone, at about 350 m.**
- **d.** **Irregular fossiliferous carbonate beds and lenses in micaceous quartzose sandstone, at about 240 m.**
- **e.** **Thin to medium bedded oolitic limestone with stylobedding and probable very-low angle cross bedding. Younging to right, at about 375 m (scale shown by hammer).**
- **f.** **Thin section, X40, of quartz, muscovite, skeletal allochems and ooids with strong radial and concentric structure; grain supported with a matrix of neomorphed carbonate mud. Crossed polarisers. From the outcrop in (e).**
- **g.** **Gorge wall near top of upper limestone showing bands of siliceous nodules parallel to bedding in massive carbonate. Jack Formation type section. The mud-covered bank near the water is about 0.5 m high. Facing to the right.**
- **h.** **Detail of silica/dolomite nodules in g. Limestone is a stromatoporoid/coral wackestone that is dolomitised in patches and contains numerous tensional calcite veins (matchbox scale).**

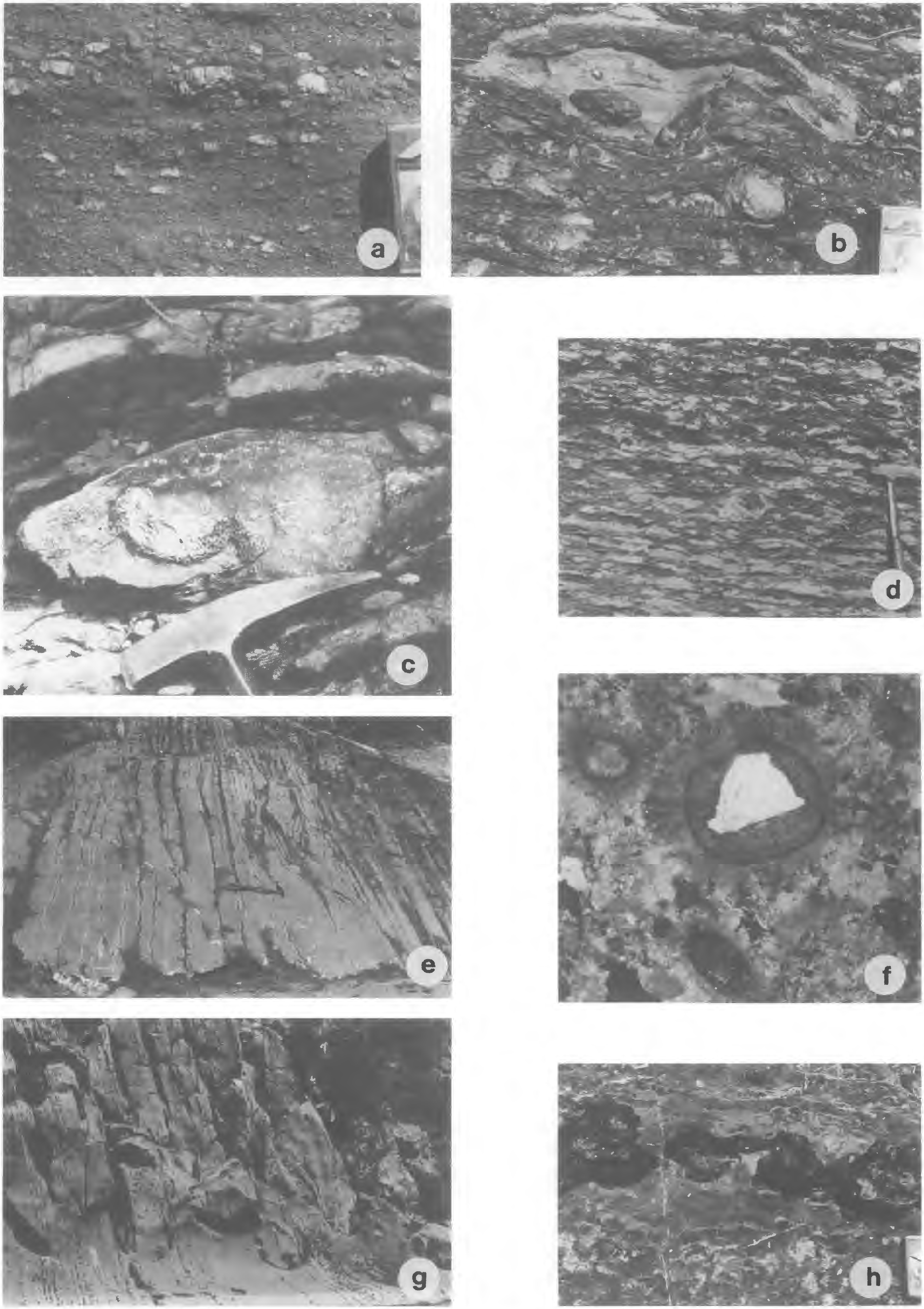


Plate 13. Detail of diagenetic and depositional structures in the middle and upper parts of the Jack Formation type section.

in the calcarenites is mainly of algal and shelly debris with crinoidal material being only minor. Nautiloids are common in the more muddy beds and calcareous sponges and trilobites are locally present.

The uppermost 26 m is very similar to the lower interval but lacks the coralline mounds, and the shale interbeds may constitute up to 5% of the section increasing to 15% at the top. The bioclastic material is more crinoidal than that of the middle beds and the nautiloid, sponge and trilobite material is absent. The calcarenites are mainly wackestones.

The member contains a rich rugose and tabulate coral fauna, of which the large solitary rugose coral, *Pseudamplexus princeps*, is a characteristic member (Plate 14d). Nautiloids, rhynchonellid and spiriferid brachiopods, crinoid calices (Plate 14e), and rostroconchs are also present. The corals were studied by Jell (1967) who referred them to his *Martinophyllum* fauna. Conodonts were described by Telford (1975). J. Talent and R. Mawson have also sampled in detail for conodont analysis from a section across the limestone near Martins Well.

The upper part of the Shield Creek Formation in the Turtle Creek area is about 450 m thick, but is poorly exposed, being largely covered by soil washed off the opposing ridges formed by the Martins Well Limestone Member and overlying Dip Creek Limestone in the Broken River Group. Coarse-grained, very thick-bedded, feldspathic arenite and calcareous mudstone crops out in deeper gullies.

Similar sequences have been observed near Martins Well and Magpie Creek, although in the latter area, the sequence is overturned and incomplete, having been faulted against the Lockup Well Limestone of the Broken River Group. Near Martins Well, calcareous mudstone and fine-grained calcareous arenite beneath the limestone member contain a brachiopod fauna and rare trilobites.

Near Martins Well, the boundary between the Quinton Formation and Shield Creek Formation is not as easy to recognise, because the former consists of thick to very thick-bedded, coarse-grained lithofeldspathic arenite (proximal turbidites), superficially similar to the feldspathic arenite of the latter. However, the arenites in the Shield Creek Formation appear to be somewhat better sorted, and have no lithic clasts, and the boundary is placed in Gray Creek at 685688.

In the Pandanus Creek/Chinaman Creek area, the boundary is also difficult to recognise for similar reasons, particularly in weathered, rubbly outcrops away from major creeks. In Chinaman Creek North, the top of the type section of the Quinton Formation is taken at the top of a 650 m-thick interval of very thick-bedded to massive, very coarse grained lithofeldspathic arenite. The overlying rocks in the basal Shield Creek Formation are fine to medium-grained, locally calcareous, thin to medium bedded arenite and mudstone. The more typical coarse-grained feldspathic arenites of the Shield Creek Formation are not present at the base. However, they do occur about a kilometre north, along strike, where several limestone lenses also crop out. These limestones are equivalent in age to the Martins Well Limestone Member (Yu & Jell, 1990), but there is no continuous limestone unit. The boundary with the overlying Tank Creek Sandstone is recognised by the first appearance of well-sorted, medium-grained quartzose sandstone.

East of Jessey Springs Hut, a sequence of very thick-bedded, coarse-grained feldspathic to quartzose arenite up to 400 m thick overlies the Jack Formation. It contains a thin, pink- weathering, highly fossiliferous limestone lens about 40 m thick, the **Arch Creek Limestone Member** (Lang & others, 1989a), which is of special interest as conodont data show it to span the Lochkovian-Pragian boundary (Mawson & others, 1988). It crops out at 716537 on the left bank of Arch Creek, immediately south of Arch Gorge (Figure 24). Farther south in the Broken River, the Shield Creek Formation is very thin, and is represented by about 20 m of feldspathic arenite directly overlying the uppermost limestone of the Jack Formation. The Shield Creek Formation thickens to 40 m to the west, near the junction of the Broken River and Dosey Creek.

In the Dosey-Bull Creek area, the Shield Creek Formation is again much thicker, and consists of up to 500 m of very coarse-grained feldspathic and quartzose arenite, commonly conglomeratic, with pebbles and cobbles of granite, gneiss, and quartzite which are locally very angular (Plate 14b). In Bull Creek, the conglomerates contain up to boulder-sized limestone clasts and are apparently interbedded with thin limestone lenses. In parts of the Storm Dam area, the Storm Hill Sandstone of the Broken River Group directly overlies the Judea Formation and, locally, the Jack Formation. It is lithologically similar to the Shield Creek Formation, and the two units may merge in this area.

Environment of deposition

Although no detailed study of the environments of deposition has been made, the presence of the coralline limestone of the Martins Well Limestone Member, a marine fauna in some of the siliciclastic sedimentary rocks both above and below the member, and local bimodal cross-bedding (Plate 14a) indicate shallow marine deposition, at least for the northern part of the outcrop area. The environment was probably fluviatile in the south, particularly in the area of the junction of Dosey Creek and the Broken River. The sandstones there are thoroughly cross-bedded with unimodal palaeocurrents to the east-northeast (Figure 19), and have no fossils, pebble lags or wave-formed structures. The presence of limestone clasts may indicate that the lowermost carbonate-bearing succession was eroded in the south, perhaps as a consequence of relative sea-level lowering. The overall environment for the unit was probably coastal plain to inner shelf.

PLATE 14:

a. **Coarse-grained feldspathic arenite from near the base of the Shield Creek Formation, showing bi-polar cross beds. 7859-685688, in Gray Creek near Martins Well.**

b. **Quartzose conglomerate, showing angular clasts. Bull Creek area.**

c. **Typical low rubbly outcrop of the Martins Well Limestone Member. A poorly defined thick bed of limestone can be seen from the lower left corner to just left of the tree in the centre of the photograph. 7859-682695 near Martins Well.**

d. **Typical specimens of the large solitary rugose coral, *Pseudamplexus princeps*, which is abundant in the Martins Well Limestone Member.**

e. **Examples of the well-preserved crinoid calices, from near the top of the Martins Well Limestone Member in the Martins Well area.**

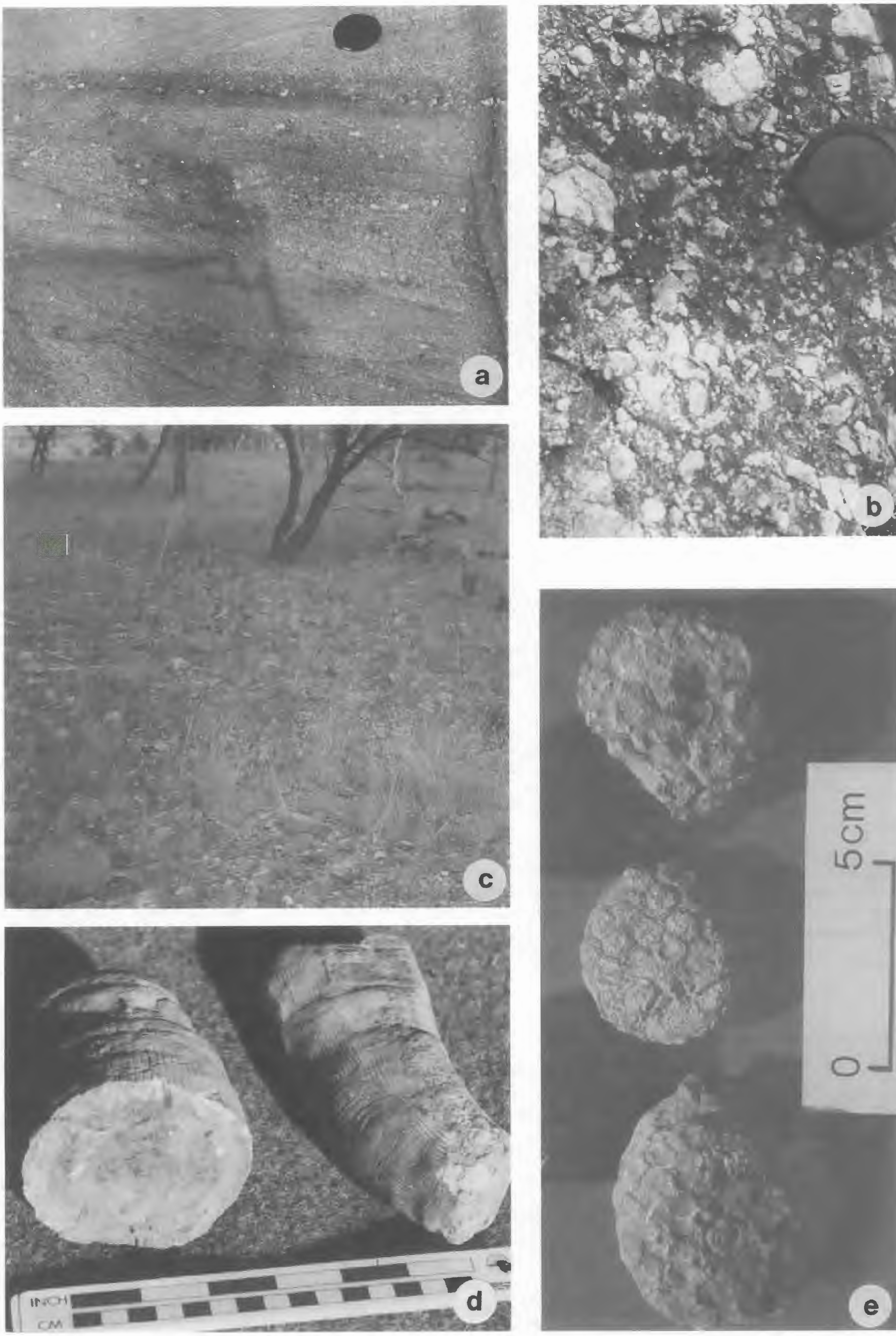


Plate 14. Shield Creek Formation.

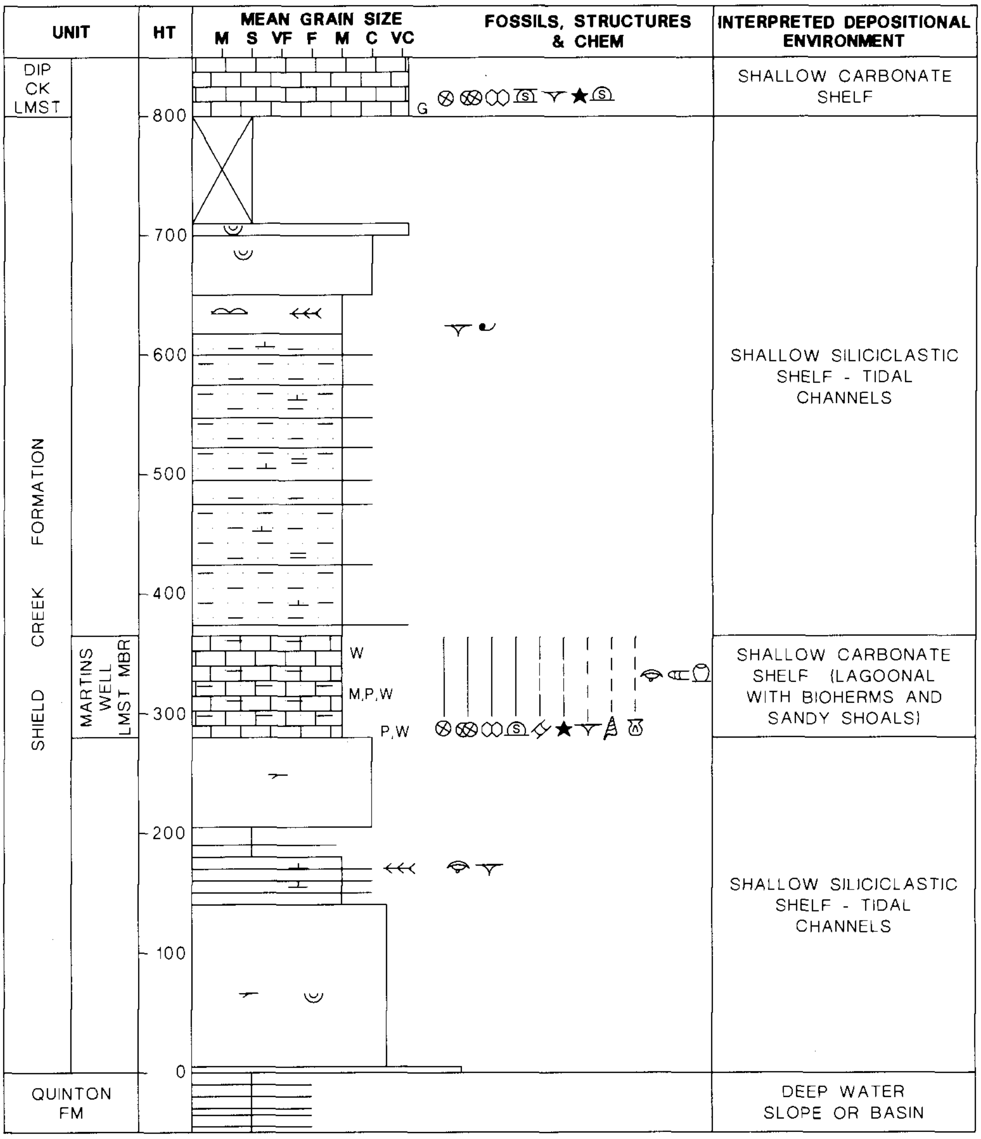


Figure 21. Composite type section for the Shield Creek Formation. The basal part is from 7859-702665 (base) to 694661 (base of Martins Well Limestone Member). The middle part is the type section of the Martins Well Limestone Member, between 682684 (base) and 683683 (top). The top part is between 680640 (top of the member) to 679635 (base of Dip Creek Limestone). See Figure 14 for reference.

Age

The conodont fauna in the Martins Well Limestone Member overlaps the Lochkovian-Pragian stage boundary (Mawson & others, 1988; Mawson & Talent, 1989), whereas the Graveyard Creek Group (Jack Formation) probably just extends into the Early Lochkovian. This Lochkovian time-break may correlate with uplift and deformation in the adjacent Georgetown Inlier and Lolworth-Ravenswood Blocks at around 400 Ma. The thick feldspathic arenites in the Shield Creek Formation record the erosion of this plutonic/metamorphic terrane and renewed subsidence allowing a marine transgression.

This time-break has also been correlated with the supposed 400 Ma age of D_4 in the Georgetown Inlier (Black & others 1979; Bell, 1980; Withnall, 1984), and also with the main "slaty-cleavage event" in the Camel Creek Subprovince. On the absolute time-scales of Harland & others (1990) and Fordham (1992), 400 Ma is equivalent to Late Lochkovian. However, if there was such a major event in the Graveyard Creek Subprovince at this time, an angular unconformity might be expected between the Graveyard Creek Group and Shield Creek Formation. Examination of the boundary in all of the areas listed above has shown it to be apparently concordant. An even longer gap occurs between the faunas in the Martins Well Limestone Member and the Middle Emsian ones in limestones in the Broken River Group. No angular break corresponds with this gap, so that it cannot be correlated with a major folding event either. It should be noted that these apparent hiatuses are based on conodonts from widely spaced samples of limestone beds separated by thick siliciclastic units. Deposition of these latter rocks could account for much of the apparent hiatuses. The significance of the time-breaks is discussed in more detail later in this report in the context of sequence stratigraphy.

STRATIGRAPHY AND SEDIMENTOLOGY OF THE BROKEN RIVER GROUP

(S.C. Lang, P. Jorgensen, P. Blake, M. Humphries, C.R. Fielding, J.S. Jell, I.W. Withnall & J.J. Draper)

White (1965) described the Broken River Formation as '17 000 feet of limestone, limestone conglomerate, pebble and cobble conglomerate, calcarenite, coquinite, calcilutite, calcareous sandstone and shale, and quartz siltstone and shale'. White & others (1960), White (1959a, 1961, 1962a), Wyatt & Jell (1967) and Jell (1968) all used this nomenclature in the same sense. Jell (1967) studied the northern part of the formation, in the vicinity of 'Pandanus Creek', and as a result defined four limestone members within the formation (Jell, 1968): Martins Well Limestone Member, Dip Creek Limestone Member, Lockup Well Limestone Member, and Chinaman Creek Limestone Member (Figure 12). Telford (1975) undertook the first study of the conodonts of the formation. A comprehensive description of the formation was given by Wyatt & Jell (1980). They separated a basal arkose sequence, including the Martins Well, Limestone Member from the Broken River Formation and named it the Shield Creek Formation. Mawson & others (1985) named the Jessey Springs Limestone Member, the probable extension of the Lockup Well Limestone Member south of a plateau of Cainozoic basalt and lateritic soil cover.

The re-mapping of the region during this study resulted in a major revision of the stratigraphic nomenclature of the Broken River Formation, with the formation being upgraded to group status. The revised nomenclature was presented at a field conference in 1987, and later published by Withnall & others (1988b). Sixteen stratigraphic units are now recognised and formal definitions were published by Lang & others (1989a). The lower part, which comprises limestone-mudstone-conglomerate-arenite lithofacies and forms most of the Group, is assigned to the Wando Vale Subgroup, and divided into twelve formations. The upper part of the Group, containing arenite-mudstone-conglomerate-limestone lithofacies, is mapped as Mytton Formation.

It must be recognised however, that this regional-scale lithostratigraphy does not allow all the vertical and lateral facies variability to be handled easily other than in a relatively arbitrary way. A sequence stratigraphy approach, more suited to understanding these rocks, is developed in a later section.

In this report, the Group will be described in terms of five major regional subdivisions, each including one or more stratigraphic units, and reflecting the distribution of most of the facies associations described by Withnall & others (1988b). This concept incorporates some of the palaeogeographic concepts of Mawson & Talent (1989). For each subdivision, the units are discussed in stratigraphic order, each being described in terms of the lithology and sequence, and interpreted in terms of depositional environment. Other essential data relating to the stratigraphy of the Broken River Group are summarised in Table 2.

The subdivisions are shown opposite.

WANDO VALE SUBGROUP
- Pandanus-Jessey Springs Area
  - Tank Creek Sandstone
  - Chinaman Creek Limestone
  - Dip Creek Limestone
  - Lockup Well Limestone
  - Jessey Springs Limestone
- Dosey-Craigie Area
  - Bracteata Mudstone
  - Lomandra Limestone
  - Storm Hill Sandstone
  - Dosey Limestone
  - Phar Lap Member
  - Papilio Mudstone
  - Spanner Limestone
- Broken River-Gorge Creek Area
  - Burges Formation
  - Phar Lap Member
- Undifferentiated Wando Vale Subgroup
  - Catfish Creek area
  - Craigie area
  - Northern area

MYTTON FORMATION
- Southern Area
  - 'Lower' Mytton Formation
  - Stanley Limestone Member
  - 'Upper' Mytton Formation
- Northern Area
  - 'Lower' Mytton Formation
  - 'Upper' Mytton Formation

PANDANUS AREA

The Pandanus area is synonymous with the 'Pandanus Carbonate Platform' of Mawson & Talent (1989), who referred to it as 'a carbonate platform in the north, now represented by four discrete outcrop tracts of carbonates'. Faulting along the Shield Creek and Lockup Well Faults dismembered what was probably one continuous carbonate sheet. Most of the constituent units are dominantly carbonates, but there are significant clastic intervals, though not to the extent seen in the Dosey-Craigie area. Whether this area actually represents a geomorphic 'platform' is subject to interpretation, and depends on the interpretation of the Burges area, which lies between this area and the Dosey-Craigie area to the south. Mawson & Talent (1989) considered the Burges area as a 'submarine valley' between the two platforms. An alternative is that the entire tract was deposited on a semi-continuous platform or gently dipping ramp, which contained carbonate 'factories' separated by areas of depressed carbonate sedimentation, due to a combination of slightly deeper water and abundant clastic sediment supply.

Tank Creek Sandstone

Description. The Tank Creek Sandstone is a laterally extensive (at least 7 km) well-sorted sandstone body up to 80 m thick, consisting of coarse-grained (locally pebbly) quartzose sandstone grading upwards into fine to medium-grained, sublabile, lithic sandstone (laminated or cross-bedded quartz or lithic arenite lithofacies - Table 4). The sandstones are generally well sorted, and contain flat lamination and low-angle planar and trough cross-bedding. The unit forms a distinctive, resistant ridge under the Chinaman Creek Limestone, and is easily distinguished from the underlying Shield Creek Formation which is

TABLE 2: STRATIGRAPHY OF THE BROKEN RIVER GROUP - SUMMARY CHART

Unit	Type and reference sections	Distribution	Thickness (m)	Lithology	Sedimentary structures	Fossils and age	Relationships	Environment of deposition
Tank Creek Sandstone (Dk)	South Chinaman Ck (80 m), base at 7859-605689, top at 604689	A 7 km-long, linear belt trending north from 'Pandanus Ck', and as a thin bed around the Dip Ck Syncline	0-80	Well-sorted coarse-grained arenite near the base to fine and medium-grained sublabile lithic arenite near the top	Thin to medium-bedded, with small to medium scale trough and low-angle cross-bedding	Poorly preserved brachiopods. ?Middle Emsian from relationships	Conformably overlies the Shield Ck Formation. Conformably overlain by the Chinaman Ck Lime-stone. Passes laterally into undifferentiated Wando Vale Subgroup in north	Siliciclastic shoreline
Chinaman Creek Limestone (Dc)	South Chinaman Ck (655 m), base at 7859-604689 to 597689	Along a linear belt west of 'Pandanus Ck', from the Tank Ck Fault in the south to the hinge of the Six Mile Ck Anticline in the north	0-650	Mainly bioclastic limestone (calcirudite calcarenite and minor calcilutite), lesser calcareous siltstone, fine to coarse lithic to quartzose arenite, and pebble con-glomerate; bioherms 2 km long and 30m thick in the lower part	Thin to very thick beds of detrital calcarenite, thin to medium-bedded siltstone. Poorly bedded, massive limestone predominates	Stromatoporoids, colonial to solitary rugose and tabulate corals; lesser brachiopods, bivalves, ostra-cods, crinoid ossicles, trilo-bites, bryozoa, algae, and conodonts. Middle Emsian to middle Givetian	Conformably overlies the Tank Ck Sandstone and the Shield Ck Formation. Conformably overlain by and interfingers with undifferentiated Wando Vale Subgroup (mudstone and arenite in the south, and conglomerate and mudstone in the north)	Shallow carbonate shelf. Bioherms occur at the base; otherwise the unit was deposited as biostromes, sandy and gravelly carbonate shoals, and quiet, possibly restricted lagoon deposits. Minor terrigenous sediments occur in places
Dip Creek Limestone (Dd)	Type section: Dip Ck (245 m), base at 7859-676648, top at 674653. Composite reference section: base in Dip Ck at 7859-678635 to 678627 (300 m), then 646606 in Atherton Ck to 648604 (650 m), then 663613 to top at 661614 (760 m) (Figure 23).	Exposed as a folded belt of rocks, forming slightly elevated topography which extends 20 km from the headwaters of Shield Ck to Turtle Ck in the east	245-760	Mainly bioclastic limestone (calcirudite, calcarenite, and lesser calcilutite - grainstone, packstone and wackestone, with lesser mudstone). Sandy and silty terrigenous material common in the lower part. Calcareous silt-stone, lesser calcareous sandstone	Small-scale, low-angle cross-bedding in calcareous sandstones. Intraclasts in sandy calcarenites. Bioturbation in calcilutites, and calcareous siltstones	Crinoid ossicles, solitary and colonial rugose corals, stroma-toporoids, less common bryozoans, gastropods, brachiopods, bivalves, ostracods, algae, and conodonts. Middle Emsian to early Givetian	Conformably to ?disconformably overlies the Shield Ck Formation. Conformably overlain by the Papilio Mudstone. Unconformably overlain by the Bundock Ck Group in the Dip Ck Syncline and faulted against the Bundock Ck Group along the Shield Ck Fault	Shallow carbonate shelf, including gravelly and sandy shoal deposits in a barrier complex, shelly carbonate banks, terrigenous and carbonate shelf lagoon deposits (restricted in part)

Unit	Type and reference sections	Distribution	Thickness (m)	Lithology	Sedimentary structures	Fossils and age	Relationships	Environment of deposition
Lockup Well Limestone (Dl)	Type section: Magpie Ck (approx. 400 m), from 7859-753650 to top at 744662.	A narrow belt, 13 km east of 'Pandanus Ck', trending 6 km southwest from Lockup Well	190-690	Mainly bioclastic limestone (calcirudite, calcarenite and calcilutite - packstone, wackestone, grainstone and lesser mudstone). Sporadic thin terrigenous interbeds	Thin to thickly bedded; massive	Colonial and solitary rugose corals, tabulate corals, stromatoporoids, crinoid ossicles, brachiopods, and conodonts. Middle Emsian to middle Givetian	The base is obscured by Tertiary laterite and basalt, and the top of the unit is conformably overlain by the Papilio Mudstone. The unit is probably in fault contact with the Shield Ck Formation in the north along the Lockup Well Fault; possibly continuous with the Jessey Springs Limestone beneath the laterite	Shallow carbonate shelf
Jessey Springs Limestone (Dj)	Type section: In the hinge of the Wade Anticline, 2 km southeast of Jessey Springs hut (280 m), base at 7859-701529, top at 698526 (Figure 24) (section sampled by Mawson & others, 1985; Mawson, 1987)	Complexly folded belt of rocks from the southwest corner of the laterite plateau to 2 km south of Jessey Springs hut	0-300	Mainly bioclastic limestone (calcarenite and calcirudite)	Well-bedded to massive; thin to thickly bedded	Colonial and solitary rugose corals, tabulate corals, stroma-toporoids, crinoid ossicles, and conodonts. Middle Emsian to middle Givetian	Conformably overlies and passes laterally into the Burges Formation. Conformably overlain by the Papilio Mudstone. Possibly continuous with the Lockup Well Limestone beneath the laterite	Shallow carbonate shelf
Burges Formation (Db)	Type section: Broken River (127 m) (transitional with undifferentiated Wando Vale Subgroup to the west), base at 7859-611441, top at 610442 (Figure 26). Reference section: Diggers Ck (approx. 800m - due to folding true thickness is unknown); base at 7859-684488, top at 670500	Mainly north of the Broken River, between 7859-650556 and 611441 in the south, to northeast of Jessey Springs at 740550. Interfingers with Jessey Springs Limestone northeast of Arch Ck between GR 712531 and 723540	125 to approx. 800m	Mainly grey, and brown calcareous mudstones, with lesser calcareous fine to medium arenite, polymictic pebble to cobble conglomerate (some with large limestone clasts), limestone, and coarse-grained quartzose arenite	Laminated and bioturbated mudstones; graded bedding and slump folding in thin bedded arenite and limestone; very thick bedded, crudely stratified or massive conglomerate and lithic arenite; and trough cross-bedded quartzose arenite at top of sequence	Calcareous mudstones contain tabulate and solitary rugose corals, brachiopods, crinoid ossicles and small stromatoporoids. Additionally limestones contain colonial rugose corals, bryozoans, and fish remains. Emsian to early Givetian	Conformably to ?disconformably overlies the Shield Ck Formation, and conformably overlain by the Papilio Mudstone. Passes laterally into the Jessey Springs Limestone in the north, and into the Bracteata Mudstone, Lomandra Limestone and Dosey Limestone in the south	Slope and lesser shelf deposits, including submarine channels, muddy and limey turbidites, slope limestone buildups. Possibly minor restricted? muddy shelf or bay deposit near base (lateral equivalent of Bracteata Mudstone)

Unit	Type and reference sections	Distribution	Thickness (m)	Lithology	Sedimentary structures	Fossils and age	Relationships	Environment of deposition
Bracteata Mudstone (Dr)	Type section: Unnamed tributary of Dosey Ck at 576388 (40 m). Reference sections: Lomandra Ck (175 m), base at 7858-609398, top at 608402 (Figure 25); Broken River (45 m), base at 7859-612441, top at 611441 (Figure 26)	Mainly south of Broken River, from near Six Mile Dam at 7859-670473 in the north, to 7858-610386 in the south	45-175	Grey, black and brown mudstone, lesser interbedded, very fine to medium-grained, calcareous, lithofeldspathic, arenite. Arenite more dominant to the west and south. Thin nodular and lenticular limestone beds more common near the top, but are rarely prominent	Bioturbation lamination, ripple cross-lamination and current ripple marks. Calcareous nodules in places	Generally poorly fossiliferous, but locally contains plant fragments, bivalves, brachio-pods, solitary corals, and lesser crinoid ossicles, ostracods, cono-donts, trilobites and small hemispherical stromatoporoids. Middle Emsian	Conformably to ?disconformably overlies the Shield Ck Formation. Conformably overlain by the Lomandra Limestone. In the north the unit passes laterally into Burges Formation whereas in the south and west it passes laterally into Storm Hill Sandstone	Muddy shelf
Lomandra Limestone (Da)	Type section: Lomandra Ck (383 m), base at 7859-613407, top at 609409 (Figure 25). Reference section: Broken River (127 m), base at 7859-611441, top at 610442 (Figure 26)	Mainly south of the Broken River, from 7859-665472 (2 km north of Jack Hills Gorge), to 7858-610370 in the south	0-400	Mainly bioclastic limestone (calci-rudite, calcarenite and calcilutite - mainly packstone, grainstone and wackestone, with mudstone more dominant in the lower part - sandy in part). Minor calcareous siltstone, arenite and polymictic conglomerate	Thin to very thick bedded limestone, some poorly bedded. Lamination, ripple cross-lamination and bioturbation in the siltstones in the lower part of the unit	Crinoid ossicles, stromatoporoids, tabulate and colonial and solitary rugose corals, rare brachiopods, gastropods, conodonts and fish fragments. Late Emsian to early Eifelian	Conformably overlies Bracteata Mudstone. Mostly conformably overlain by the Storm Hill Formation, but north of the type section it is conformably overlain directly by the Dosey Limestone. Lenses out in the Storm Hill area	Shallow carbonate shelf, including biostromes, sandy and gravelly shoal deposits, and quiet shallow lagoon deposits - some with possible patch reefs
Storm Hill Sandstone (Dh)	Type section: Lomandra Ck (50 m), base at 7858-609409, top at 608410 (Figure 25). Reference section: north arm of Papilio Ck (100 m) from 7858-567400 (anticlinal hinge) to 566401 (top)	Intricately folded with other units south of the Broken River. Thickest in the southwest particularly north of Storm Dam	0-?100	Medium to very coarse-grained sandstone and lesser pebble and granule quartzose to sublabile feldspathic conglomerate	Medium to very thick bedded, with erosive scours, trough cross-bedding and horizontal stratification	Generally unfossiliferous but poorly preserved tabulate corals, crinoids, brachiopods, rugose corals, bivalves, and trilobites occur in the few places. Emsian to middleEifelian	Conformably overlies the Lomandra Limestone and is conformably overlain by the Dosey Limestone; gradually lenses out northwest-wards between these two units. Thickens in the Storm Hill area where it unconformably overlies the Judea Formation	Siliciclastic shelf and siliciclastic shoreline. Sandy and conglomeratic shallow shelf deposits lateral to fan-delta deposits. Sandy terrigenous beach in Craigie/ Cleanskin bore area

Unit	Type and reference sections	Distribution	Thickness (m)	Lithology	Sedimentary structures	Fossils and age	Relationships	Environment of deposition
Dosey Limestone (Do)	Type section: Lomandra Ck (243 m), base at 7858-608410, top at 606412 (Figure 25). Reference section: Broken River (55 m), base at 7859-610442, top at 609443 (Figure 26)	Mainly south of the Broken River, from 7859-634461 in the north to 7858-610365 in the south	0-243	Mainly bioclastic limestone (calcirudite, calcarenite and calcilutite - mainly packstone and wackestone, with lesser grain-stone, mudstone and bindstone). Lesser sandy limestone, calcareous arenite and mudstone	Thin to very thick bedded, and massive limestone	Branching and lesser lamellar and hemispherical stromatoporoids, crinoid ossicles, brachiopods, solitary and colonial rugose, and tabulate corals, minor gastropods, ostracods, conodonts and fish remains. Eifelian to early Givetian	Conformably overlies the Storm Hill Formation and conformably overlain by the Papilio Formation. Passes laterally into Burges Formation in the north. Lenses out in the Storm Hill area	Shallow carbonate shelf, including biostromes, sandy and gravelly shoal deposits, and quiet, shallow, possibly restricted shelf lagoon deposits. Minor 'reef-top' deposits containing stromatoporoid bindstones. Thin, sandy, shelf deposits at the very top of the unit
Phar Lap Member (Do_p)	Type section: Unnamed tributary of Broken River (112 m), base at 7859-593437, top at 591438 (Figure 28)	From Storm Hill (7858-564395) to 7859-669500. Thickest around Phar Lap mine	0-130	Mainly calcareous quartzose to lithic sandstone. Commonly with fossiliferous limestone clasts. Minor limestone and sandy limestone	Medium to thick bedded, bimodal and low-angle cross-bedding	Sparse crinoid ossicles, solitary and colonial rugose corals, tabulate corals, stromatoporoids. Eifelian to early Givetian. Limestone clasts reworked from underlying Dosey Limestone	Channelised erosive base at the top of the Dosey Limestone and Burges Formation. Conformably overlain by the Papilio Formation. Lenses out north of Diggers Ck	Siliciclastic tidal channels and shallow carbonate shelf
Papilio Mudstone (Dp)	Type section: Tributary of Bracteata Ck (200 m), base at 7858-574403, top at 575402 (Figure 29). Reference sections: Unnamed gully, base at 7858-595402, top on left flank of Dosey Ck at 593405. Lomandra Ck (295 m), base at 7858-606412, top in small gully W of Lomandra Ck at 604414 (Figure 25).	Above the Lockup Well Limestone at 7859-720636, SW to 7858-500350, and to 610364, 3.5 km north of Cleanskin Bore in S. Interpreted above the Dip Ck Limestone between 7859-655596 and 679609	0-300	Mainly grey to brown calcareous mudstone, with minor very fine to fine-grained calcareous arenite. Nodular limestone (wackestones and packstones) is more important in the upper part of the sequence, particularly between 7859-580436 and 591449. See also Spanner Limestone Member	Bioturbation, lamination and ripple cross-lamination. Minor horizontally laminated arenite occurs near the base	Common to locally abundant brachio-pods, tabulate and solitary rugose corals, crinoids, stromatoporoids, conodonts, bivalves, gastro-pods and plant fragments. Late Eifelian to early Givetian	Conformably overlies Dosey, Jessey Springs, Lockup Well and Dip Ck Limestones, and conformably overlain by Mytton Formation. Passes laterally into Storm Hill Sandstone in the south	Muddy shelf; minor carbonate banks

Unit	Type and reference sections	Distribution	Thickness (m)	Lithology	Sedimentary structures	Fossils and age	Relationships	Environment of deposition
Spanner Limestone Member (Dp_s)	Type section: West of Spanner Hill (156 m), base at 7858-513369, top at 513366 (Figure 30).	Confined to the southwest between Spanner Hill at 7858-520360, and east of Page Ck at 7858-545415.	0-200	Mainly bioclastic limestone	Nodular to thin to medium-bedded limestone	Stromatoporoids, tabulate corals, colonial and solitary rugose corals, crinoid ossicles, brachiopods, gastropods, conodonts. Late Eifelian to early Givetian	A member of the Papilio Mudstone. Faulted against Mytton Formation along a major shear zone splaying off the Jessey Springs Fault. Laterally equivalent to limestone lenses in a syncline to the east in the Papilio Mudstone between 7858-570408 and 575410	Shallow carbonate shelf
Mytton Formation (Dm)	Type section: Broken River (450 m), base at 7859-589449, top at 578447 (Figure 26). Reference sections: Gorge Ck (at least 940 m), base at 7859-668513, top at 632517 (the sequence is complexly folded and faulted); GSQ Clarke River 2 from 139 to 389.89m	From between Burges 580549 and 712625 in the north to 7858-500330 in the southwest to 670380 northwest of 'Craigie'	0-940	Grey mudstone and interbedded, very fine to coarse-grained sublabile lithic arenite. Lesser granule and pebble (shale clasts) conglom-erate, and oolitic/ oncolitic dirty conglomerates. Oolitic limestone lenses occur southwest of the Stanley Limestone Member (see also Stanley Limestone Member)	Mudstones are either massive and bioturbated, or laminated, ripple cross-laminated with ripple marks, and 'runzelmarken'. Arenites are typically massive, graded or laminated, with dish structures, hummocky cross-stratification, flutes and ripple marks	Mainly lycopod plant fragments, but also minor tabulate corals, crinoid ossicles, brachiopods, bivalves, bryozoans, and rare stromatoporoids, trilobites and fish. However, the Broken River-Gorge Ck area is nearly barren of fossils. Givetian	Conformably overlies the Papilio Mudstone. Unconformably to disconformably over-lain by the Bulgeri Formation of the Bundock Ck Group (the unit is completely eroded away by uncon-formable onlap at the nose of the Atherton Ck Anticlinorium)	Storm influenced muddy shelf, possibly restricted, with minor sub-marine channels and oolitic/oncolitic shoals
Stanley Limestone Member (Dm_s)	Type section: Unnamed gully on north bank of Page Ck (65 m), at 7858-543414 (Figure 33)	Mainly on the northwest side of Page Ck, 3 km southwest of the confluence with the Broken River; the lens extends from 7859-561430 in the northeast, to 7858-505378 in the southwest	0-65	Bioclastic limestone (calcirudite, calcarenite and calcilutite - packstone and lesser grainstone). Two thin oolitic/ oncolitic limestones (calcirudite and calcarenite - grainstone and packstone) at the base; minor calcareous siltstone and fine-grained arenite	Low-angle planar and trough cross-bedding in the ooid grainstones. Ripple cross-lamination and bioturbation in the calcareous arenites and siltstones	Abundant stromatoporoids, tabulate corals, solitary and colonial rugose corals, crinoid ossicles, brachiopods, fish scales, algae, and more conodonts. Givetian	A member of the Mytton Formation, in the lower part. Oolites and oncolites have been found in thin conglomerates in Gorge Ck, and these may be a lateral lithological equivalent	Shallow carbonate shelf, including ooid/oncolite shoals, and sandy and gravelly biostromal deposits

Unit	Type and reference sections	Distribution	Thickness (m)	Lithology	Sedimentary structures	Fossils and age	Relationships	Environment of deposition
Undifferentiated Wando Vale Subgroup (Dw)		Up to 800m on the western limb of the Six-Mile Syncline and about 300m overlying the Chinaman Ck Limestone on the southern limb. About 400m in the Corner Ck area near Gregory Springs in the SW	0-800	Sandstone, conglomerate, calcareous siltstone, mudstone, and local bioclastic limestone in the Six-Mile Syncline area. Sandstone conglomerate, mudstone (redbeds) with minor muddy, laminated limestone (locally coralline) in the southwest	Trough and low-angle planar cross-bedding and horizontal stratification in the sandstone and conglomerate; laminated and bioturbated calcilutite and green/red mudstone with possible dessication cracks	Rare brachiopods and plant fragments in the terrigenous sediments. Solitary and colonial rugose and tabulate corals, and stromatoporoids, bivalves, gastro-pods and conodonts in the limestones. Emsian to Givetian in the Six-Mile Syncline and Craigie areas. Givetian in the southwest	Overlies and passes laterally into the Chinaman Ck Limestone in the Six-Mile Syncline. Unconformably overlies Precambrian(?) granite and metamorphics in the southwest	Shallow, sandy to muddy terrigenous shelf throughout. Marginal marine redbeds/carbonate tidal flat facies and fluviatile(?) in the southwest

arkosic rather than quartzose. A thin extension of the unit has been recognised under the Dip Creek Limestone (Wyatt & Jell, 1980).

Interpretation. The sedimentary structures and textures indicate high to moderate energy depositional conditions. The lateral extent and stratigraphic position suggest that the unit may have been deposited in a shoreline environment. Withnall & others (1988b) included this unit in the Siliciclastic Shoreline Facies Association (Table 3). Sandstones in the upper part may grade into subtidal siliciclastic shelf deposits.

The formation was probably deposited during a lowstand and/or the beginning of a transgression after a period of relatively low sea-level in the mid Emsian (probably *inversus* Zone; Mawson & Talent, 1989). Previous workers (Wyatt & Jell, 1980; Mawson & Talent, 1989) have preferred to show a major break between the top of the Shield Creek Formation and the base of the Broken River Group, based on the apparent hiatus between samples in the limestones above and below the boundary. However, the siliciclastics of the upper Shield Creek Formation and the Tank Creek Sandstone lack fossils, and this does not allow firm placement of a hiatus at the base of the Tank Creek Sandstone. The apparent time gap between the samples in the Martins Well Limestone Member and the first samples in the lower part of Chinaman Creek Limestone could easily be represented by the cross-bedded and winnowed sandstones in between. It is likely that the break is at i) the base of the upper sandy part of the Shield Creek Formation, or ii) at the base of the Tank Creek Sandstone, or iii) represented by a series of breaks spread throughout the upper Shield Creek Formation and the Tank Creek Sandstone.

Chinaman Creek Limestone

Description. The formation is 655 m thick in the type section along South Chinaman Creek, and can be divided into three major limestone sequences, each separated by terrigenous intervals of sublabile lithic and lithic arenite with minor mudstone and conglomerate (Jell, 1967). Four main limestone types were recognised by Jell (1967): i) nonbedded detrital limestones, ii) bedded detrital limestones, iii) reefal (biohermal and biostromal) limestones, and iv) fine-grained limestones. The lower limestone sequence is 168 m thick and comprises both bedded and nonbedded detrital limestones and calcareous shales, biohermal limestones and interbedded shales and minor arenites. Overlying the lower limestones is a 61 m thick siliciclastic interval, which is overlain by the 228 m thick middle limestone sequence which comprises mainly bedded detrital limestones and interbedded calcareous shales, with lesser unbedded detrital limestones and biostromal limestones. In places (eg. in the middle of the 'CCD' section of Mawson & Talent, 1989), this limestone sequence becomes sandy, and contains thin calcareous sandstones. The middle limestone sequence is separated by a 46 m thick siliciclastic interval from the 152 m thick upper limestone sequence which comprises bedded detrital limestones and calcareous shales. Fine-grained limestones occur in the upper part and sandstone interbeds in the south.

Non-bedded detrital limestones occur in all three limestone sequences, and are mainly rudstone or packstone (calcarenite and calcirudite). They are usually massive beds commonly more than 3 m thick, or alternating sequences of 0.6-3.0 m thick limestone and calcareous mudstone interbeds. In thin section, they are dominantly biomicrites and biomicrudites containing varying amounts of sandy terrigenous material. Intramicrites and

TABLE 3: FACIES ASSOCIATIONS OF THE BROKEN RIVER GROUP

FACIES ASSOCIATIONS	*INTERPRETED DEPOSIT TYPES*
Siliciclastic Shoreline	Well sorted laterally extensive sandy shoreline deposits, fan-delta conglomerates.
Mixed Siliciclastic - Carbonate Tidal	Calcareous, lithic to quartzose sandstone or granule conglomerate with limestone clasts (tidal channel fill), intertidal to subtidal redbeds, limestones, algal laminates, and mudflats.
Siliciclastic Shelf	Sandy and conglomeratic shallow shelf deposits adjacent to shoreline and fan-delta deposits. Storm influenced, wave-dominated sandy shelf deposits.
Muddy Shelf	Richly fossiliferous mudstones, and minor nodular limestones and calcareous sandstones. These probably range from intertidal to deeper muddy shelf deposits. Minor carbonate banks, and locally restricted areas.
Carbonate Shelf	Carbonate barrier/shoal complex with limited development of wave-resistant stromatoporoid-coral buildups (biostromes and rare bioherms). Extensive quiet carbonate shelf lagoons. Oncolitic/oolitic shoals.
Mixed Siliciclastic - Carbonate Slope	Conglomeratic submarine channel deposits, some with allochthonous limestone blocks. Mudstone, limestone and arenite deposits interpreted as subtidal shelf deposits, though some may represent turbidites, slump blocks and debris flows.

intramicrudites also occur low in the sequence, south of 'Pandanus Creek' homestead. Bioclastic detritus includes a mixture of corals, stromatoporoids, bryozoa, brachiopods, crinoid ossicles, bivalves, gastropods, ostracodes and algae. Coral, stromatoporoid and shell detritus comprise most of the coarser bioclasts 1 mm in diameter, and some rounded boulders of stromatoporoid colonies are up to 0.5 m in diameter. In the lower part of the sequence, locally abundant bioclasts include the small cuneate coral *Protomacgeea,* or sheet-like deposits of the colonial rugose corals *Taimyrophyllum* and *Endophyllum*. Some of the sandy limestones contain low-angle cross-bedding.

Bedded detrital limestones are the most common type, and occur in all three parts of the formation. They are mainly rudstone, packstone and floatstone (calcirudite and calcarenite) beds 0.3-3.0 m thick, interbedded with calcareous mudstone beds up to 0.3 m thick. In thin-section, the limestones are dominantly biomicrudite or biomicrite. The main difference from the nonbedded limestones is the dominance in any particular bed of one type of bioclastic material. Most common is the branching stromatoporoid *Amphipora ramosa,* which occurs in thick, laterally extensive beds of biomicrudite and biomicrite. The *Amphipora* 'sticks' range up to 40 mm long and 7 mm wide, and are commonly aligned in the bedding plane. Large globular stromatoporoid colonies (up to 0.5 m in diameter) or tabular stromatoporoids form the dominant bioclast type in other beds, and generally they are not in growth position. Another common type of bioclastic material is stick-like fragments (or more rarely branching masses) of the rugose coral *Dendrostella*. Other types of corals (eg. *Tabulophyllum*, or large cystimorphs) may be locally abundant, and these appear to be mainly in growth position. In the upper part of the sequence, beds up to 1 m thick contain coarse bioclasts dominated by large disarticulated brachiopods (*Stringocephalus*).

Reefal limestones up to 2 km long and 30 m thick, and composed mainly of framestone, occur sparingly throughout the sequence, but mainly in the lower part. Sheet-like beds up to 1 m thick, containing a large proportion of undisturbed coral and stromatoporoid colonies, were considered by Jell (1967) to represent biostromes; these occur mainly in the middle limestone interval. The best developed biostrome occurs 90 m above the base of the middle limestone sequence, and is 0.6 m thick extending for more than 5 km. The biostrome is composed of intergrown massive colonies of *Endophyllum*. Bioherms are the most common type, however. They are lensoidal outcrops which show no bedding, and have a framework of large *in situ* masses of *Endophyllum* (up to 1.6 m across and 2 m high), as well as massive *Phillipsastrea* colonies, globular stromatoporoids, flat and inverted, conical masses of *Favosites*, domed colonies of heliolitids, and large colonies of dendroid favositids. Many of these frame-building colonies are encrusted by stromatoporoids, rugose and tabulate corals, algae, and bryozoans (Wyatt & Jell, 1980, page 204). The detrital limestone enclosing the framework of both the bioherms and the biostromes is mainly a poorly sorted rudstone or packstone (biomicrudite and biomicrite), with minor patches of well sorted grainstone (biosparite). The detritus is composed mainly of coral and crinoidal debris, with lesser amounts of brachiopod, gastropod, algal and bryozoan remains.

The fine-grained limestones (calcilutites) occur only in the upper limestone interval, and comprise sparsely fossiliferous, dark grey, massive lime mudstone, wackestone and packstone. In thin section these rocks are pelmicrites, and contain *Amphipora* 'sticks', small solitary corals, brachiopod and thin bivalve shells, ostracodes, and calcispheres.

The lower siliciclastic interval is 61 m thick in the type section, and can be recognised throughout the outcrop length of the formation. It comprises mainly coarse-grained lithic quartz sandstone, with conglomerate at the base and shale at the top. The sandstones are cross-bedded in places. Small incipient bioherms occur in the upper part of this clastic interval, associated with sandy biomicrites (calcarenites). The bioherms are up to 20 m in length and 1.5 m high and are composed of massive tabulate and colonial rugose corals and stromatoporoids.

Sandy limestones and thin calcareous sandstones occur in the middle part of the middle limestone sequence (eg. between 348 and 455 m in the 'CCD' section of Mawson & Talent, 1989).

The upper siliciclastic interval is 46 m thick in the type section, but is irregular in thickness and composed of pebbly lithic quartz sandstone, mudstone and shale. West of the Six Mile Syncline hinge, a sharp facies change occurs between the Chinaman Creek Limestone and undifferentiated Wando Vale Subgroup. Two thick beds of polymictic conglomerate, as well as lithic arenite and mudstone, either abut the limestones, or are continuous with the terrigenous intervals of the Chinaman Creek Limestone.

Interpretation. The sedimentology of the unit has not been studied in detail. However, the description of the unit by Jell (1967) suggests that with the exception of the bioherms, many similarities exist with the facies described from the Dip Creek Limestone by Law (1985), as well as many facies from the other limestones of the Wando Vale Subgroup (see Table 4). In general, the Chinaman Creek Limestone was deposited on a shallow water carbonate platform, and was therefore included by Withnall & others (1988b) in the Carbonate Shelf Facies Association.

In the Pandanus area, the first major transgression of the Broken River Group began in the mid Emsian (Jell, 1967; Wyatt & Jell, 1980; Withnall & others, 1988b; Mawson & Talent, 1989). It resulted in development of biohermal reefs over the lowstand or early transgressive shoreline facies of the Tank Creek Sandstone. Biohermal reefs developed, initially well below wave base, but gradually grew upwards into the wave agitated zone (Jell, 1967) as carbonate production increased.

The dominance of lime mud in the rest of the limestones indicates deposition in a relatively low-energy environment, generally below wave base. However, agitated conditions regularly shifted or broke up the larger coral and stromatoporoid colonies. By comparison with the facies described by Law (1985) from the Dip Creek Limestone, most of these limestones were deposited in a shelf lagoon, and to a lesser extent as carbonate shoals. The *Amphipora* pelmicrites in parts of the upper two limestones were probably deposited in partly restricted lagoonal conditions. The shelf lagoon may have been very shallow, and Mawson & Talent (1989) suggested the influence of intertidal and possibly supratidal conditions, based on the overall low diversity of faunas in the formation.

The two major sandy and muddy terrigenous intervals represent influxes of siliciclastic material under moderate to high energy, during either periods of lowered relative-sea level, or periods of excess sediment supply due to uplift in the hinterland. These intervals are interpreted as shallow shelf deposits, and therefore are included in the Siliciclastic Shelf Facies Association. By comparison with the Phar Lap Member, some of the sandy limestones in these intervals may represent tidal channel deposits. The bioherms represent reefal development during the beginning of the next transgressive phase.

The three limestone sequences were probably deposited during transgressive and highstand periods, separated by

TABLE 4: LITHOFACIES OF THE BROKEN RIVER GROUP

Lithofacies	Description	Interpretation	Unit	Section/Location	Thin sections
<u>SILICICLASTIC SHORELINE FACIES ASSOCIATION</u>					
SS.1 Well-sorted arenite	Well-sorted, medium to coarse-grained labile to quartzose arenite. Laterally extensive with flat lamination and trough or low-angle planar cross-stratification. Rare brachiopod and crinoid remains.	High energy, siliciclastic shoreline	Dt, Dw	Chinaman Creek, Top Craigie Bore	GSQR 18187, 18188
SS.2 Quartzose arenite and conglomerate	White or reddish, coarse to very coarse-grained arenites and pebble conglomerates dominated by angular quartz; cross-bedding and horizontal stratification.	Shallow, open marine siliciclastic shelf	Dh, Dc, Dw	Lomandra Creek type section	GSQR 13632, 13633, 13825, 13826, 13827, 13899 UQ 47495
<u>MIXED SILICLASTIC - CARBONATE TIDAL ZONE FACIES ASSOCIATION</u>					
T.1 Fossiliferous micaceous calcareous quartzose arenite/ micaceous quartzose biosparite	Well-sorted, fine to coarse-grained grainstones ranging from calcareous quartzose arenites to quartzose biosparites. They contain abundant quartz and mica grains, a diverse fossil assemblage and scattered intraclasts in spar cement. Allochems are well rounded and some laminations are developed	Turbulent tidal channel	Do_p	Lomandra Creek type section, Phar Lap type section	GSQR 13879, 13880, 13881 UQ 47502
T.2 Micaceous quartzose biopelmicrite	Well-sorted, fine-grained packstones containing abundant peloids and small quartz and mica grains, plus scattered fossil fragments in a micritic matrix. The mica grains are roughly aligned, producing vague laminations	Tidal channel/ tidal flat	Do_p, Dp	Lomandra Creek type section	GSQR 13882, 13883
T.3 Quartzose intrasparite	Well-sorted packstone to grainstone with abundant dark grey intraclasts, some terrigenous material (quartz, mica, oxide and lithic grains) and relatively diverse fossils in spar cement	Turbulent tidal channel	Do_p	Lomandra Creek type section	GSQR 13878

Lithofacies	Description	Interpretation	Unit	Section/Location	Thin sections
T.4 Silty micaceous pelmicrite	Vaguely to poorly laminated mudstones and wackestones containing peloids and scattered fossil fragments (crinoids and brachiopods) in a matrix of micrite and silt-sized quartz, muscovite and oxide grains	Intertidal zone of a muddy tidal flat	Dd	Atherton Creek	UQ 44854, 44857
T.5 Laminated, algal micrite	Thin-bedded, dark grey to reddish algal laminated micrite (calcilutite) with disarticulated shelly fossils, bioturbation and desiccation clasts	Intertidal to supratidal zone of a muddy tidal flat	Dw	'Gregory Springs'-Catfish Creek area	GSQR 13904
T.6 *Disphyllum* limestone	Fossiliferous, fine to coarse-grained, grey to reddish, poorly sorted (dirty) calcarenite; diverse fauna including *Disphyllum*	Intertidal, fossilerous rubble mixed with nearshore siliciclastics	Dw	As for T.5	GSQR 13634
<u>SILICICLASTIC SHELF FACIES ASSOCIATION</u>					
S.1 Polymictic conglomerate	Grey-white conglomerate with well-rounded quartz pebbles and some altered igneous and shale clasts in a ferruginised matrix of quartz sand, oxides, mica and minor calcite	Basal part of siliciclastic channel	Da, Dc, Dm	Dosey Creek south, Chinaman Creek, upper Mytton Formation south of Broken River, Gorge Creek, Atherton Creek	UQ 47531
S.2 Silty quartzose arenite	Red, fine to coarse-grained silty arenites containing abundant, well-sorted, sub-angular quartz grains	Upper sandy section of siliciclastic channel	Da, Dc	Dosey Creek south, Chinaman Creek	UQ 47532, 47533
S.3 Laminated micaceous calcareous quartzose arenite	Fine to very fine-grained arenites dominated by very angular quartz grains, plus minor amounts of muscovite, feldspar and oxides, and very sparse fossils in a micritic matrix. Finely laminated.	Shallow, subtidal, siliciclastic shoal; storm-induced	Da, Dd, Dp_s	Dosey Creek north, Atherton Creek, Spanner Hill 1, Storm Hill 1, Phar Lap 2	UQ 44858, 47444, 47457, 47480, 47529, 47536
S.4 Flat-laminated arenite	Very fine to medium-grained, flat-laminated arenite, typically with parting or streaming lineation, and flute and load casts at the base. The upper part of beds may be ripple-cross-laminated.	Storm deposits (turbidites?)	Dm	Mytton Formation type section, Dosey Syncline, Diggers Creek, Gorge Creek, Atherton Creek	GSQR 13618, 14650, 14651

Lithofacies	Description	Interpretation	Unit	Section/Location	Thin sections
S.5 Massive arenite	Massive, very fine to medium-grained arenite; local lamination; commonly show dewatering and convolute laminae.	Storm deposits (liquefaction due to cyclic wave loading)	Dm	As for S.4	GSQR 14653, 14654 UQ 47494
S.6 Hummocky cross-stratified arenites	Medium to thick-bedded, well-sorted, fine-grained quartzose arenite with hummocky cross-stratification, flat lamination, ripple cross-lamination and rare planar cross-bedding.	Storm deposits	Dm	Mytton Formation type section	GSQR 14662, 14663
S.7 Thinly interbedded arenite and mudstone	Ripple cross-laminated, very fine to fine-grained arenite, interbedded with laminated and burrowed mudstone; rare plant fragments and invertebrates	Fair weather shelf deposits	Dm	As for S.4	
<u>MUDDY SHELF FACIES ASSOCIATION</u> M.1 Mudstone = Lithofacies C (Law, 1985)	Light brown to grey, micaceous, calcareous mudstone with a locally well-developed axial plane cleavage and locally preserved small-scale ripple cross-lamination. Commonly bioturbated and locally carbonaceous.	Quiet, shallow muddy shelf, at times alternating with lagoonal conditions	Dr, Da, Dd, Dp, Do	Lomandra Creek type section, Atherton Creek	GSQR 13884, 13886 to 13889, 13892, 13894 to 13896
M.2 Very fine quartzose arenite	Weakly to strongly laminated, very fine- grained, micaceous, calcareous quartzose arenites containing very scattered fossil fragments and abundant fine quartz, mica and oxide grains in a clay and micrite matrix	Storm sand layers on a quiet muddy shelf	Dr, Dp	Lomandra Creek type section	GSQR 13885, 13893, 13897
M.3 Micaceous quartzose biomicrudite	Orange coloured, shelly calcirudite with large thin-shelled brachiopods and crinoid fragments in an arenitic matrix of quartz, mica and oxide grains, fossil clasts, micrite and minor spar cement	Shelly lag deposits on a quiet muddy shelf	Do	Lomandra Creek type section, Broken River	GSQR 13890
M.4 Stromatoporoid-coral-brachiopod biomicrite	Wackestones to packstones containing abundant fossil allochems and very scattered, small quartz grains in a partially neomorphosed micrite matrix	Shallow carbonate banks on a quiet, muddy shelf	Dp, Dp_s	Lomandra Creek type section	GSQR 13891
M.5 Banded lime mudstone	Non-fossiliferous micrite ironstained in red, green, brown and yellow bands and patches	Quiet, restricted muddy shelf	Dr	Lomandra Creek type section	GSQR 13742

Lithofacies	Description	Interpretation	Unit	Section/Location	Thin sections
M.6 Brachiopod-mollusc biomicrudite	Poorly sorted calcirudite with thin-shelled, disarticulated brachiopods and molluscs in a micritic matrix that also contains scattered terrigenous sediment and carbonised plant fragments. The shells are either scattered throughout the matrix or as thin concentrations parallel to bedding	Muddy, shelly banks on a quiet muddy shelf	Dd	Atherton Creek	UQ 44856
M.7 Interbedded mudstone and lamellar stromatoporoid micrudite	Medium to thinly interbedded calcareous mudstone and stromatoporoid calcirudite. The limestone is a poorly sorted packstone containing abundant stromatoporoids and lesser amounts of other fossil debris (corals, brachiopods, crinoids) in a matrix of micrite and minor terrigenous sediment	Very quiet, possibly restricted, muddy shelf	Dp	Phar Lap 2	UQ 47482
M.8 Nodular limestone	Mudstones and wackestones containing scattered fossil allochems (crinoids, brachiopods, corals, algae) in a micrite matrix. Various amounts of terrigenous sediment in the matrix. The nodular appearance is due to bioturbation and stylolitisation	Mixed carbonate-siliciclastic, possibly restricted, quite muddy shelf	Dp, Dp_s	Broken River, Stanley Limestone Member type section	
M.9 Thinly interbedded mudstone and fine arenite	Grey mudstone interbedded with lenticular to wavy bedded, very fine to fine-grained arenite. Ripple marks commonly including "runzelmarken" are common	Low energy, muddy shelf or bay (possibly intertidal)	Dm	Mytton Formation type section	
<u>CARBONATE SHELF FACIES ASSOCIATION</u> C.1 Biosparite = Lithofacies A1 (Law, 1985) = Lithofacies E (Jorgensen, 1990)	Well-sorted packstones and grainstones containing abundant and diverse fossil allochems (particularly crinoids) in a cement-dominated groundmass	Shallow, open marine sandy shoal	Da, Dd, Dc	Lomandra Creek type section, Dosey Creek south, Dosey Creek north, Atherton Creek	GSQR 13749, 13750, 13759, 13763, 13765, 13766, 13767, 13770, 13782, 13784, 13786, 13788 to 13798, 13801, 13804, 13807, 13808, 13813, 13815 to 13821, 13853, 13855, 13860, 13861 UQ 47509, 47513, 47535, 44851

Lithofacies	Description	Interpretation	Unit	Section/Location	Thin sections
C.2 Biomicrite = Lithofacies A (Jorgensen, 1990)	Fossiliferous wackestones and packstones with diverse fossil assemblages (dominated by crinoids) in a micritic matrix	Shallow, open marine shelf lagoon	Dr, Da, Do, Dc, Dp_s, Dd	Lomandra Creek type section, Dosey Creek south, Spanner Hill 1	GSQR 13743, 13746, 13748, 13751, 13752, 13753, 13758, 13768, 13769, 13777, 13780, 13781, 13789, 13790, 13792, 13803, 13810, 13811 to 13814 13816, 13834 UQ 17027, 47507, 47508, 47443, 47456
C.3 *Amphipora* pelmicrite = Lithofacies S & J (Law, 1985)	Wackestones and packstones with scattered fossil debris, dominated by *Amphipora* fragments, in a micrite matrix that contains abundant pellets	Quiet, shallow, restricted lagoon	Do, Dd, Dc	Lomandra Creek type section, Atherton Creek, Chinaman Creek	GSQR 13835 to 13845, 13862, 13864, 13865, 13869, 13870, 13872, 13874 UQ 17026, 44860, 47503, 47505
C.4 Biopelsparite = Lithofacies F (Jorgensen, 1990)	Fine to very fine-grained, well-sorted packstones and grainstones containing abundant peloids and diverse fossils in a spar cement-dominated groundmass	Inter-tidally influenced shoal on a shallow, open marine shelf	Da, Do	Lomandra Creek type section, Dosey Creek north	GSQR 13757, 13762, 13763, 13764, 13770, 13771, 13793, 13797, 13799, 13809, 13810, 13822, 13823A, 13823B, 13824, 13866 UQ 47521
C.5 Biopelmicrite = Lithofacies B (Jorgensen, 1990)	Fine-grained wackestones and packstones distinguished by a high peloid content and diverse fossils in a micritic matrix	Shallow, open marine shelf lagoon. Possibly inter-tidally influenced	Da, Do, Dd, Dc, Dm_s	Lomandra Creek type section, Dosey Creek south, Storm Hill 1, Stanley Limestone Member type section	GSQR 13747, 13772, 13775, 13776, 13778, 13779, 13800, 13812, 13822, 13823A, 13831, 13858, 13867, 13868, 13877 UQ 47507, 47458
C.6 Stromatoporoid-coral biosparrudite = Lithofacies I & J (Jorgensen, 1990) = Lithofacies A2 (Law, 1985)	Floatstones to rudstones (and possibly boundstones) which have abundant large fossil allochems (dominated by stromatoporoids and corals) and up to 15% terrigenous material in a clean to poorly washed spar cement groundmass	Shallow subtidal gravelly shoal with abundant reef rubble. Also associated with some bioherms and biostromes.	Da, Do, Dc, Dm_s	Lomandra Creek type section, Dosey Creek south, Atherton Creek, Stanley Limestone Member type section	GSQR 13833, 13846, 13847, 13848 to 13851, 13857, 13876 UQ 47511, 47534
C.7 Laminated calcisphere-ostracod biomicrite = Lithofacies C (Jorgensen, 1990)	Fine-grained, laminated mudstones and wackestones with a restricted fossil assemblage, dominated by ostracods and calcispheres, in a micritic matrix	Shallow, restricted marine shelf lagoon	Da, Dc, Dm_s	Lomandra Creek type section, Stanley Limestone Member type section	GSQR 13754A, 13754B, 13760, 13761, 13773, 13774 UQ 47510, 47640

Lithofacies	Description	Interpretation	Unit	Section/Location	Thin sections
C.8 Quartzose biomicrite/biopelmicrite = Lithofacies E (Blake, 1990)	Very fine-grained wackestones and packstones containing peloids, scattered fossils (mainly crinoids) and a terrigenous content (quartz, micas, oxides, clays and lithic grains) of between 10 and 15% in a micrite matrix	Shallow, open marine shelf lagoon receiving siliciclastic sediment. Possibly intertidally influenced	Do, Dp_s	Lomandra Creek type section, Spanner Hill 1, Storm Hill 1, Phar Lap 2	GSQR 13832, 13852 UQ 47442, 47448, 47449, 47451, 47456, 47481
C.9 Fossiliferous calcareous quartzose arenite = Lithofacies L (Jorgensen, 1990)	Fine to medium-grained quartzose arenites containing over 70% quartz, plus lesser amounts of other terrigenous material, and scattered fossil clasts (corals, crinoids, stromatoporoids, brachiopods) in a calcareous cement	Mixed carbonate-siliciclastic sandy shoal on a shallow, open marine shelf	Da, Do	Lomandra Creek type section	GSQR 13805, 13829, 13830, 13863 UQ 47512, 47522
C.10 Stromatoporoid-coral biomicrudite = Lithofacies I (Law, 1985)	Dark grey floatstones and framestones (calcirudites) containing large fossil allochems (tabulate and rugose corals, stromatoporoids, crinoids, brachiopods) and minor amounts of terrigenous material in a dominantly micritic matrix	Shallow water banks and bioherms in a restricted to open, marine shelf lagoon	Dc, Do, Dd, Dp_s, Dm_s	Lomandra Creek type section, Atherton Creek, Spanner Hill 1, Spanner Hill 2, Stanley Limestone Member type section	GSQR 13828, 13834 UQ 44859, 47445, 47446, 47447, 47452, 47454, 47641
C.11 *Stringocephalus* biomicrudite	Poorly sorted packstones and floatstones (calcirudites) containing abundant, disarticulated *Stringocephalus* shells in a micrite-dominated matrix	Storm deposited shell beds in a restricted lagoon	Dc, Do, Dm_s	Lomandra Creek type section, Stanley Limestone Member type section	GSQR 13873, 13875
C.12 Quartzose (oolitic) biopelsparite	Well-sorted packstone containing abundant peloids, diverse fossils, scattered ooids and approximately 10% terrigenous sediment in a well washed spar cement. Weakly laminated	Intertidally influenced, mixed carbonate - siliciclastic sandy shoal on a shallow, open marine shelf	Da, Dm_s	Lomandra Creek type section, Stanley Limestone Member type section	GSQR 11283, 13806
C.13 Quartzose biosparite	Fine to medium-grained packstones and grainstones characterised by a rich fossil assemblage and significant amounts of terrigenous sediment (10 to 15%) in a cement dominated groundmass	Mixed carbonate-siliciclastic sandy shoal on a shallow, open marine shelf	Da	Lomandra Creek type section, Dosey Creek south, Dosey Creek north	UQ 47514, 47519
C.14 Gastropod-*Dendrostella* stromatoporoid biomicrudite = Lithofacies L (Law, 1985)	Poorly sorted calcirudite containing large (0.5 to >10cm) fossil fragments (gastropods, *Dendrostella*, stromatoporoids) in a matrix of micrite, smaller skeletal debris, peloids and scattered terrigenous material	Quiet, shallow lagoon	Dd	Atherton Creek	UQ 44862

Lithofacies	Description	Interpretation	Unit	Section/Location	Thin sections
C.15 Intraclast biosparite	Coarse to very coarse-grained grainstones with abundant, abraded and rounded fossils, and up to 20% intraclasts in a cement-dominated groundmass	Sandy subtidal shoal on a shallow, open marine shelf	Da	Dosey Creek north, Dosey Creek south	UQ 47530
C.16 Ooid-intraclast biosparite	Well-sorted grainstones with intraclasts, radially fibrous ooids and strongly abraded fossil allochems in a clean spar cement	Sandy subtidal shoal on a shallow, open marine shelf	Dc, Da, Dp_s	Dosey Creek north	UQ 47527, 47528
C.17 Intramicrite/ intramicrudite = Lithofacies D (Jorgensen, 1990) = Lithofacies F (Blake, 1990)	Calcarenites and calcirudites characterised by sand to cobble sized limestone (biomicrite) intraclasts and fossil allochems in a micrite matrix	Storm influenced, shallow open marine shelf lagoon	Da, Dp_s	Lomandra Creek type section, Storm Hill 1	UQ 47506, 47520, 47459
C.18 Crinoidal intrasparrudite	Coarse calcarenites with well-rounded, elongate intraclasts (0.5 - 10cm long) and abundant crinoid debris in spar cement	Shallow subtidal storm lag deposit	Dd	Atherton Creek	UQ 44853
C.19 Pelmicrite = Lithofacies E (Law, 1985)	Grey-green mudstone containing abundant pellets and scattered fossil fragments in a neomorphosed micrite matrix	Quiet, shallow lagoon	Dd	Atherton Creek	UQ 44855
C.20 Branching tabulate coral fossiliferous micrite = Lithofacies K (Law, 1985)	Mottled, pinkish-red and grey carbonate mud with fragments of a branching tabulate coral and rare crinoid ossicles in the matrix	Low energy, lagoonal shoal	Dd	Atherton Creek	UQ 44861
C.21 Oosparite	Well-sorted, commonly cross-bedded grainstones with well developed ooids (some containing limonite in their laminae) and oncolites in sparry cement	Sandy subtidal shoal on a shallow, open marine shelf	Dp_s, Dm_s	Spanner Hill 1, Spanner Hill 2, Stanley Limestone Member type section	UQ 47450, 47453, 47637, 47638 GSQR 11287, 11289

Lithofacies	Description	Interpretation	Unit	Section/Location	Thin sections
<u>MIXED SILICICLASTIC -CARBONATE SLOPE FACIES ASSOCIATION</u>					
SL.1 Polymictic conglomerate-calcirudite-arenite	Thick to very thick-bedded, clast-supported, polymictic, pebble to boulder conglomerate; includes locally derived limestone clasts and where abundant these form calcirudite lenses; interbedded with calcareous, lithic arenite grading to sandy limestone	Gravelly submarine channels	Db	Dosey Creek north, Broken River, Gorge Creek, Fish Hill	GSQR 11303, 13612, 13613 UQ 47523, 47524
SL.2 Thinly interbedded mudstone-limestone-arenite	Thin to medium-bedded mudstone, bioclastic calcilutite, calcarenite and calcirudite with lesser interbedded fine to medium-grained arenite; slump blocks, including chotic calcirudite	Mixed carbonate-terrigenous slope; probably deposited by slumping, debris flow and turbidity currents	Db	Dosey Creek north, Broken River	UQ 47525, 47526
SL.3 Limestone	Lenses of thin to medium-bedded calcirudite with lesser calcilutite (packstone, wackestone, mudstone and minor grainstone); contains a diverse fauna including fish remains	Carbonate ramp to slope; includes some allochthonous limestones	Db	Fish Hill	GSQR 11200, 13611
SL.4 Massive mudstone - minor arenite	Thin to very thick-bedded, massive to laminated and bioturbated mudstone; interbedded with thin-bedded, graded, ripple cross-laminated, fine to very fine-grained arenite	Muddy slope; turbidites?	Db, Dr	Diggers Creek, Gorge Creek, Broken River	

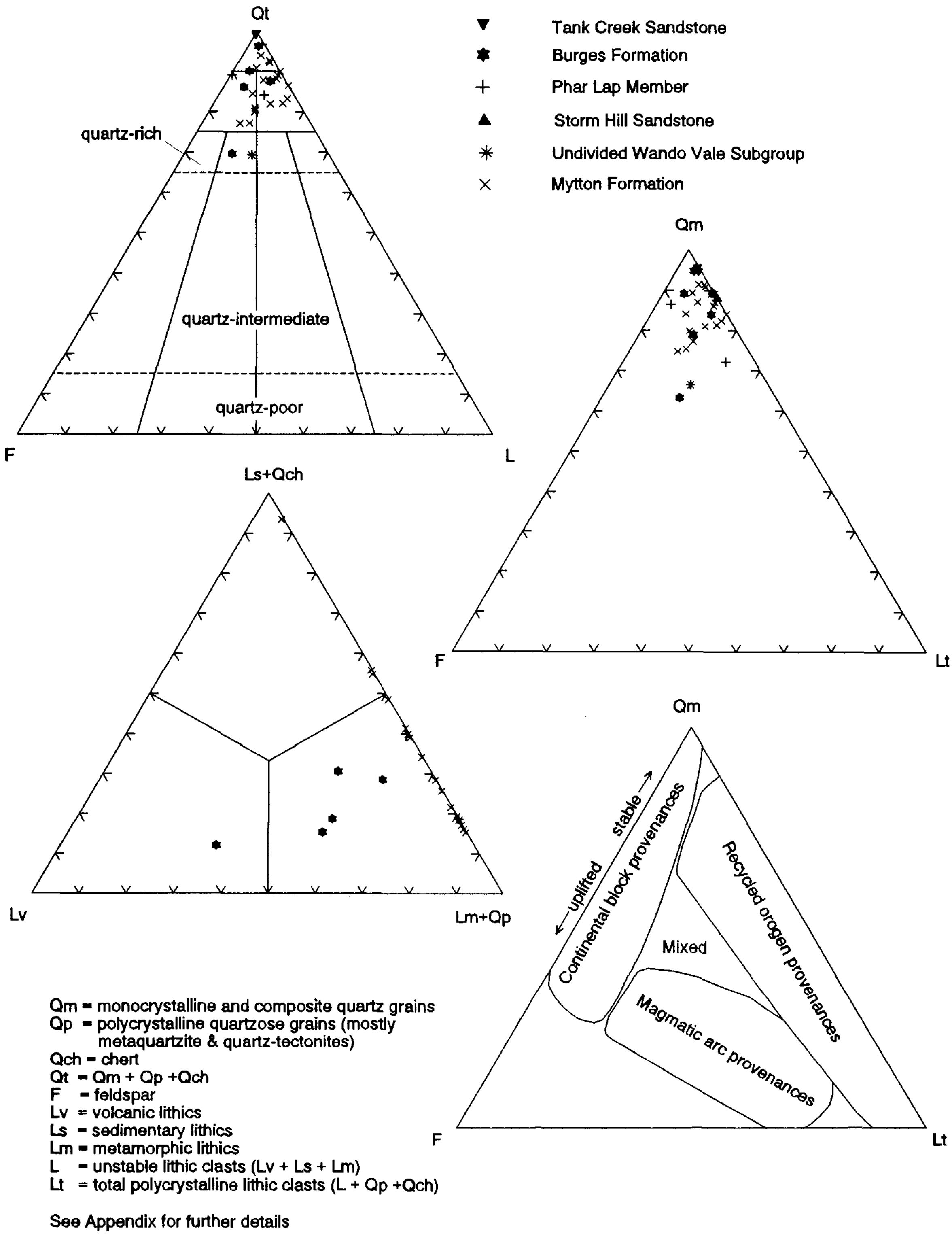


Figure 22. Plots of modal data from arenites in the Broken River Group. See Appendix for full analyses and more details. Compositional fields are after Crook (1960, 1974) and inferred provenance fields are after Dickinson & Suczek (1979).

siliciclastic and mixed siliciclastic-carbonate deposition during periods of relatively lower sea-level (eg. lowstand, or early transgressive deposits), or periods of major sediment influx. Based on conodont data from the 'CCD' section by Mawson & Talent (1989) the following depositional history can be deduced.

The first major transgression began in the mid Emsian (*inversus* Zone), continued through the *serotinus* Zone, with carbonate aggradation occurring during the highstand conditions in the late Emsian to early Eifelian (*patulus* - *partitus* Zones, and possibly into the lower *costatus* Zone). Carbonate deposition in the Pandanus area was interrupted by the first terrigenous interval in the mid Eifelian (apparently early in the *costatus* Zone in Mawson & Talents 'CCD' section). The second major transgression began in the mid Eifelian and continued into the late Eifelian (*costatus* to ?*australis* Zones). The sandy part of the middle limestone sequence appears to contain either one or more breaks or a significant condensation of the conodont zones. In the 'CCD' section, conodonts indicative of

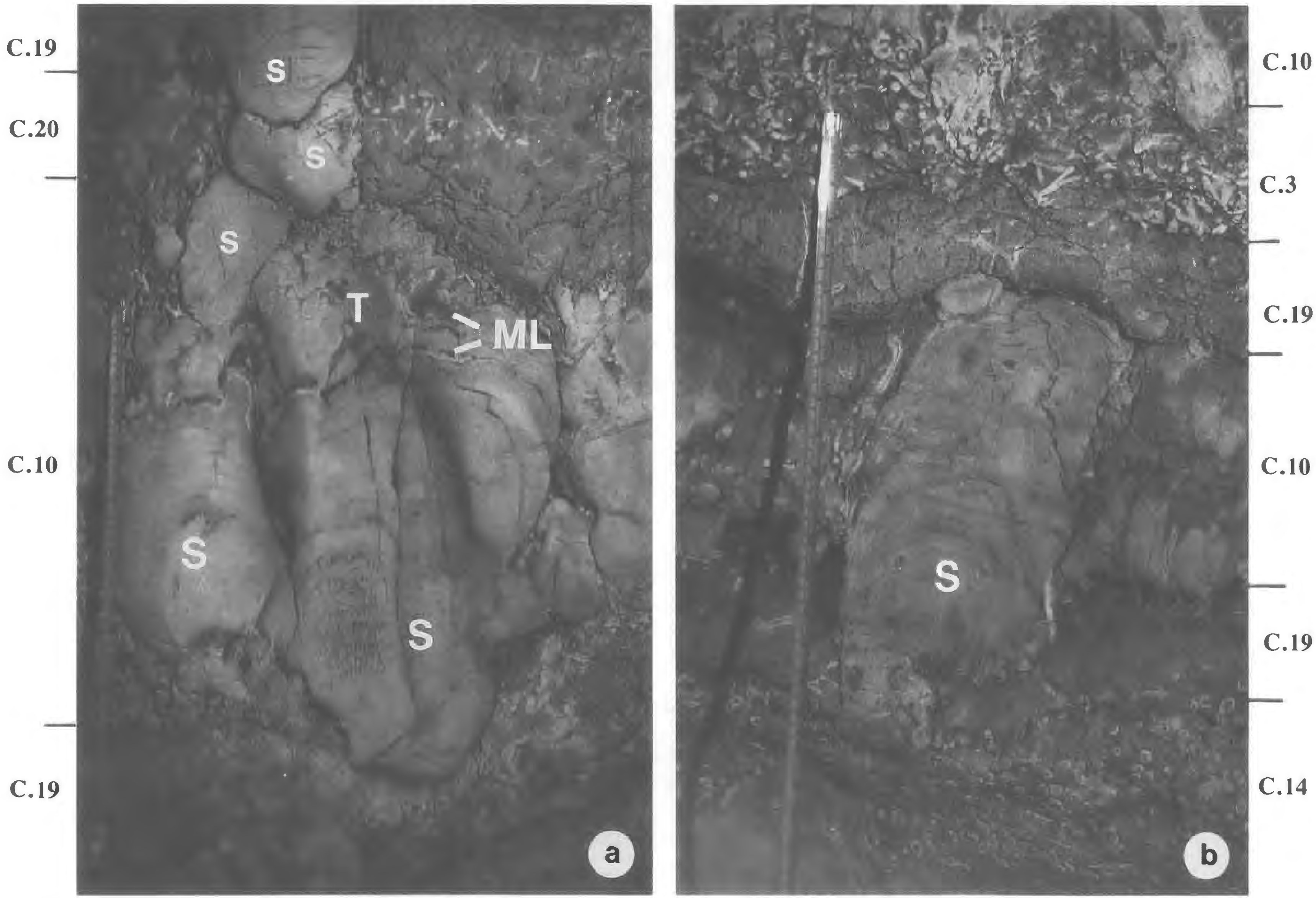


Plate 15. Stromatoporoids on the walls of Dip Creek Caves showing some of the lithofacies referred to in the text (see Table 4 for explanation).

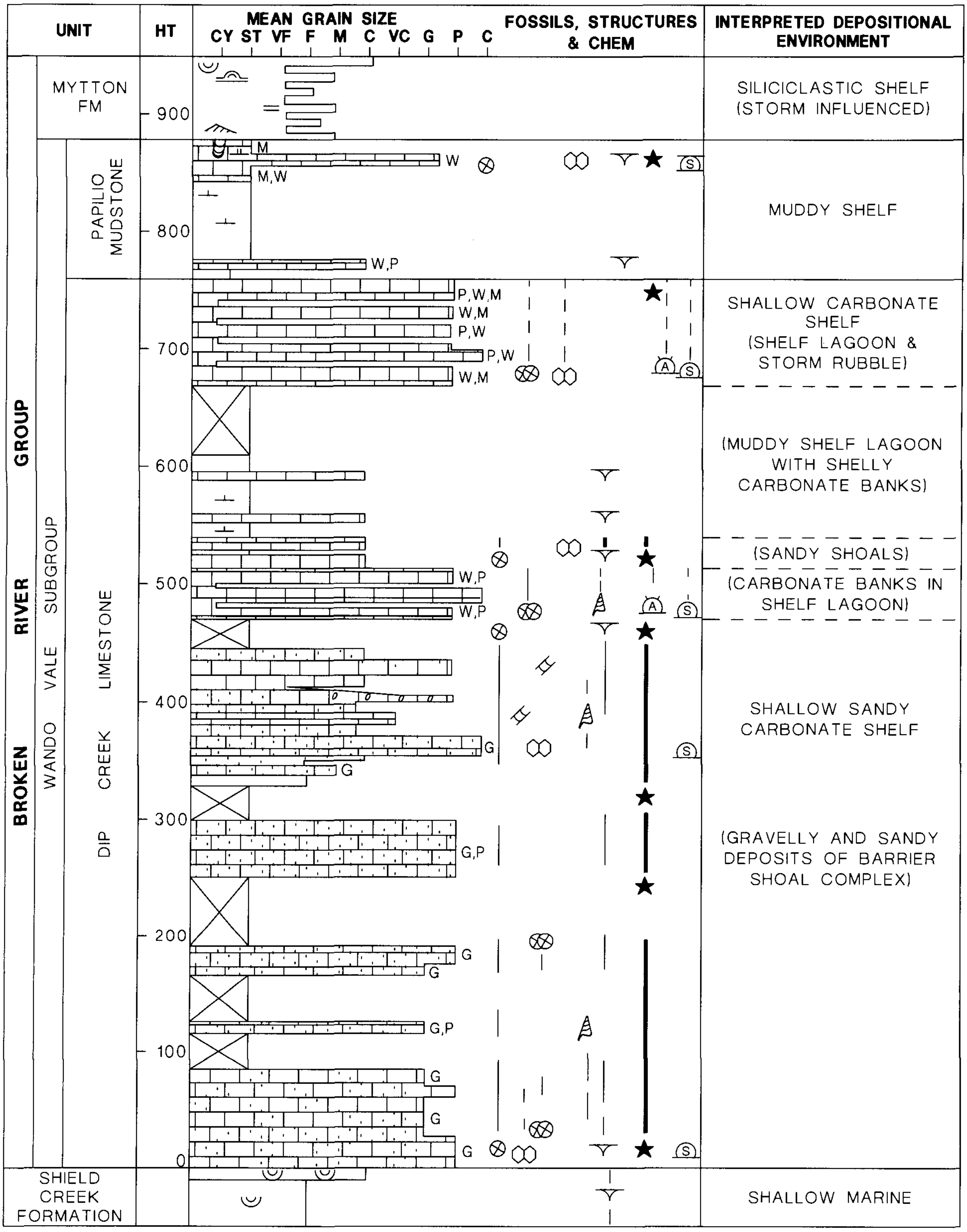


Figure 23. Dip Creek Limestone, composite section: 7859-680638 (base) to 680627 (300 m); 646606 (300 m) to 648604 (650 m); 663613 (650 m) to 661614 (760 m); and 671604 (760 m) to 673603 (top). See Figure 14 for reference.

early Givetian occur at 400 m. The combination of *P. parawebbi*, *P. pseudofoliatus*, *I. struvei*, *I. arkonensis*, *P. hermiansatus*, *I. obliquimarginatus*, and *P. xylus xylus* in the one sample indicates either that the sample lies on the boundary of *ensensis* and lower *varcus* Zone, or is lower *varcus* Zone, and is mixed with conodonts recycled from *ensensis* Zone. In either case, most of the *australis*, *kockelianus*, and *ensensis* Zones must occur between the base of the sandy limestone interval at 340 m and the middle of the sandy limestone interval at 400 m. This interval is equivalent to much of the entire Dosey Limestone in the south. It is possible that the sandy sequence below 400 m is coeval with the Storm Hill Sandstone in the south, which was also deposited during a period of relative sea-level lowering (see later). The sandy limestones above 400 m may be equivalent to the Phar Lap Member, and therefore a significant break may have occurred during a lowstand event. The upper half of the middle limestone sequence (above the sandy limestones) was apparently deposited in another major transgressive phase, perhaps continuing during a highstand phase in the middle *varcus* Zone. This would make this part of the section equivalent to the lower Papilio Mudstone in the south. The upper siliciclastic interval appears to mark yet another relative lowering of sea-level in the middle *varcus* Zone, and may be comparable with the sandy limestones of the Spanner Limestone Member in the south. The uppermost limestone sequence was deposited in another transgressive phase, mainly during the middle to upper *varcus* Zones.

The polymictic conglomerates described by Jell (1967) may represent channel-fill shelf or slope deposits, laid down during the periods of lowered relative sea-level, when coarse siliciclastics could be swept out across the shelf. Judging by their composition, texture, and stratigraphic position, they may therefore be analogous to some of the gravelly channel-fill deposits in the Storm Hill Sandstone, Burges Formation and Phar Lap Member. Such correlations must, however, remain purely speculative until further fieldwork is carried out.

Dip Creek Limestone

Description. The formation is approximately 245 m thick in the type section in Dip Creek. However, in the main outcrop area, Law (1985, 1986a) measured a composite section up to 890 m thick of limestone with interbedded calcareous siltstone and fine-grained arenite (Figure 23). The sequence in the type section is shorter due to a combination of structural thinning and erosion by the overlying Bundock Creek Group.

Law (1985, 1986a) carried out a detailed facies analysis of the formation, and described and interpreted 13 lithofacies. These lithofacies have been revised and integrated into a comprehensive facies scheme based largely on the Wando Vale Subgroup sequence in the Dosey creek area by Jorgensen & Lang (in preparation). The definitions of the lithofacies are based mainly on thin section description, and are described in Table 4, and the interpretation of the constituent lithofacies forms the basis for the interpretation of the formation. Lithofacies of the Carbonate Shelf Facies Association form more than half of the formation, and in order of decreasing relative abundance, the lithofacies are as follows: biosparite, *Amphipora* pelmicrite, biomicrite, stromatoporoid-coral biosparrudite and biomicrudite, with lesser *Stringocephalus* biomicrudite, crinoidal intrasparrudite, pelmicrite, gastropod-*Dendrostella*-stromatoporoid biomicrudite, and branching tabulate coral fossiliferous micrite. Lithofacies of the Muddy Shelf Facies Association comprise up to 40% of the formation, and include interbedded calaceous siltstone, with lesser brachiopod-mollusc biomicrudite. Laminated, silty micaceous pelmicrites of the Mixed Siliciclastic - Carbonate Tidal Facies Association also make up a small percentage of the formation.

In the field, individual lithofacies are not easy to recognise, and therefore the limestones in outcrop or slab are described in terms of the classification of Embry & Klovan (1971). The formation can be divided into three broad sequences.

The **lowermost 540 m** consists of thin to medium-bedded limestones, sandy limestones and calcareous sandstones, interbedded with poorly exposed calcareous siltstones. A thin, clean, quartzose sandstone occurs at the very base of the sequence in places (laminated or cross-bedded quartz or lithic arenite lithofacies) and is probably equivalent to the Tank Creek Sandstone. Also near the base of the sequence, but apparently restricted to the northern area southwest of Martins Well (Jell, 1967; Wyatt & Jell, 1980), are mound-like limestones consisting of framestone dominated by massive rugose corals with lesser stromatoporoids (stromatoporoid-coral biomicrudite lithofacies). These are apparently biohermal structures, being semi-circular to elliptical in plan with a semicircular cross-section, and are 1-4 m high, and 2-20 m in diameter. These bioherms form a substrate for framestone of other colonial rugose and tabulate corals, large solitary rugose corals, stromatoporoids, and calcareous algae.

The rest of the sequence is dominated by limestones which comprise mainly grainstones and packstones, with lesser wackestones (calcarenites and calcirudites). Sparry calcite cement forms the matrix in the grainstones (crinoidal biosparites, stromatoporoid-coral biosparrudite, crinoidal intrasparrudite lithofacies), whereas lime mud forms the matrix in the packstones and wackestones (gastropod-*Dendrostella*-stromatoporoid biomicrudite, biomicrite, laminated silty micaceous pelmicrite lithofacies in the lower part, with pelmicrite, and branching tabulate coral fossiliferous micrite near the top of the succession). A diverse faunal assemblage occurs in the limestones, although it is dominated by crinoids and solitary rugose corals. Other fossils include brachiopods, gastropods, bivalves, bryozoans, branching and compound tabulate corals, algae, and lamellar stromatoporoids. The sandy limestones contain siliciclastic quartzose sand, and are common in the upper two-thirds of the sequence (some of the biomicrites are micaceous and silty, and quartz sand occurs in the biosparites). The calcareous sandstones (laminated micaceous calcareous quartz arenite lithofacies) contain low-angle, small-scale cross-stratification in places.

Between the limestone-dominated successions, there are poorly exposed siltstones and associated fine-grained limestones (brachiopod-mollusc biomicrudite, and laminated, silty micaceous pelmicrite lithofacies).

The **middle 225 m** of the sequence consists largely of poorly exposed calcareous siltstone (M.1 - mudstone lithofacies), interbedded with micritic limestones (M.6 - brachiopod-mollusc biomicrudite lithofacies).

The limestones towards the top of this sequence are mainly thin to medium-bedded mudstones, wackestones and lesser packstones (calcilutites and calcirudites). In contrast to the sparry calcite common throughout the lower sequence, these limestones are dominated by micritic lime mud. The limestones comprise *Amphipora* pelmicrite, stromatoporoid-coral biomicrudite, gastropod-*Dendrostella*-stromatoporoid biomicrudite, branching tabulate coral fossiliferous micrite, and pelmicrite lithofacies. The faunal assemblage is dominated by bulbous stromatoporoids, heliolitid corals, the branching rugose coral *Dendrostella*, and the branching stromatoporoid *Amphipora*, with lesser encrusting and branching tabulate corals, gastropods, brachiopods, and bivalves.

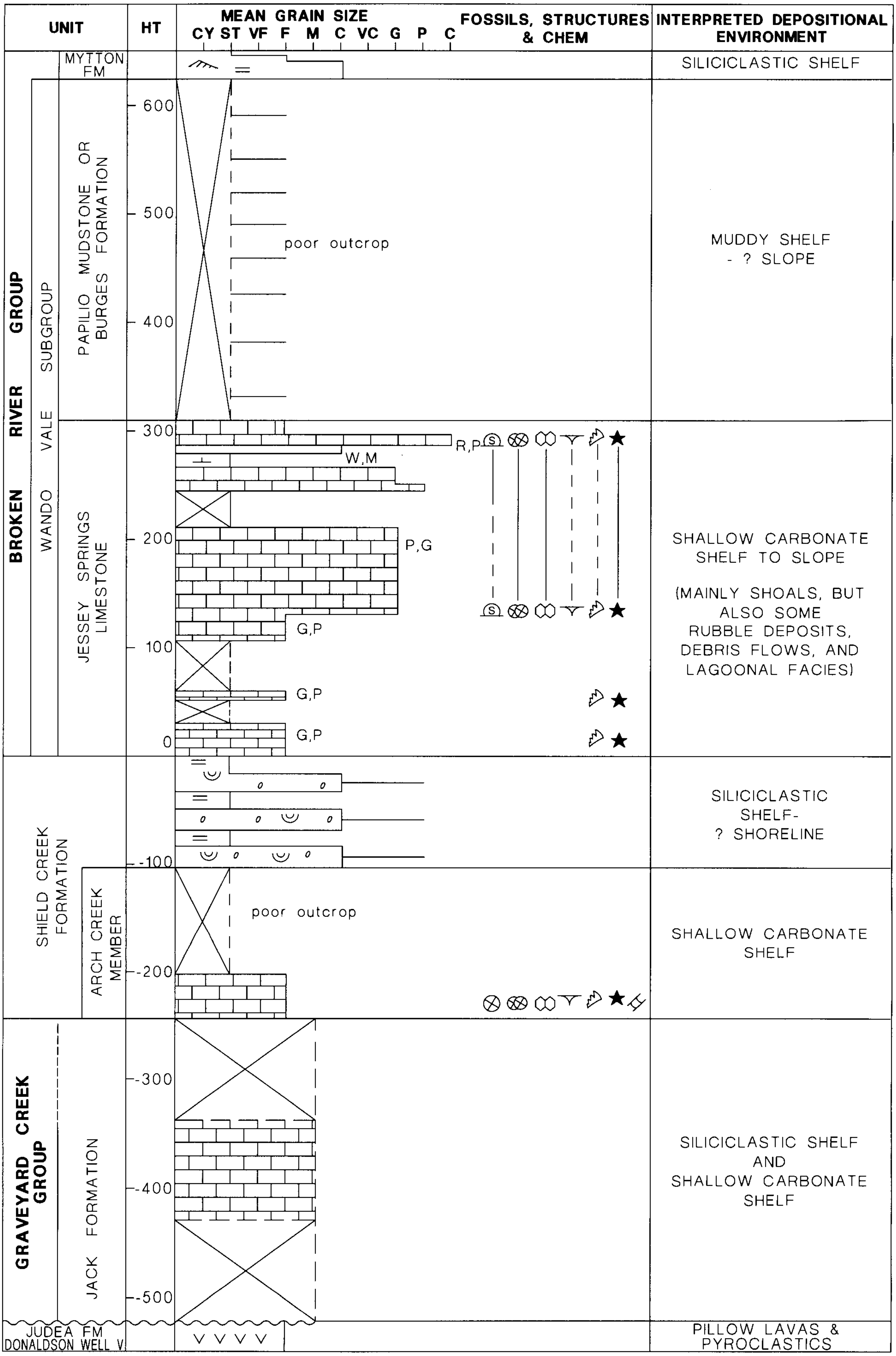


Figure 24. Composite section in the Jessey Springs area: lower part through the Jack Formation and Shield Creek Formation from 7859-721545 to 715534 (including the type section of the Arch Creek Limestone Member at 716537); middle part is the type section for the Jessey Springs Limestone between 701529 and 698526; and upper part is from 691540 to base of Mytton Formation at 686540. See Figure 14 for reference.

This sequence is best exposed in the Dip Creek Caves (7859-667614). The cave walls display a shallowly dipping sequence of thin to medium-bedded limestones consisting of several distinct lithofacies. The limestones comprise *Amphipora* pelmicrite and pelmicrite, interbedded with gastropod-*Dendrostella*-stromatoporoid biomicrudite, and stromatoporoid-coral biomicrite. In places, thin to medium bedded *Amphipora* pelmicrite are intercalated with thin beds of grain-supported, *Amphipora* dominated biomicrudite. Most beds however, show pervasive pressure solution, and many of the apparently grain-supported facies were probably mud supported originally. Stylolites form a pervasive, anastomosing fabric throughout the rocks, and commonly envelope whole fossil clasts. Despite these diagenetic fabrics however, many palaeoecological relationships between different organisms are still well preserved in places, and the effects of original sedimentation processes can also be observed (Plate 15).

Plate 15 shows photographs from the caves showing the main fossil types and lithofacies. They show the following features:

(a) Bedding planes are not always well defined, having been partly obscured by compaction and pressure solution processes;

(b) Palaeoecological relationships between organisms such as shown by the encrusting tabulate coral (T) growing on the large stromatoporoid (S) in Plate 15a;

(c) The effects of different rates of mud sedimentation on tabulate coral (T) growth can be seen by the development of mud pockets and laminae (ML) within the coral structure and the eventual death of an organism due to increased sedimentation of mud;

(d) Subsequent changes caused by pressure solution processes such as shown by the three stromatoporoids in the upper part of Plate 15a.

The strong development of stylobedding in the caves was probably caused by tectonism rather than purely compactional processes. At this stage no regularly developed cyclicity of the different lithofacies has been observed.

The **upper 125 m** of the sequence included in the Dip Creek Limestone in the composite section (Figure 23) consists of micaceous calcareous siltstones with a thin limestone interval near the base (wackestones and packstones) and a thicker limestone interval near the top (wackestones and mudstones). Brachiopods are especially common in the sequence, but the upper limestones also contain solitary rugose corals, branching tabulate corals, crinoids, and lamellar stromatoporoids. The upper limestone interval contains bioturbation in the upper part, and passes upwards into weakly calcareous siltstones containing ripple marks. At 7859-673603, this sequence passes gradationally up into thin bedded, very-fine to fine-grained arenites and interbedded calcareous siltstones, and eventually into thin to medium bedded, fine-grained arenites containing flat lamination, hummocky cross-stratification and ripple marks. These arenaceous rocks form the base of the Mytton Formation. As this upper sequence is traced towards the nose of the Atherton Creek Anticlinorium, it becomes increasingly difficult to distinguish, and it is eventually eroded by the Bulgeri Formation.

Interpretation. Law (1985, 1986a) interpreted the Dip Creek Limestone as open shallow-water carbonate shelf, lagoonal and barrier shoal deposits, mixed or interbedded with muddy and locally sandy siliciclastic deposits.

At the base of the **lower 540 m** sequence the thin, clean, quartzose sandstones probably represent an equivalent to the Tank Creek Sandstone. They are interpreted as siliciclastic shoreline deposits laid down during a lowstand or during the beginning of a transgression following a period of relatively low sea-level. The biohermal limestones, which lie in the northern part of the unit at the base of the sequence, are smaller, but not unlike those described from the base of Chinaman Creek Limestone by Jell (1967).

The bulk of the sequence of dominantly sandy limestones is interpreted as sandy and gravelly carbonate shoal deposits, which formed a low barrier behind which extensive sedimentation in a quiet shallow shelf lagoon occurred.

The **middle 225 m** sequence is best understood from the exposures in the Dip Creek caves. Law (1985, 1986a) interpreted the *Amphipora* pelmicrites as quiet, possibly restricted shallow shelf lagoon deposits. He interpreted the interbedded gastropod-*Dendrostella*-stromatoporoid biomicrudites, and stromatoporoid-coral biomicrites as carbonate banks and low energy shoals within a lagoon complex. The banks formed *in situ* (local growth of organisms without the construction of a prominent structure and mechanical buildup of the transported skeletal remains). The thin beds of grain-supported *Amphipora*- or *Dendrostella*-dominated biomicrudites which are intercalated with the *Amphipora* pelmicrites are interpreted as storm deposits derived from the destruction of what were probably thickets of *Amphipora* or *Dendrostella* growing in the lagoon. Periodic high energy conditions are evidenced by the presence of intraclast-bearing facies, which were also probably formed during storms. Given that the Broken River area lay in tropical latitudes during the Middle Devonian (Li & others, 1991), it was probably subject to cyclonic weather much like that experienced by the Great Barrier Reef and the reefs around Indonesia and Papua New Guinea today.

The interbedded siliciclastic siltstones and calcareous mudstones that occur throughout the sequence probably represent those parts of the lagoon subject to silt deposition from suspension. The silt may have originated directly from nearby fluvial sources, which were draining into the shelf lagoon. Tropical storms however, can play an important role in distributing silt a long way across the shelf, away from the original site of accumulation near river mouths and deltas (Johnson & others, 1986). Taking into consideration the palaeogeography of the Broken River area during the Middle Devonian, it is unlikely that the site of deposition of the Dip Creek Limestone would have been more than a few tens of kilometres from the shore, and probably less than 100 km.

The upper 125 m sequence exposed on the southern side of the Atherton Creek Anticlinorium is mapped as Dip Creek Limestone, but it probably represents a lateral equivalent of the Papilio Mudstone, including a vestige of the Spanner Limestone Member. The sequence is interpreted as muddy shelf deposits, interbedded with relatively shallow carbonate banks and shoals (Muddy Shelf Facies Association).

Lockup Well Limestone and Jessey Springs Limestone

Little is known about the sedimentology of these limestones, although preliminary field work suggests that they are broadly similar to the Dip Creek Limestone. They are composed mainly of well-bedded crinoidal and coralline calcarenites and calcirudites, with lesser calcilutites. The units are probably continuous with each other under laterite cover, and were probably part of the same limestone buildup as the Dip Creek Limestone before being separated from it by the Lockup Well Fault. The Jessey Springs Limestone thins dramatically over an anticlinal structure east of Jessey Springs Hut (Figure 24); this is due to a facies change into the adjacent Burges Formation, and possibly represents a transition from shelf to slope facies. Detailed conodont data from stratigraphic sections northeast of Arch Creek support a progressive deepening eastwards (Mawson & Talent, 1989).

THE DOSEY-CRAIGIE PLATFORM

Bracteata Mudstone

Description. The Bracteata Mudstone and the basal part of the Burges Formation are characterised by massive or laminated, ripple cross-laminated (Figures 25, 26 and 27), bioturbated, and pyritic mudstone. The mudstone is interbedded with thin-bedded, fine-grained, calcareous arenite. Thin-bedded limestones become more common near the top and indicate a transition into the carbonate sequence of the Lomandra Limestone. At the base of the unit in the Broken River (7859-654455), the mudstones are rich in carbonaceous material, including stems and simple dichotomous plant fragments. The associated fauna is limited mainly to small bivalves, ostracodes, and solitary corals. However, higher up the sequence there is an increase in the abundance of brachiopods (especially *Notanoplia*), cephalopods, hyolithids, branching tabulate corals, gastropods, crinoids, bryozoans, hemispherical stromatoporoids, and rare trilobites (Figures 25 and 26). *Protomacgeea*, a small solitary rugose coral, is common in the upper part of the formation, especially in the Phar Lap-Dosey Creek area. In places, for example the type section, and near the Broken River-Dosey Creek confluence, the lower part of the sequence is quite sandy. In the latter area, the lower contact with the Shield Creek Formation appears transitional. The upper contact in this area is transitional with the Burges Formation, the contact being placed at the base of the first thick-bedded limestone. To the south, the unit is conformably overlain by the Lomandra Limestone.

Interpretation. The lithologies of the Bracteata Formation are consistent with deposition on a shallow muddy shelf. Initially the sequence was deposited under very shallow conditions; the abundant plant material suggests possibly paralic conditions. However, as a marine transgression engulfed the area during the late Emsian (*serotinus* Zone), more open marine conditions developed and eventually carbonate deposition was promoted during the highstand leading to the deposition of the overlying Lomandra Limestone.

Lomandra Limestone

Description. The Lomandra Limestone (Plate 16) consists of up to 430 m of bioclastic limestone, minor calcareous mudstone and arenite, and rare quartz arenite and pebble conglomerate lenses. It forms the lower half of the major limestone buildup south of the Broken River. Detailed mapping and microfacies analysis by Jorgensen (1990), led to the recognition of numerous sub-environments within the unit (Table 4).

The **lower 150 m** of the Lomandra Limestone in the type section (Figure 25) is composed mainly of thin to medium-bedded limestones, comprising mudstones and wackestones (calcisiltites and calcarenites), with lesser packstones and grainstones (calcarenites and calcirudites). The main fossil groups present are crinoids, rugose and tabulate corals, brachiopods, ostracodes and algae (*Girvanella*). Hemispherical, globular, and occasional finely branching stromatoporoids occur in places. Bivalves, bryozoans and gastropods are poorly represented. The finer-grained limestones are bioturbated, and contain lamination and ripple cross-lamination. Scattered ooids and oncolites occur in the grainstones in the lowermost part of the formation. Northeast of the type section, in the Broken River, the sequence contains more crinoidal material, and is interbedded with more terrigenous mudstone and arenite.

The **middle 130 m** of the Lomandra Limestone in the type section is considerably coarser-grained than the lower part, and is composed mainly of medium to thick-bedded packstones and grainstones (calcarenites and calcirudites), with minor wackestones (calcisiltites and calcarenites). Siliciclastic rocks occur towards the top of the interval and one prominent (16 m thick) section of calcareous quartzose sandstone is present. Large, *in situ*, colonial rugose corals (*Endophyllum*, 1.2 m wide and 0.3 m high), coral heads of *Favosites* (0.4 m wide and 0.3 m high), and lamellar stromatoporoids (1 m wide and 0.3 m high) occur near the base of this interval. Large bulbous heads of *Phillipsastrea* also occur in places. They are surrounded by bioclastic debris which includes crinoids, corals, stromatoporoids, brachiopods, and rare gastropods. Higher in the interval, the limestone becomes very coarse-grained, and consists almost entirely of rubble with a locally siliciclastic matrix.

The **upper 110 m** of the unit in the type section is composed mainly of packstones and grainstones (calcisiltites and calcarenites), with lesser wackestones (calcisiltites). All of the fossil groups that occur in the lower intervals are represented, but large brachiopods are more abundant and large corals and stromatoporoids are rare. This sequence is abruptly overlain by quartzose sandstone and conglomerate of the Storm Hill Sandstone.

Interpretation. The Lomandra Limestone is interpreted as a sequence of carbonate shelf deposits, with an offshore trend towards the northeast where the unit passes into the slope deposits of the Burges Formation. The lower sequence was deposited in shallow, open to restricted, relatively quiet, shelf lagoons, with the coarser grainstones and packstones representing banks or shoals. These shoals migrated across the shelf and at times may have sealed off parts of the lagoon, creating the restricted conditions.

The large *in situ* corals and stromatoporoids of the lowermost middle interval may have formed biostromal deposits comprising small 'patch reefs' or 'knolls' on the shelf. The overlying sandy and gravelly sequence, and the upper packstones and grainstones of the Lomandra Limestone may represent rubble or shoal deposits. The interbedded wackestones represent periodic returns to lagoonal conditions. The interval of mixed

PLATE 16:

a. **Photomicrograph X60 (crossed polars) of intraclasts of quartzose biomicrite, biomicrite, and completely micritised and abraded skeletal grains in sparry calcite cement. This facies overlies the sequence boundary at the base of the Lomandra Limestone, and is interpreted as a sandy subtidal shoal deposit on a shallow, open-marine shelf. Carbonate Shelf Facies Association, Lithofacies C.15, intraclast biosparite. 7859-604424, UQ47530.**

b. **Folded limestone with asphaltic injectate and intense calcite veining in the hinge area (above and just to the left of the hammer). On the northern bank of Dosey Creek at 7859-602425.**

c. **Placoderm fish bone fragment in packstone. Same locality as (b).**

d. **Large colony of the rugose coral *Endophyllum*. Type section, 173 m above the base.**

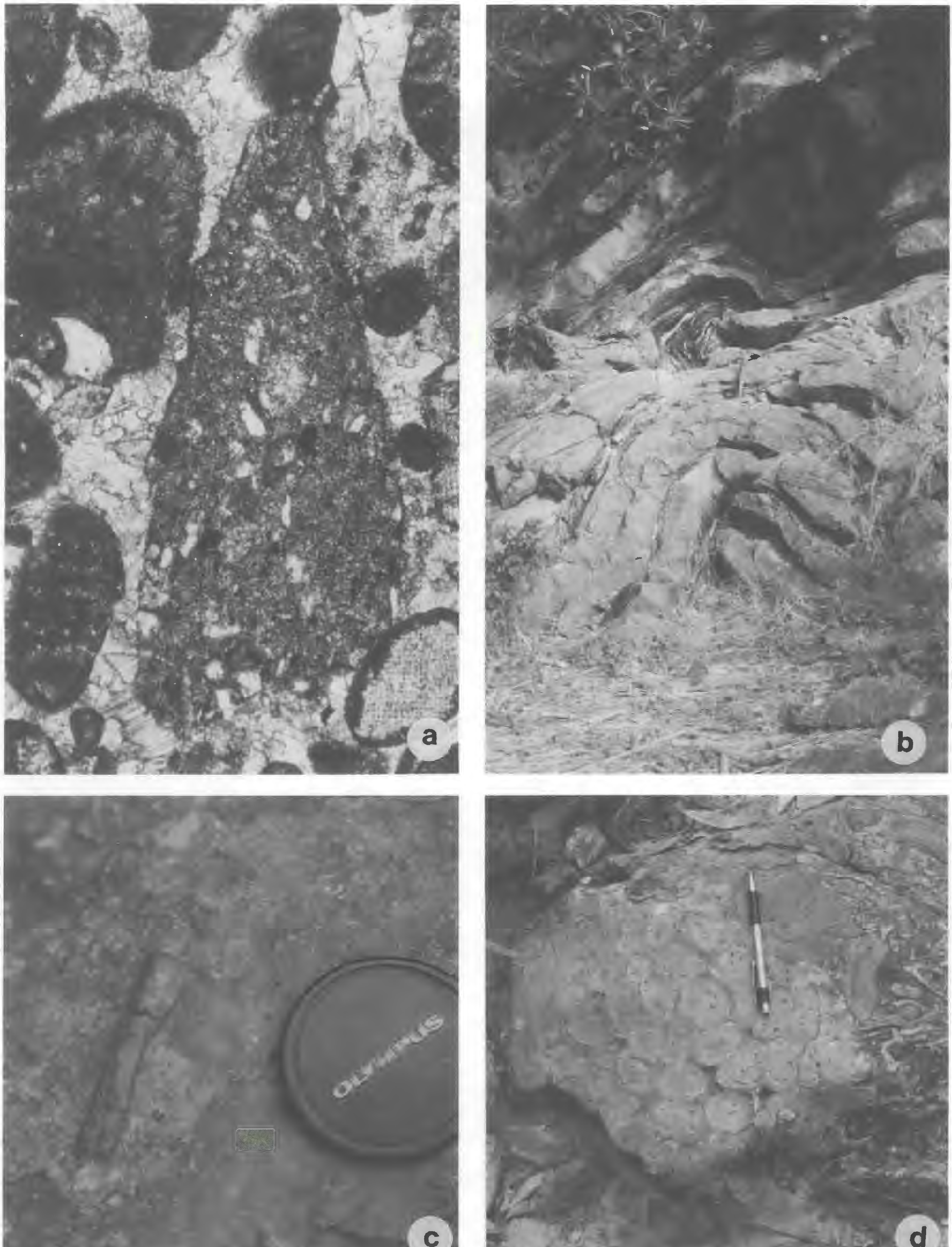


Plate 16. Lomandra Limestone.

calcareous-siliciclastic arenites records a brief incursion of terrigenous material onto the carbonate shelf.

Although no framestones or bindstones (which might represent wave resistant reefal structures) have been recorded from the Lomandra Limestone, a wave resistant rim could explain the source of the rubble. Alternatively, the rubble could have been derived from a seaward dipping biostrome (eg. on a carbonate ramp), the main transport agent being storm-generated currents. Both of these interpretations are consistent with a general trend towards inferred deeper water in the northeast, where crinoidal material becomes more dominant, and the Lomandra Limestone passes into slope deposits of the Burges Formation.

The facies of the Lomandra Limestone are summarised in Table 4.

Storm Hill Sandstone

Description. The Storm Hill Sandstone is a wedge-like unit that divides the Lomandra and Dosey Limestone throughout most of the area south of the Broken River (Figures 12, 25 and 27). The unit becomes considerably thicker towards the southwest. Around Storm Dam it appears to be thickest although because of folding its exact thickness is unknown. It consists of granular to pebbly, feldspathic to quartzose and polymictic conglomerate, and coarse to very coarse-grained sandstone. Trough cross-bedding and horizontal stratification are common. Poorly preserved moulds of tabulate corals (*Cladopora* and *Favosites*), rugose corals, brachiopods, crinoids, bivalves and rare trilobites occur in the Storm Dam area. *Stringocephalus* was reported from the unit in the Storm Dam area by Mawson & Talent (1989) in the 'SD196' section. Subsequent detailed mapping of this area has shown that the unit was probably misidentified, and is probably the Phar Lap Member. On the northern side of Storm Hill, it is clear that the Storm Hill Sandstone unconformably overlies the Judea Formation (Plate 19a, 7858-537391). As the unit is traced to the south, it appears to overlie siliciclastic rocks of the Jack Formation and Shield Creek Formation respectively. The Dosey Limestone is very thin on the northern side of the hill, and is overlain by the Phar Lap Member, which resembles the Storm Hill Sandstone when it is not calcareous. In places therefore, an almost continuous siliciclastic sequence is developed, with the lower four siliciclastic units progressively onlapping each other, and resting unconformably on Judea Formation.

Interpretation. The general position of the Storm Hill Sandstone between two major carbonate shelf deposits, and the presence of marine fossils, indicates that it was probably mainly a lobe of siliciclastic shelf deposits, which wedged-out to the northeast. The coarse-grained sandstones and conglomerates probably represent fan-delta channel deposits along a shoreline, which fed the clastics onto the shelf. The large parts of the Storm Hill Sandstone which contain no fossils and are cross-bedded, may even represent fluvial channel deposits. The angular nature of many of the clasts (Plate 19c), suggests that they have not travelled far. The quartzose nature of the sediments indicates either that the source was quartz-rich (eg. quartz veins in Judea Formation or granitoids and metamorphics of the Lolworth-Ravenswood Province), and/or the labile component was broken down in the high energy conditions of the shallow marine shelf.

To get this major pulse of siliciclastics deposited over what was a relatively pure carbonate shelf required either a major eustatic sea-level lowering, or a major uplift in the hinterland to the southwest. Either way, a major lowering of relative sea-level allowed a great lobe of coarse siliciclastic detritus to be distributed across the shelf. During the preceding highstand, much of the detritus may have been locked up in the adjacent river systems, but with the lowering of base level, it was flushed downstream and out to sea.

The age of this event is poorly controlled. According to Mawson & Talent (1989), the unit is diachronous, beginning at least in the *costatus* Zone, and apparently extending into the *kockelianus* Zone. However, age control within the formation is virtually nonexistent. In the Storm Dam area the thinning or wedging-out of the enveloping carbonate units against a thickening wedge of sandstone leads to an impression of age-equivalence between the Storm Hill Sandstone and the Lomandra and Dosey Limestones although this is not proven. It appears that four relatively similar sandy units (Jack Formation siliciclastics, Shield Creek Formation, Storm Hill Sandstone, and the Phar Lap Member) form almost one continuous sequence, and therefore it is possible that at least the last three units have been confused. An alternative to the interpretation presented by Mawson & Talent (1989), would be that the Storm Hill Sandstone unconformably eroded into the Lomandra Limestone, Bracteata Mudstone, Shield Creek Formation, and eventually Jack Formation. The upper part may be diachronous, with the Dosey Limestone not established in places until the very peak of the transgression at the end of the Eifelian (*kockelianus* Zone).

The apparent wedge-out of both Silurian and Early to Middle Devonian units between the Broken River and Storm Dam, whether by erosion or because of original depositional constraints, suggests that this area may have been the southwestern basin margin during this time. The area was certainly the locus for accumulation of a thick wedge of conglomeratic and sandy sediments derived from the south and west.

Dosey Limestone

Description. The Dosey Limestone (Plate 17) consists of 230 m of bioclastic limestones and calcareous quartzose arenites and mudstones.

The **lower 100 m** interval in the type section (Figure 25) consists of calcarenites, calcirudites, and calcilutites, which are represented by interbedded packstones, wackestones and mudstones. The lower part of the interval is mainly calcirudite, whereas the upper half contains much more calcilutite. Fossils include solitary and tabulate corals, but colonial rugose corals are rare. Crinoids and brachiopods occur throughout. Gastropods occur in the lower part. Lamellar, hemispherical, and globular stromatoporoids occur in places, but most significant is the abundance of the delicate branching stromatoporoid *Amphipora*. *Amphipora* packstones and wackestones (Plate 17a) make up the bulk of this lower interval, and these beds are very similar to those described from the upper half of the Dip Creek Limestone (Law, 1985, 1986a, see Figure 23). They contain a relatively restricted fauna, including broken debris of the branching rugose coral *Dendrostella*.

The **middle 120 m** of the Dosey Limestone is considerably coarser-grained than the lower part, and consists almost entirely of thin to very thick-bedded calcarenites and calcirudites, with lesser siliciclastic mudstones and sandy limestones towards the top. Most of the limestones are packstones and grainstones, although there are also wackestones and lesser limestones. Boundstone occurs in the lower part of the interval (110-120 m). It consists of very coarse bioclastic rubble that has been bound together by lamellar stromatoporoids (Plate 17b). The abundance of *Amphipora* decreases considerably in this lower part although it increases in abundance again up the sequence. Locally, eg. in the Lomandra Creek section, there may be

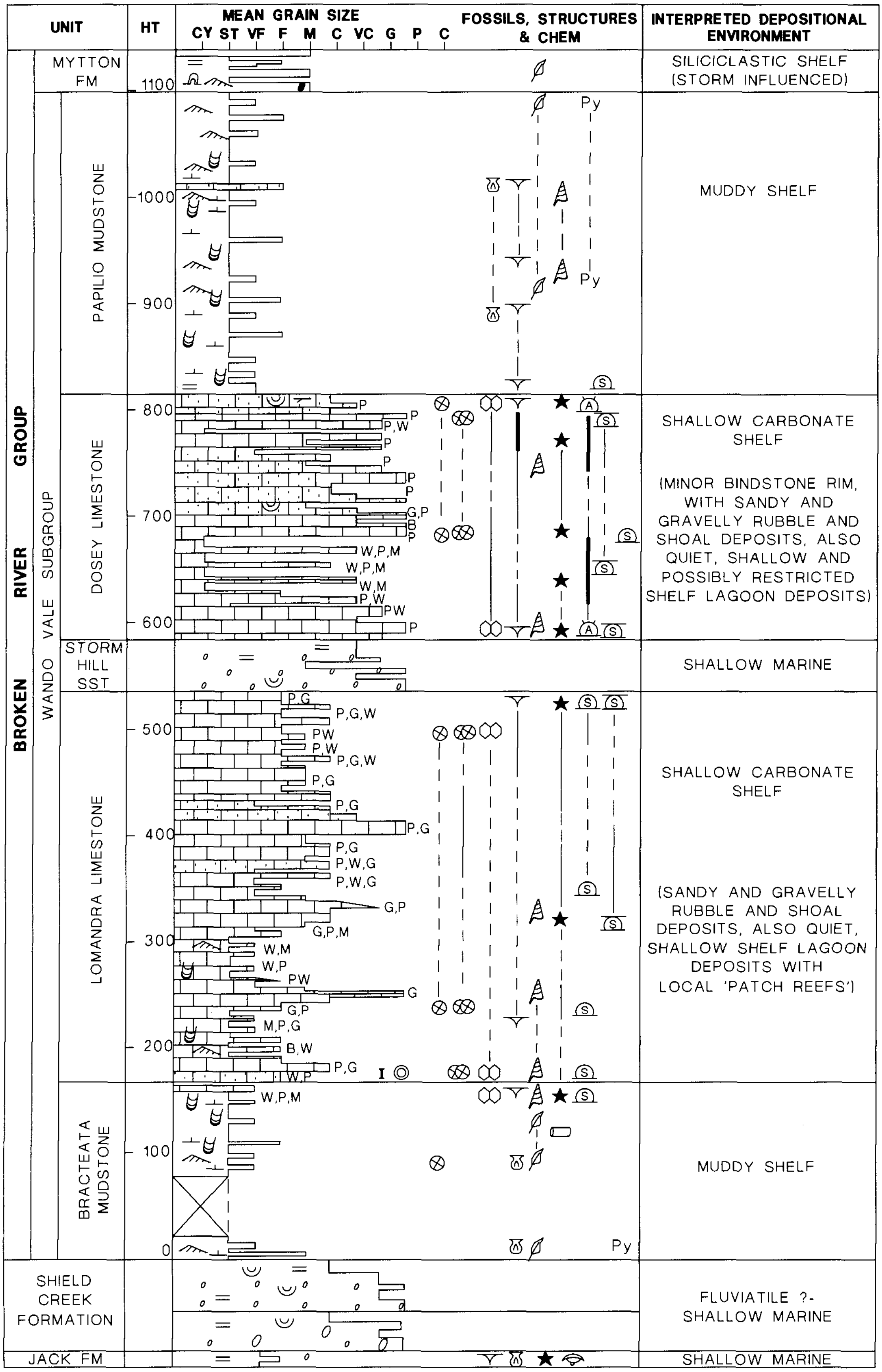


Figure 25. Section through the Wando Vale Subgroup in Lomandra Creek between 7858-609398 (base of the Bracteata Mudstone) and 604415 (top of the Papilio Mudstone), including type and reference sections of the constituent formations. See Figure 14 for reference.

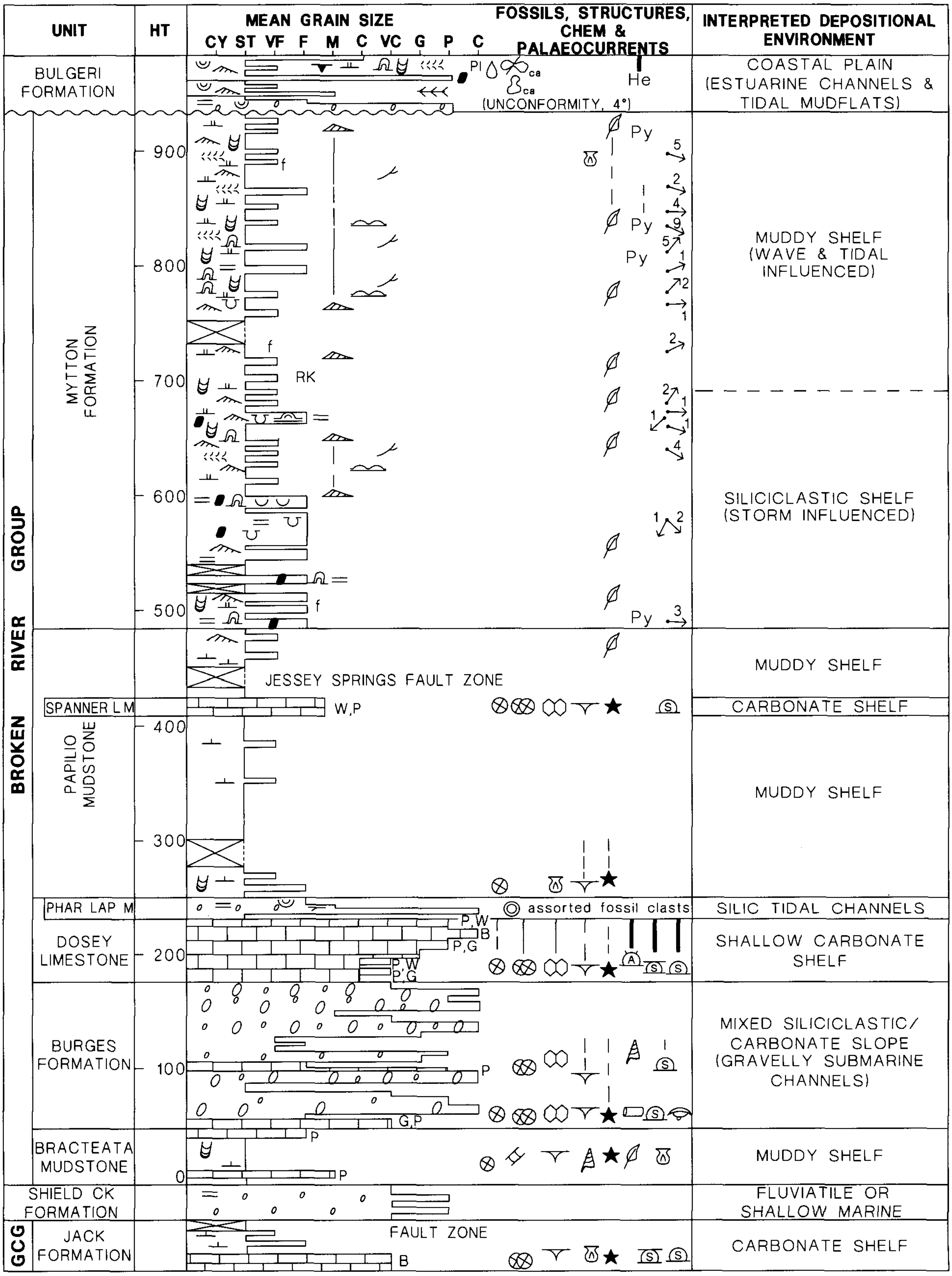


Figure 26. Composite section along the Broken River: 7859-613440 to 609443 through the Jack Formation, Shield Creek Formation, and the Wando Vale Subgroup (including the type section for the Burges Formation); type section for the Mytton Formation between 589449 and 578447. See Figure 14 for reference.

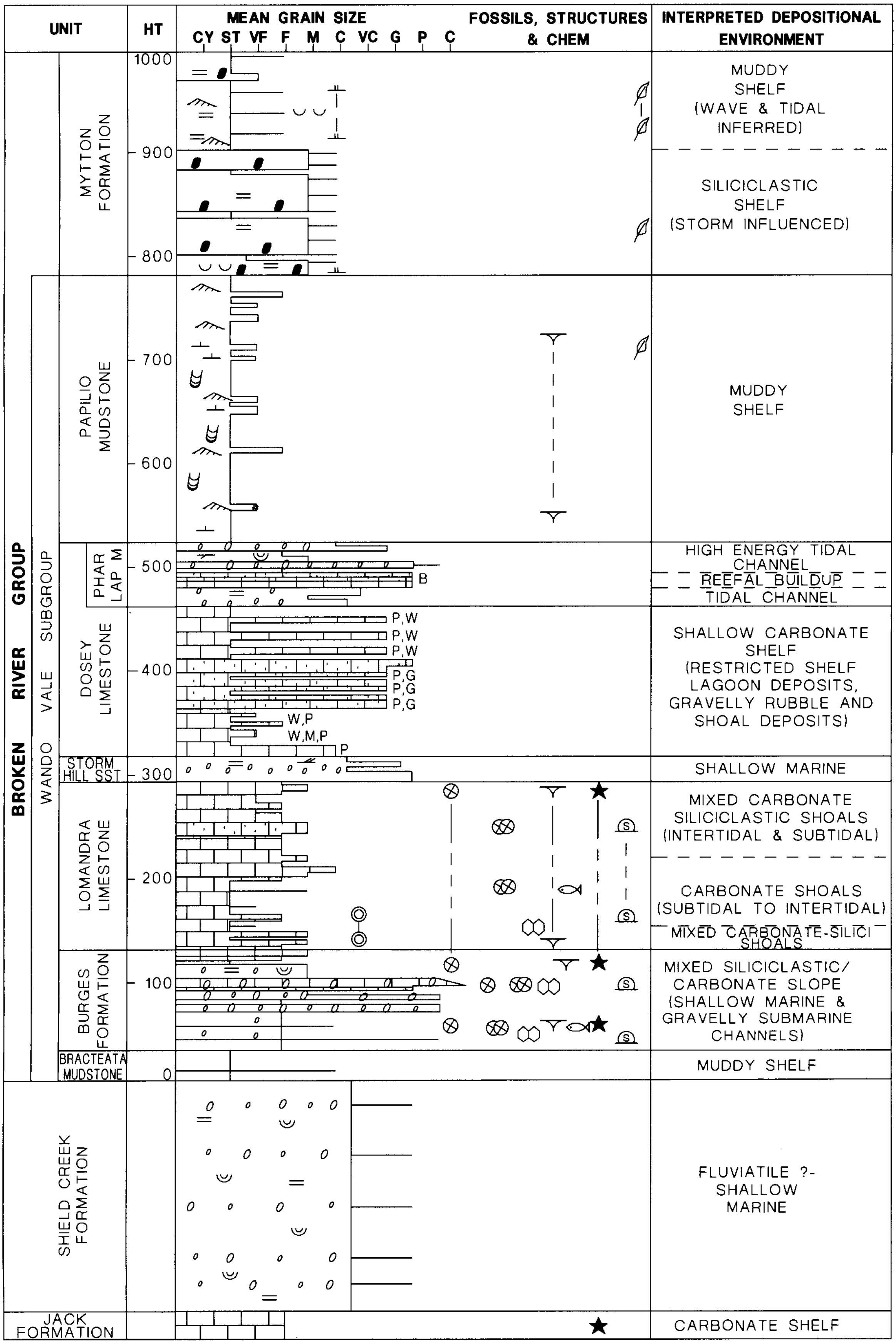


Figure 27. Section through the Wando Vale Subgroup on the northern side of the Dosey Syncline between 7859-604429 (base of the Bracteata Mudstone) and 599416 (base of the Mytton Formation). See Figure 14 for reference.

a notable entry of large terebratulid brachiopods (*Stringocephalus*). These *Stringocephalus* limestones (Plate 17c) are typically graded, from packstones at the base, to wackestones and even mudstones at the top. Most of the brachiopods are disarticulated, and commonly abraded.

The upper 10 m of the Dosey Limestone in the type section consists mainly of cross-bedded, sandy limestone and calcareous sandstone. This sandy unit is regarded as part of the Phar Lap Member, which becomes much thicker to the north (see below). Withnall & others (1988b) considered this sequence as part of the Siliciclastic Shelf Facies Association, and treated it as a distinct facies of the upper Dosey Limestone. Therefore, when Aung (1991), Blake (1990), Humphries (1990) and Jorgensen (1990) completed mapping the upper part of the Dosey Limestone and recognised that this unit was lenticular and deeply channelised, eroding into the top of the Dosey Limestone, it was decided to map the unit as a discrete entity, the Phar Lap Member. Because this 10 m sequence lies within the type section of the Dosey Limestone, the new unit has to be a member of the Dosey Limestone, even though it may be more genetically related to the overlying sequence. To give it separate formation status would require the rest of the Dosey Limestone to be renamed (Staines, 1985). Because the unit is so thin, it has not been shown on the Broken River Special 1:100 000 map (Map 1).

North of the type section, along the Broken River (Figure 26), the Dosey Limestone is considerably thinner, but contains many of the lithofacies found in Lomandra Creek. Boundstone also occurs here and consists of large, amalgamated, lamellar stromatoporoids. The fossils are tightly packed together, with stylolites surrounding nearly all of them, but without any stylo-residuum. *Amphipora* packstones and wackestones occur immediately below the boundstone. *Stringocephalus* is absent in this sequence. Much of the limestone is composed of rubbly material. The limestones also thin dramatically along strike to the southwest becoming interbedded with arenites. In the Storm Dam area, calcirudites composed of abraded bioclastic rubble become particularly common. In this area, the unit is difficult to distinguish from the Phar Lap Member which also consists of calcirudites in its upper part, but overall is sandstone-dominated.

Interpretation. The Dosey Limestone is interpreted as a sequence of carbonate shelf deposits. The *Amphipora*-rich lithofacies has been recorded from Devonian carbonate deposits all over the world, and has always been interpreted as being indicative of low energy, shallow water, and possibly restricted lagoonal or sheltered shelf conditions (eg. Krebs, 1968; Dolphin & Klovan, 1970; Jamieson, 1971; Jansa & Fischbuch, 1974; Burchette, 1981). The lower part of the Dosey Limestone in the type section is therefore interpreted as mainly quiet, possibly restricted shelf lagoon or sheltered shelf deposits, but the coarser packstones may represent banks, shoals, or storm deposits. The boundstone and bioclastic rubble is interpreted as part of a wave resistant rim. However, this lithofacies needs to be mapped in more detail to ascertain its lateral extent and relationship with other lithofacies. The upper *Amphipora* and *Stringocephalus* wackestone and packstone lithofacies may represent a return to shelf lagoon or sheltered shelf conditions. Many of the graded shelly beds may represent storm deposits. Like the Lomandra Limestone, the offshore trend was dominantly towards the northeast. In the Storm Dam area, where the unit wedges out and is composed of rubbly bioclastic material, it may represent storm deposits lying along the margin between the carbonate shelf and the sand-dominated siliciclastic shelf.

The facies of the Dosey Limestone are summarised in Table 4.

Phar Lap Member

Description. The Phar Lap Member is usually a thin unit of calcareous sandstone and sandy calcirudite at the top of the Dosey Limestone and the Burges Formation. It has been mapped from Storm Hill in the southwest (7858-564395) to the northeastern hinge of the Dosey Syncline (7859-636441). It has also been mapped from 7859-570433 in the northwest to 593439 near the 'Phar Lap' gold diggings, then intermittently northeast. In the Dosey Creek-Page Creek area, the Phar Lap Member thickens.

The type section of the Phar Lap Member is 112 m thick (Figure 28). The lower 71 m consists of 63 m of bidirectional trough cross-bedded calcareous sandstone (Plate 17d), overlain by 2 m of granule to pebble conglomerate, and 6 m of calcirudite. The sandstone is generally feldspathic, but some lithic sandstone occurs towards the top of this interval. The sandstone is fine to coarse-grained, poorly to moderately sorted, and contains clasts of limestone (Plate 17b). The granule to pebble conglomerate is composed of well-rounded metamorphic clasts, many of which possess a carbonate coating. The

PLATE 17:

a. ***Amphipora* packstone with *Stringocephalus* shells, in a shallow, open-marine lagoon deposit. Carbonate Shelf Facies Association, Lithofacies C.3, *Amphipora* pelmicrite. Type section of the Dosey Limestone, 205 m above the base.**

b. Boundstone with lamellar stromatoporoids encrusting bioclastic rubble, in a possible biostromal deposit. Carbonate Shelf Facies Association, Lithofacies C.6, stromatoporoid-coral biosparrudite. Type section of the Dosey Limestone, 110 m above the base.

c. ***Stringocephalus* packstone, in a storm-deposited shell bank within a restricted lagoon. Carbonate Shelf Facies Association, Lithofacies C.11, *Stringocephalus* biomicrudite. Type section of the Dosey Limestone, 225 m above the base.**

d. Trough cross-bedded calcareous sandstone in a tidal channel deposit. Mixed Siliciclastic-Carbonate Shelf Facies Association, Lithofacies T.5, calcareous sandstone. Type section of the Phar Lap Member in the interval 86 m to 126.5 m.

e. Conglomerate with rounded limestone clasts and quartz pebbles interbedded with calcareous sandstone in a tidal channel deposit. Note bi-directional, trough cross-bedding. Mixed Siliciclastic-Carbonate Shelf Facies Association, Lithofacies T.6, calcareous coarse-grained sandstone/conglomerate. Phar Lap Member. Locality as for (d).

f. Limestone conglomerate with feldspathic and quartzose sandstone matrix in a tidal channel deposit. Blocks of limestone are from the underlying Dosey Limestone. Mixed Siliciclastic-Carbonate Facies Association, Lithofacies T.6, calcareous coarse-grained sandstone/conglomerate. Phar Lap Member. 7859-597418.

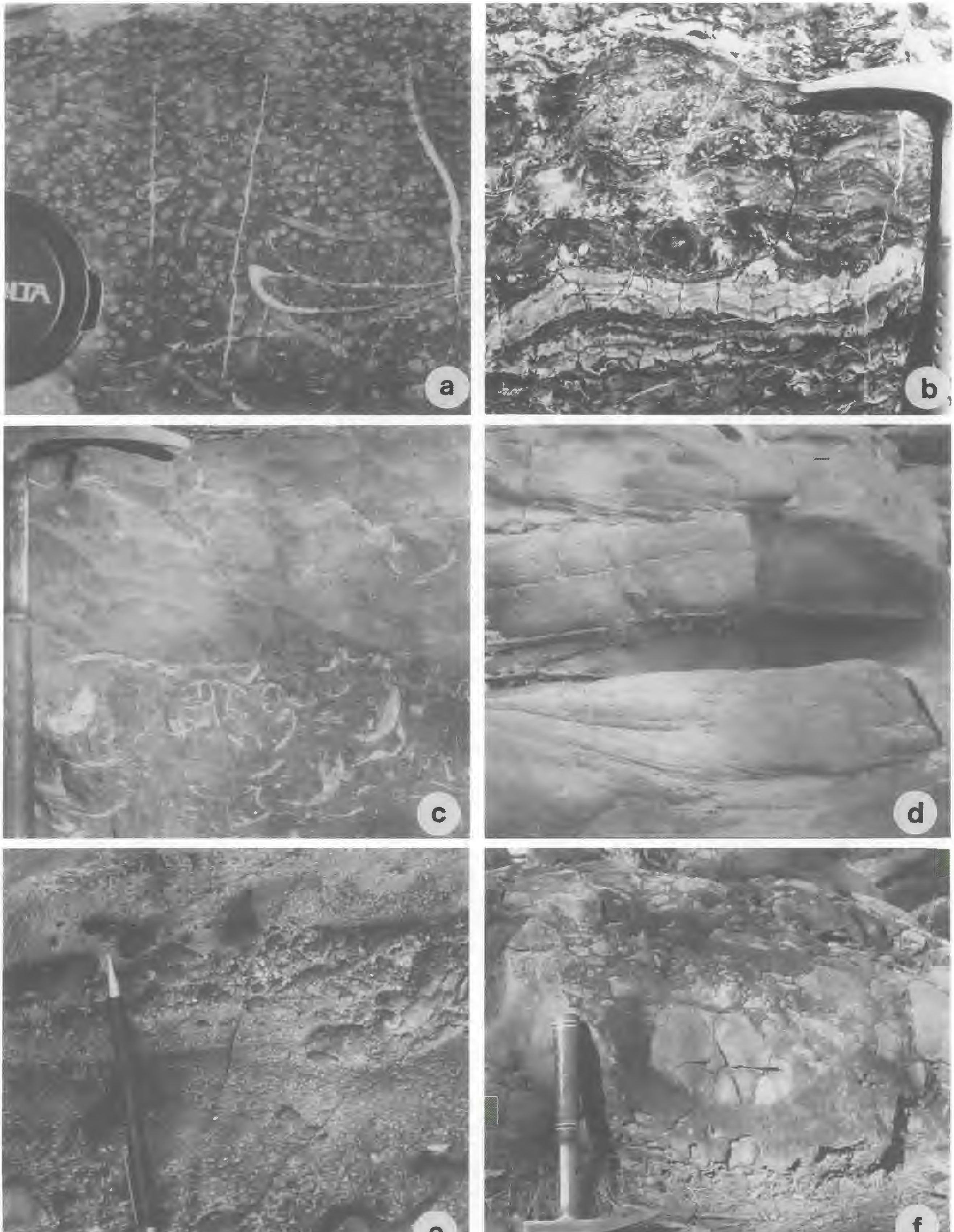


Plate 17. Dosey Limestone and Phar Lap Member.

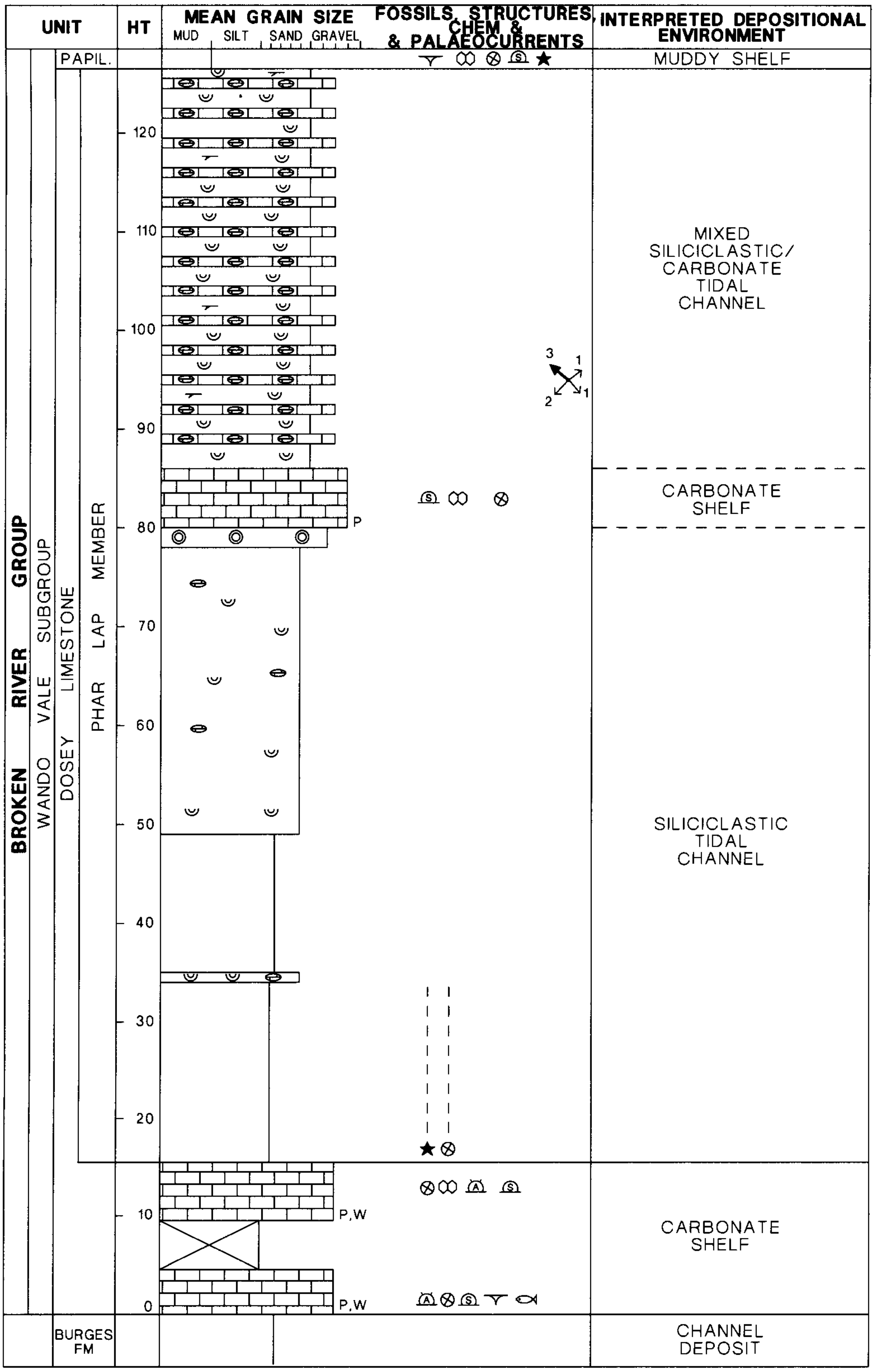


Figure 28. Type section for the Phar Lap Member between 7859-593437 and 591438. See Figure 14 for reference.

calcirudite contains large stromatoporoids as well as rugose and tabulate corals.

The upper 41 m of the type section consists of interbedded calcareous sandstone and sandy calcirudite. The sandstone displays abundant trough cross-bedding (Plate 17d) which is bidirectional in nature, and rare low angle planar cross bedding. It is very coarse grained, and well sorted, the sand grains being generally well rounded. The sandstone is usually feldspathic to feldspatholithic in the type section and the quartz and lithic grains indicate a dominantly metamorphic provenance. Elsewhere clean quartzose sandstone is also present. The sandy calcirudite contains granule to cobble-sized, generally well-rounded clasts of limestone (Plate 17f) and sparse granules of quartz, in a coarse-grained sandstone matrix. The limestone clasts are fragments of biomicrite, biosparite, corals, stromatoporoids, and crinoid stems. The sandy calcirudite is usually less abundant than the calcareous sandstones, but is still a major constituent of the Phar Lap Member. Sparse lenses of calcirudite, and rare calcareous polymictic conglomerate occur in places.

The Phar Lap Member lies at the top of both the Burges Formation and the Dosey Limestone. As explained above, it was originally included in the type section of the Dosey Limestone and has been given member status in this formation. However it is also a member of the Burges Formation. This is allowable under the Australian Stratigraphic Code (Staines, 1985). The base of the Phar Lap Member appears to be erosive, because some of the clasts in the sandy calcirudites are reworked corals from the underlying rocks, particularly the Dosey Limestone (Aung, 1991). The Phar Lap Member is overlain conformably by the Papilio Mudstone.

Interpretation. The Phar Lap Member is a mixed siliciclastic-carbonate tidal channel deposit. The well rounded nature of the limestone clasts, the generally moderate to good sorting of the sandstones, and the presence of carbonate coats on the clasts in the granule to pebble conglomerate indicates that the Phar Lap Member was deposited in a high energy, warm, shallow marine environment. The palaeocurrents (Figure 19) clearly indicate the tidal nature of the environment. Such conditions could have occurred in tidal channels which cut through the underlying carbonate shelf. The change from the quiet lagoonal environment of the Dosey Limestone to the high energy environment of the Phar Lap Member is thought to reflect a period of regression. A subsequent transgression resulted in the deposition of the overlying Papilio Mudstone.

Fossils are not usually abundant in the Phar Lap Member. Sparse crinoids and solitary rugose corals occur in the basal 20 m of the type section. The sporadic calcirudite lenses contain a rich fauna of hemispherical and lamellar stromatoporoids, solitary and colonial rugose corals, and tabulate corals. Gastropods (*Labrocuspis* sp.), indicative of shallow water environments, are found in the Spanner Hill area, where the Phar Lap Member occurs as only a thin unit. Reworked corals, stromatoporoids, and crinoids, most likely from the Dosey Limestone, occur in the sandy calcirudite.

The age of the Phar Lap Member can only be determined by inference from the enveloping units, and is therefore early Givetian (*ensensis* to lower *varcus* Zones). The precise lengths of the hiatus under the unit cannot be determined from the existing conodont data. The unit probably correlates with the upper part of the sandy limestone sequence in the middle of the 'CCD' section of Mawson & Talent (1989).

Papilio Mudstone

Description. The Papilio Mudstone is the uppermost unit in the Wando Vale Subgroup. The unit is generally dominated by calcareous mudstone, with lesser calcareous sandstone and nodular limestone (Plate 18a,b).

In the Broken River area and to the south, the Papilio Mudstone conformably overlies the Phar Lap Member. To the north of Gorge Creek the Papilio Mudstone conformably overlies the Burges Formation. Thin, partly calcareous mudstone intervals overlying the Lockup Well and Dip Creek Limestones are also equated with the Papilio Mudstone, but are mostly too thin to map out. The unit is conformably overlain by the Mytton Formation.

In the type section near Storm Dam (Figure 29; Lang & others, 1989a), the Papilio Mudstone is 200 m thick and consists of calcareous mudstone with minor fine grained calcareous sandstone and nodular limestone (packstone and wackestone). In the Phar Lap area, the Papilio Mudstone is 239 m thick, and in the Spanner Hill area it is 324 m thick. Although the Papilio Mudstone is dominated by calcareous mudstones, the unit becomes more sandy to the southwest; west of Pages Dam it contains almost 40 percent of fine grained arenite (Withnall & others, 1988b). A major limestone member trending southwest from Pages Creek to Spanner Hill, and south of the Broken River (between 7859-580436 and 591449), is assigned to the Spanner Limestone Member (see below).

The Papilio Mudstone contains a rich fossil fauna, which includes common to locally abundant brachiopods, crinoids, solitary and colonial rugose corals, tabulate corals, algae, stromatoporoids, sparse bivalves, *Amphipora*, gastropods, plant fragments, colonial rugose corals, and rare trilobites and nautiloids.

In the Phar Lap and the Page Creek area, the Papilio Mudstone can be divided into three units. A lower muddy unit, a middle limey unit (the Spanner Limestone Member), and an upper muddy unit. The lower unit is dominated by mudstones, but a thin sequence of interbedded limestone and mudstone occurs in the lower part of this unit in places. The unit is moderately fossiliferous, mostly towards the base of the sequence. Fossils are particularly abundant just above the thin interbedded limestone and mudstone sequence, where it is present. The fauna contains solitary rugose corals, tabulate corals, lesser crinoids, brachiopods, stromatoporoids, and rare plant fragments and colonial rugose corals. Crinoid calices are relatively common.

The middle unit, the Spanner Limestone Member, consists of fossiliferous wackestones and packstones, and lesser calcareous sandstone. This unit is the most fossiliferous part of the Papilio Mudstone, and its fauna contains stromatoporoids, tabulate corals, lesser solitary and colonial rugose corals, brachiopods, gastropods, *Amphipora*, crinoids, and rare nautiloids and fish fragments (for more detail see below). The rugose coral fauna of this interval is equivalent to the *Temnophyllum* fauna, which is the uppermost fauna of the Chinaman Creek Limestone (Wyatt & Jell, 1967). Therefore, at least the lower two thirds of the Papilio Mudstone is equivalent to the upper part of the Chinaman Creek Limestone.

The upper unit is dominated by mudstones, with only rare limestone lenses. It is only sparsely fossiliferous, containing plant fragments, rare brachiopods and small solitary rugose corals.

Interpretation. The Papilio Mudstone is interpreted to have been deposited on a *muddy shelf* that contained a *carbonate shelf* (resulting in the deposition of the Spanner Limestone Member - Withnall & others, 1988b), and a few minor carbonate banks (Mawson & Talent, 1989). The rich fossil fauna indicates that the shelf experienced open marine conditions, and the abundance of articulated brachiopods as well as the occurrence of whole crinoid calyces indicates that the shelf was protected from current action. Towards the top of the unit, an increase in the abundance of plant fragments, may reflect the beginning of the regression that resulted in the deposition of the Mytton Formation.

Spanner Limestone Member

Description. The Spanner Limestone Member consists dominantly of bioclastic calcarenite and calcirudite wackestone and packstone, lesser calcarenite grainstone, calcareous quartzose arenites, and mudstones.

The nominated type section (Lang & others, 1989a) lies in the Spanner Hill area. However, detailed work by Blake (1990) showed that the section was faulted. Blake (1990) therefore nominated a nearby reference section based at 7858-510_5-376_{25} and this report mainly relates to this section (Figure 30). The Spanner Limestone Member can be divided into an upper and a lower sequence.

The lower 90 m is dominantly packstones and wackestones (calcarenite and calcirudite), sparse calcareous sandstone, and rare calcarenite grainstone. The packstones and wackestones are dominated by stromatoporoids, tabulate corals, and lesser rugose corals, in a micrite matrix. At the base of the reference section, stromatoporoids are dominantly hemispherical, but up-sequence the proportion of lamellar to hemispherical stromatoporoids increases. Some of the packstone and wackestone beds contain 15 to 20 percent quartz sand. In the reference section a 7 m thick unit of calcareous sandstone occurs 22 m above the base. The sandstone is laterally extensive, and can be traced to the Phar Lap area where it increases to 15 m in thickness, and lies at the base of the sequence (Figure 32), due to lensing out of the lowermost limestone beds. Since the lower sequence in the Phar Lap area is only 22 m thick, this sandstone becomes the dominant lithology. Ooid grainstone occurs towards the top of the lower unit in the reference section (Figure 30), whereas intramicrite occurs in the Storm Hill area.

The upper 47 m of the Spanner Limestone Member in the reference section is composed of calcirudite packstone dominated by lamellar stromatoporoids in a micrite matrix (Plate 18c). The unit also contains rare branching tabulate corals, and solitary rugose corals, and very rare colonial rugose corals. This sequence contains the greatest proportion of lamellar to hemispherical stromatoporoids in the member.

The Spanner Limestone Member is a wedge shaped unit, being thickest near Spanner Hill, and thinning northward. The proportion of terrigenous sediment in the Spanner Limestone Member increases northward, and in the Phar Lap area, the member contains up to 50 percent terrigenous sandstone and mudstone. Farther north it is recognisable only as a more calcareous interval of the Papilio Mudstone. Eventually, the unit becomes indistinguishable from the Papilio Mudstone. A possible lithological correlative occurs in the upper part of the Dip Creek Limestone in the southern limb of the Atherton Creek Anticlinorium (Figure 23).

The Spanner Limestone Member contains a rich fauna, dominantly of stromatoporoids and tabulate corals, lesser rugose corals, *Amphipora*, crinoids, brachiopods (including *Stringocephalus*), sponges and gastropods, and rare nautiloids, fish and *Receptaculites*. Algae (*Girvanella* and dasycladaceans), ostracodes, bryozoans and calcispheres have also been identified in thin sections. The rugose coral fauna is similar to the *Temnophyllum* fauna which is the uppermost fauna of the Chinaman Creek Limestone (Wyatt & Jell, 1967).

Interpretation. Fossils such as brachiopods, crinoids, and nautiloids indicate that the Spanner Limestone Member was deposited in open marine conditions with normal salinity (Wilson & Jordan, 1983). The presence of marine calcareous algae indicates water depths within the photic zone (d m). The dasycladacean algae indicate very shallow water because they are commonly found in water depths less than 5 m (Wilson & Jordan, 1983). Conodonts from the Spanner Limestone Member also indicate a shallow water environment (Withnall & others, 1988b). The abundance of micrite in the matrix of the wackestones and packstones, and the presence of ostracodes and calcispheres, indicate that the Spanner Limestone Member was deposited in a low energy to sheltered marine environment.

The Spanner Limestone Member is interpreted as a shoaling upwards carbonate sequence for two reasons. Firstly, ooids which commonly form in shoaling environments occur in a thin bed towards the top of the unit in the Spanner Hill area. Secondly, the proportion of lamellar stromatoporoids to hemispherical stromatoporoids increases from the base to the top of the sequence, probably indicating a reduction in the height of the water column above the growing environment. This shoaling upwards sequence is probably the result of the limestone building upwards to sea level during the highstand. The sandy packstone and wackestone units, and the calcareous sandstone bed possibly reflect small-scale lowering of relative sea-level, which resulted in a more basinward distribution of terrigenous sand.

The source of the sand in the Spanner Limestone Member was probably north of the Spanner Hill area because the calcareous sandstone bed thickens northward.The conodont faunas (Mawson & Talent, 1989), and coral faunas (Blake, 1990) indicate an early to middle Givetian age for

PLATE 18:

a. Thin-bedded mudstone and fine-grained arenite. Muddy Shelf Facies Association, Lithofacies M.1, mudstone and M.2, very fine quartzose arenite. Papilio Mudstone. Dosey Creek.

b. Nodular limestone (mudstone to wackestone), with an intensely bioturbated calcareous muddy matrix. Muddy Shelf Facies Association, Lithofacies M.8, nodular limestone. Spanner Limestone Member, Papilio Mudstone. Broken River at 7859-591449.

c. Fossilferous wackestone to packstone containing thin, delicate plate-like and globular stromatoporoids, brachiopods, and branching tabulate corals. Muddy Shelf Facies Association, Lithofacies M.4, coral-stromatoporoid-brachiopod biomicrite. Spanner Limestone Member, Papilio Mudstone. Same locality as (b).

d. Laminated and wavy bedded reddish-grey calcilutite. In places this limestone contains desiccation cracks, calcilutite rip-up-clasts, intense bioturbation, rare small disarticulated bivalve shells, and delicate algal-laminate structures. Mixed Siliciclastic-Carbonate Tidal Zone Facies Association, Lithofacies T.1, laminated algal micrite. Undifferentiated Wando Vale Subgroup. 7 km northeast of 'Gregory Springs' at 7758-310240.

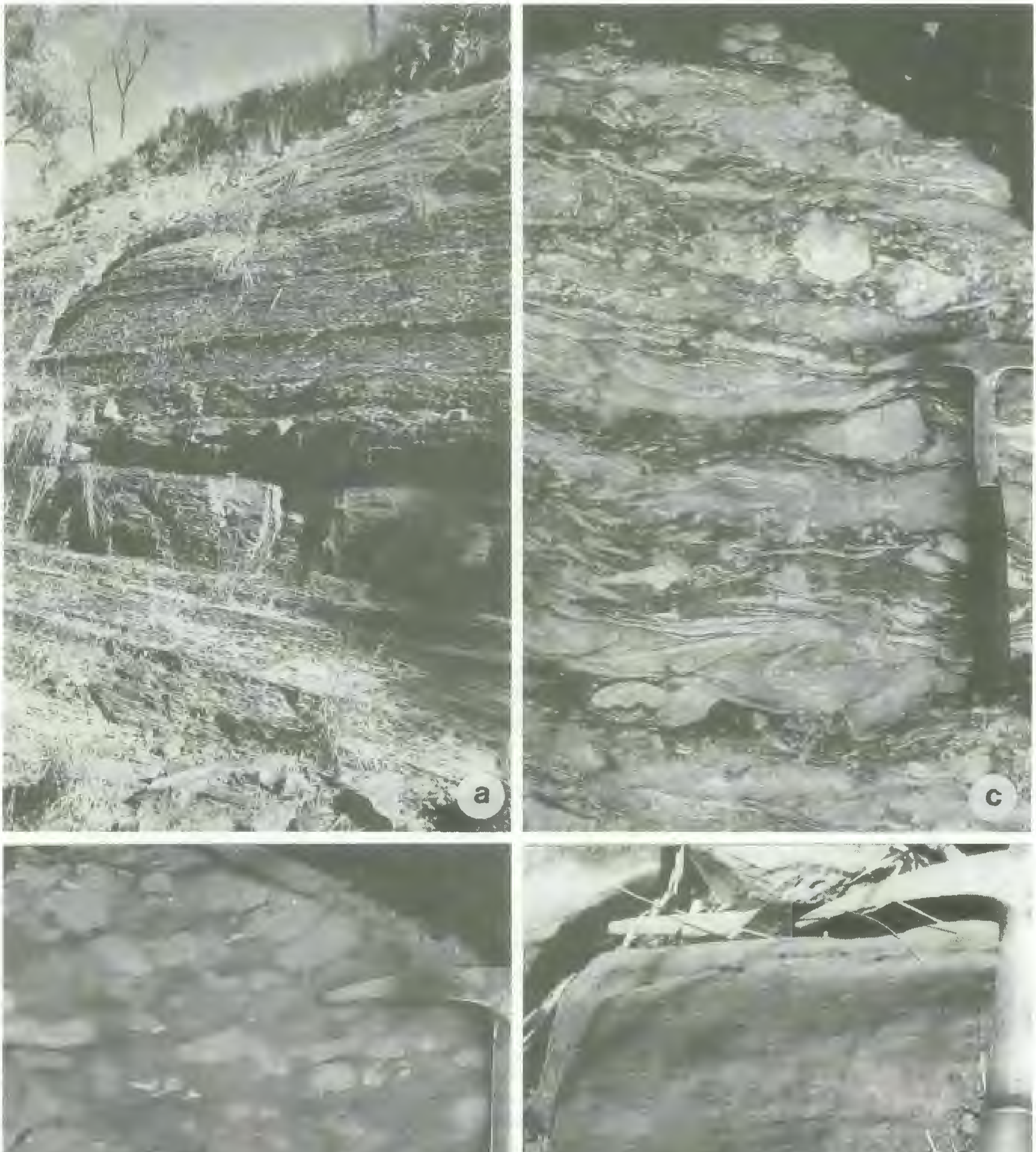


Plate 18. Papilio Mudstone, Spanner Limestone Member and undifferentiated Wando Vale Subgroup.

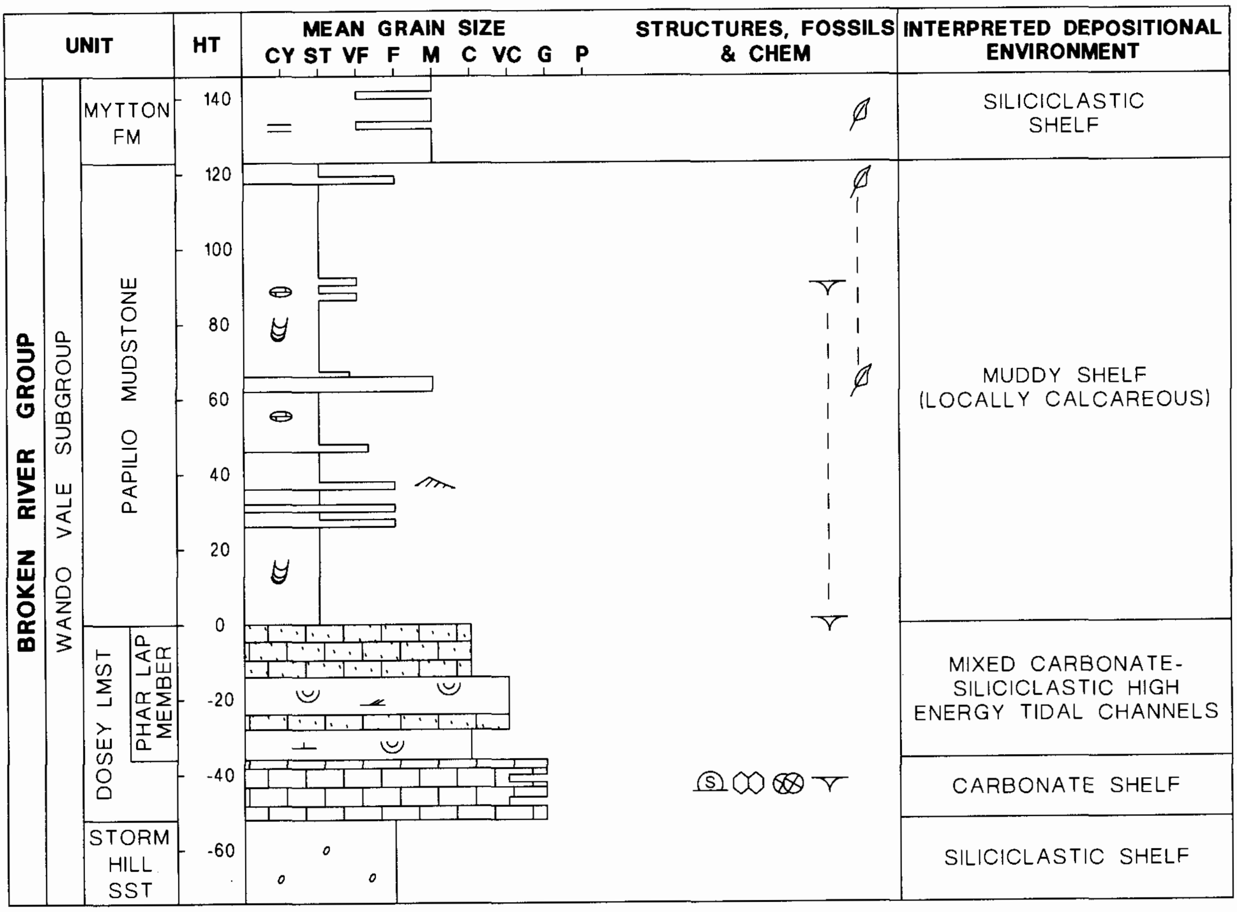


Figure 29. Type section for the Papilio Mudstone in tributary of Bracteata Creek between 7858-574403 and 575402. See Figure 14 for reference.

PLATE 19:

a. **Unconformity between quartzose sandstone and conglomerate of the Storm Hill Sandstone (SHS) and thin-bedded fine-grained quartzose arenite of the Judea Formation (JF). Siliciclastic Shelf Facies Association, Lithofacies SS.2, quartz arenite and conglomerate. 7858-536391, 2 km NW of Storm Dam.**

b. **Low-angle planar cross-stratified, well-sorted, medium to coarse-grained lithofeldspathic sandstone, deposited on a high-energy siliciclastic shoreline. Siliciclastic Shoreline Facies Association, Lithofacies SS.1, well-sorted arenite. Undifferentiated Wando Vale Subgroup. 7858-668365, 1.5 km NE of Top Craigie Bore.**

c. **Photomicrograph X15 (plane polarised light) of angular to subrounded fine-grained to pebbly quartz grains in a ferruginous matrix, deposited in a shallow, open-marine siliciclastic shelf. Siliciclastic Shelf Facies Association, Lithofacies SS.2, quartz arenite and conglomerate. Unnamed sandstone lens in Lomandra Limestone overlying a possible sequence boundary. Rock type also typical of the Storm Hill Sandstone. UQ47531. 7858-590393 in Dosey Creek.**

d. **Interbedded sandstone and quartz-pebble conglomerate in a gravelly submarine channel deposit. Mixed Siliciclastic-Carbonate Slope Facies Association, Lithofacies SL.1, polymictic conglomerate-calcirudite-arenite facies. Burges Formation. 7859-604427 in Dosey Creek, underlying the Lomandra Limestone.**

e. **Polymictic conglomerate, containing clasts possibly derived from the Craigie Tonalite and/or Netherwood Tonalite and Donaldsons Well Volcanic Member, in a gravelly submarine channel deposit. Mixed Siliciclastic-Carbonate Slope Facies Association, Lithofacies SL.1, polymictic conglomerate-calcirudite-arenite facies. Burges Formation. Near 'Fish Hill'.**

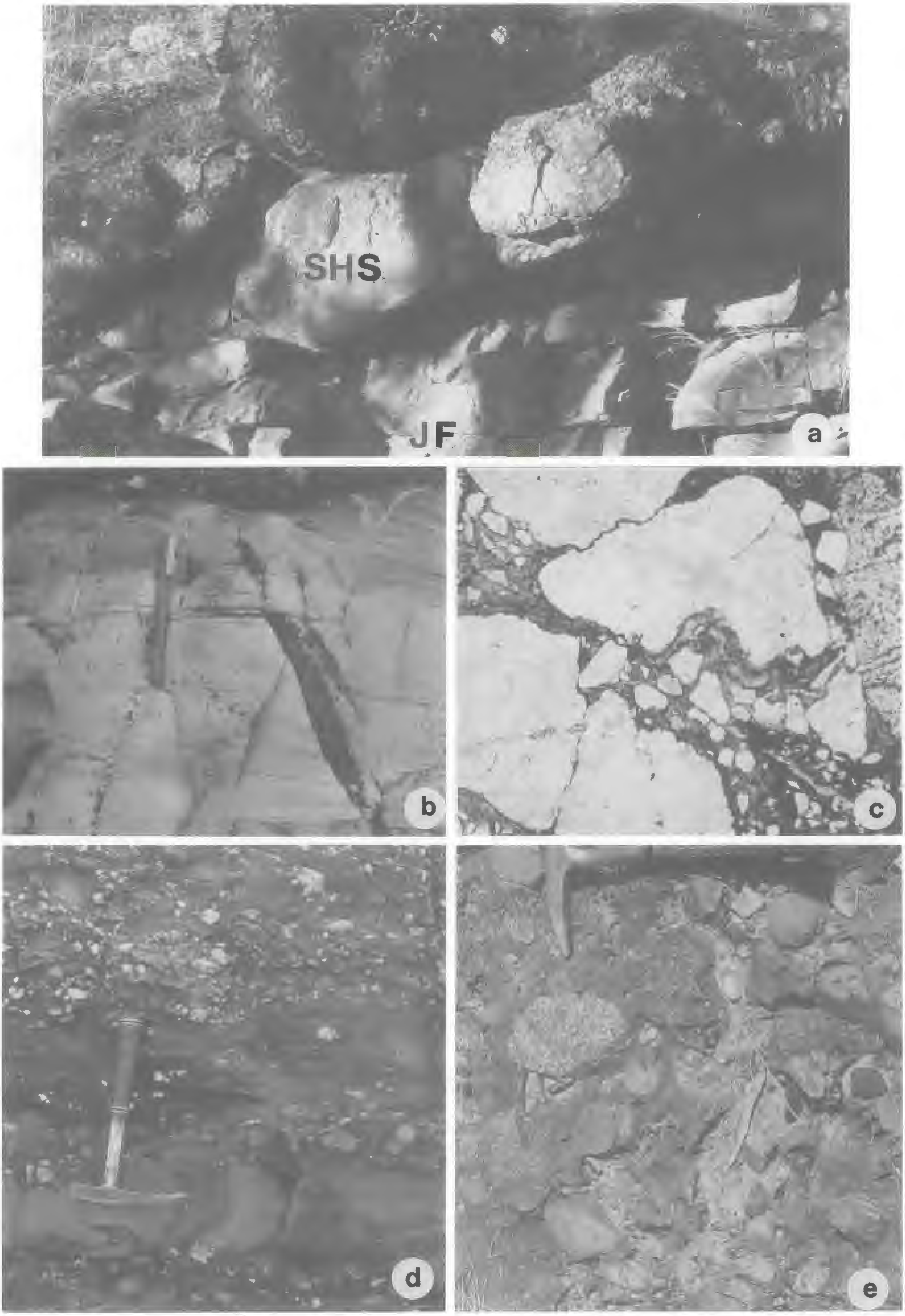


Plate 19. Arenites and conglomerates in the Wando Vale Subgroup.

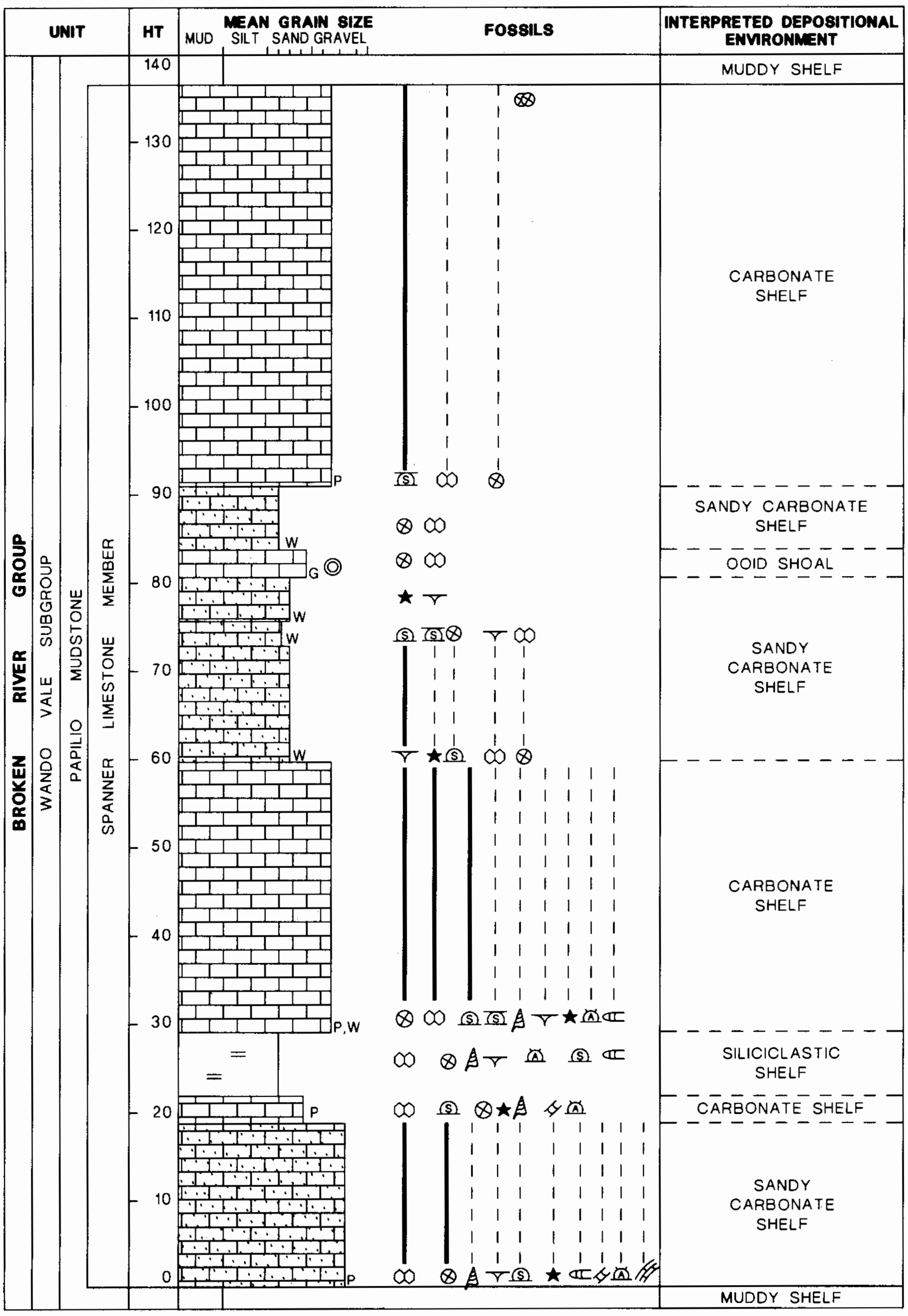


Figure 30. Type section for the Spanner Limestone Member of the Papilio Mudstone, west of Spanner Hill between 7858-513369 and 513366. See Figure 14 for reference.

the Spanner Limestone Member. The Member was probably deposited during the highstand that followed the peak of the Papilio Mudstone transgression that began in the latest Eifelian or early Givetian. The calcareous sandstone unit at the base of the Member appears to be a particularly important small-scale event, and may be equivalent to the sandstone interval that occurs towards the top of the Chinaman Creek Limestone. This may indicate that the distribution of terrigenous sand was widespread, reflecting an episode of lowering relative sea-level.

THE BURGES INTER-PLATFORM

Burges Formation

Description. Withnall & others (1988b), and Aung (1991) recognised four lithofacies within the formation (excluding the Phar Lap Member):

(a) polymictic conglomerate-calcirudite-arenite lithofacies;
(b) thinly interbedded mudstone-limestone-arenite lithofacies;
(c) limestone lithofacies; and
(d) massive mudstone-minor arenite lithofacies.

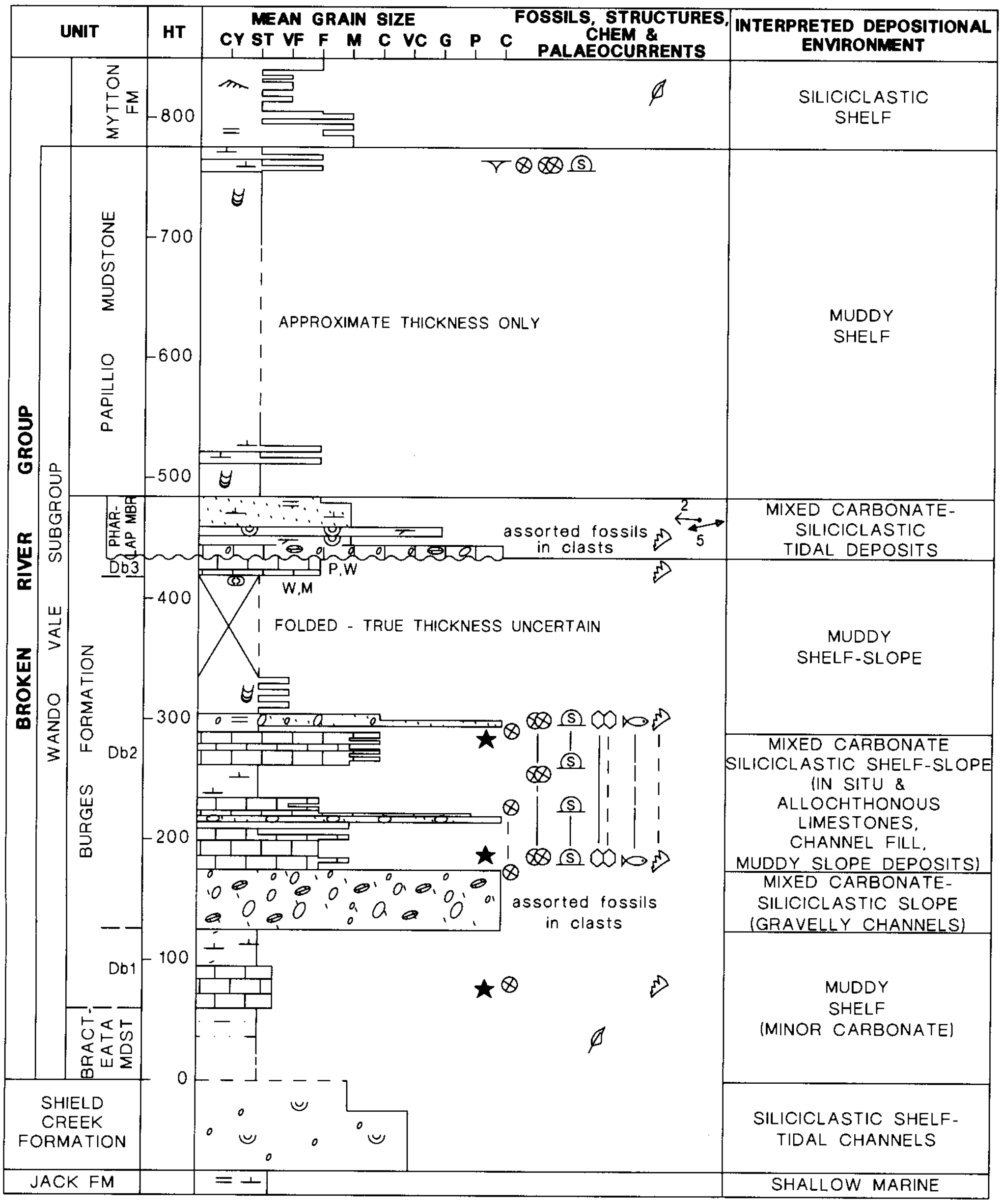


Figure 31. Composite section through the Wando Vale Subgroup: lower part is from the base of the Bracteata Mudstone at 7859-680485 to the top of an unnamed limestone lens in the Burges Formation at 'Fish Hill' - 677487 (300 m), and then to 664488 (435 m) at the top of another unnamed limestone lens; the upper part is from 636463 (435 m) to the top of Phar Lap Member at 635464 (480 m) and then to the base of Mytton Formation at 630466. See Figure 14 for reference.

(a) Polymictic conglomerate-calcirudite-arenite lithofacies. This lithofacies is interbedded with, and locally erodes the other lithofacies of the Mixed Siliciclastic/Carbonate Facies Association. Most of the Burges Formation in the type section (Figure 26) is composed of this lithofacies. Typically it forms thick to very thick beds of polymictic, pebbly and cobbly conglomerate (Plate 19d,e), but in places locally-derived limestone clasts become dominant, forming the calcirudites (Plate 20a). These beds are crudely stratified, locally cross-bedded, and contain both normal and reverse grading in places. Weak imbrication is developed locally. A few palaeocurrent directions collected from cross-bedding indicate an easterly current direction, with minor northerly and southerly components.

Most conglomerates and calcirudites are clast supported, the matrix being sandy to granular, and usually calcareous. The terrigenous clasts are mainly well-rounded, and are composed mainly of greenish mafic volcanics, quartz, foliated granodiorite, and metasediments (Plate 19d, e). Most of these clasts were derived from the Judea Formation (specifically the Donaldsons Well Volcanic Member) and the Lolworth-Ravenswood Block to the south and southwest. Limestone clasts contain fossils (eg. *Phillipsastrea*) commonly found in the adjacent Lomandra and lower Jessey Springs Limestones. Calcareous lithic arenite is interbedded with the conglomerates in places. It is commonly poorly sorted, and grades into sandy limestone. Individual beds of this lithofacies range from laterally extensive to restricted, and locally erode into the limestone lithofacies. North of 7859-649456 on the Broken River, this conglomerate lithofacies can be observed passing laterally into the Lomandra Limestone. In the northern limb of the Dosey Syncline, conglomerates and calcirudites interbedded with arenites underlie a much thinner limestone sequence (Figure 27).

This lithofacies is interpreted as gravelly submarine channel deposits. The channels presumably cut through

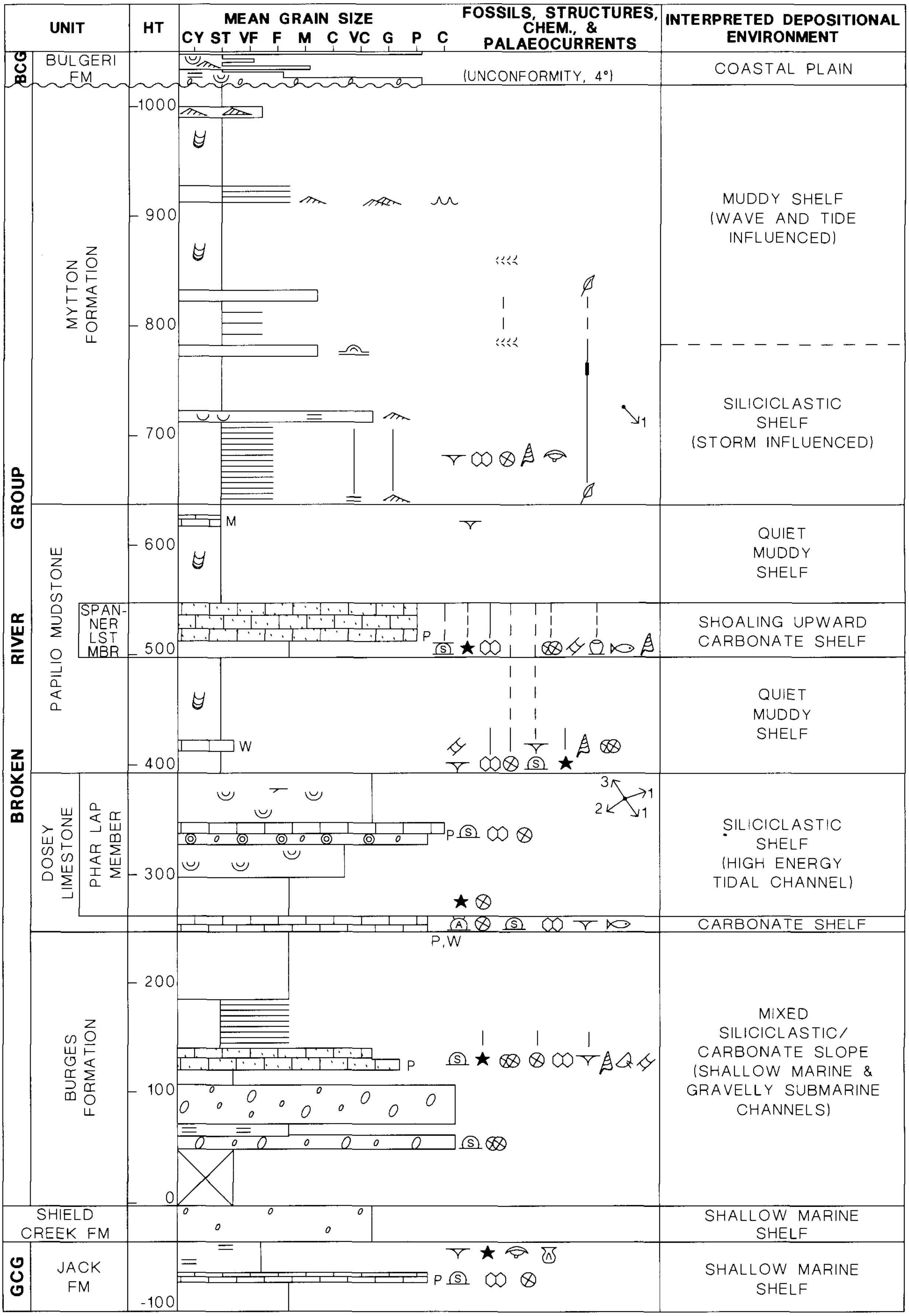


Figure 32. Composite section through the Wando Vale Subgroup in the Phar Lap area: through the Jack Formation and Shield Creek Formation from 7859-584429 to 583429; the base of the Burges Formation to the base of the Spanner Limestone Member from 592434 to 591440; Spanner Limestone from 581443 to 581444; upper part of the Papilio Mudstone from 592441 to 591442; and Mytton Formation from 572438 to 569441. See Figure 14 for reference.

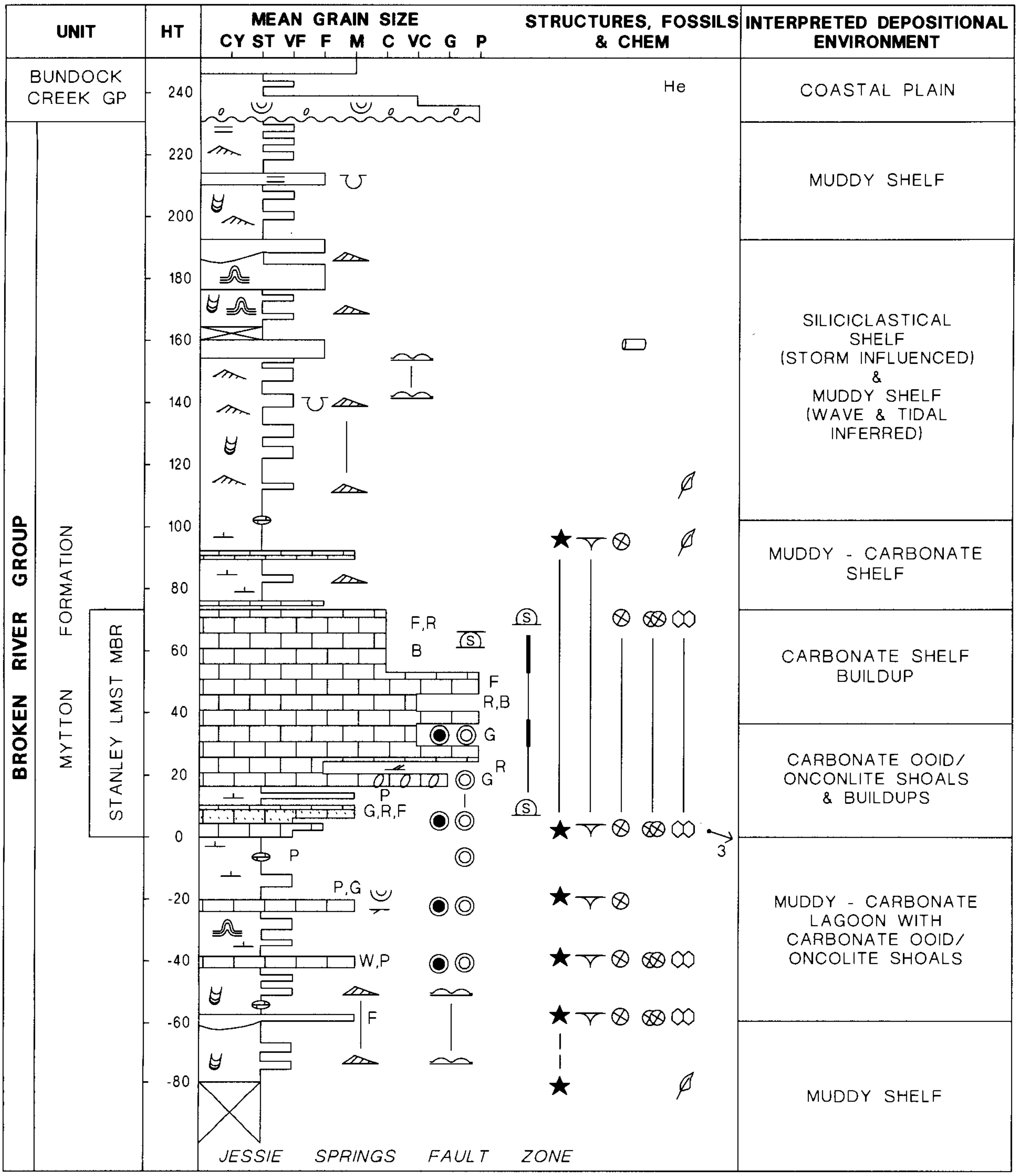


Figure 33. Type section for the Stanley Limestone Member near Page Creek at 7858-543414. See Figure 14 for reference.

the carbonate shelf in places, and provided an avenue for both carbonate and terrigenous clasts to move down an easterly directed slope. The release of coarse clastics across the shelf probably was associated with a relative lowering of sea-level. Several such pulses appear to have occurred during the deposition of the Burges Formation.

(b) Thinly interbedded mudstone-limestone-arenite lithofacies. This lithofacies interfingers with the northern margin of the Lomandra and Dosey Limestones along the Broken River . Thin to medium-bedded, bioturbated, calcareous mudstone is interbedded with thin to medium-bedded, bioclastic calcilutite, calcarenite and calcirudite. In the Broken River these beds are generally overlain by mudstones containing large slump blocks of limestone (Plate 20c). The blocks are up to 3 m in size, and are composed mainly of skeletal debris shed from the adjacent limestones. Some of the blocks are internally chaotic, indicative of debris flow deposits. Some calcarenite blocks contain examples of *Stromatactis* (Plate 20d). These calcite-filled voids are commonly associated with carbonate buildups in deeper waters, although their origin is uncertain (James, 1984, Sellwood, 1986). These beds pass into thinly interbedded, fine-grained arenite and mudstone, with lesser thin, lenticular calcilutite. Many of the arenite beds are graded and laterally continuous. Small slump folds occur in places, and the few palaeocurrents (allowing for folding) indicate an easterly or southeasterly slope.

The lithofacies is interpreted as mixed carbonate-terrigenous slope deposits which formed an apron along the seaward side of the Carbonate Shelf Facies Association. Slumping, debris flow, and to a lesser extent, turbidity currents, were the main depositional processes, suggesting a slope of greater than 0.5-1 degree (Stow, 1986). The water depth is uncertain, although it would probably be deeper than the storm wave base (eg. 10-50 m, Flugel, 1982). This lithofacies is considered to be proximal to the massive mudstone-minor arenite lithofacies.

(c) **Limestone lithofacies**. This includes several limestone lenses, ranging from 1 to 50 m thick, and 10 m to 5 km long. The largest of these lenses crosses the Jessey Springs-Jack Hills Gorge track at 7859-683490, although it is best observed on a low ridge, 500 m southwest along strike (676486), where it is thickest (50 m) and consists mainly of thin to medium-bedded calcarenite and calcirudite (dominantly skeletal packstones) with lesser calcilutite (Figure 31). It overlies and is overlain by polymictic conglomerates and calcirudites. A variety of coral, stromatoporoid, and abundant crinoid debris make up the bulk of the limestone. The most distinctive aspect of this limestone is the abundance of fish remains, which are scattered throughout the beds.

Large, broken placoderm bones (up to 40 cm), crossopterygian teeth (up to 7 cm long), and lungfish skull bones (up to 30 cm) are obvious. However, there is also an abundant microvertebrate fauna, including shark remains, and the acanthodian genus *Cheirancanthoides* (S. Turner, Queensland Museum, personal communication). Other thinner limestones interbedded throughout the muddy sequence contain a terrigenous muddy matrix, and commonly abundant crinoid debris, with lesser amounts of other skeletal material.

The lack of *in situ* corals and stromatoporoids, and the abundance of broken skeletal debris, particularly crinoids, suggest that strong wave or current action was involved. However, the well-bedded, allochthonous character of the limestone, in combination with its setting amongst slope and channel deposits, indicates that the debris accumulated on a slope. Some of the lenses possibly formed as banks of carbonate debris on the upper part of the slope. The relationship between this facies and the thinly interbedded mudstone-limestone-arenite lithofacies is unknown.

(d) **Massive mudstone-minor arenite lithofacies**. This lithofacies is typical of the bulk of the Burges Formation between the Jessey Springs Limestone and the Lomandra and Dosey Limestones. Examples of the lithofacies can be seen along the track between Jessey Springs Hut and the crossing of Gorge Creek. The mudstones are thin to very thick bedded, massive to laminated, and are bioturbated in places. They are interbedded with a variable amount of thin-bedded, graded, very fine to fine-grained arenite. The massive mudstones are strongly pencil cleaved (Plate 20e). Locally, thin, poorly-sorted calcarenite lenses crop out, containing a mixture of shelly debris, limestone clasts, and quartz pebbles. South of Gorge Creek, the lithofacies is interbedded with the limestone lithofacies, and passes laterally into the thinly interbedded mudstone-limestone-arenite lithofacies, and the polymictic conglomerate-calcirudite-arenite lithofacies.

Aung (1991) divided the Burges Formation into three informal units, Db1 (lower mudstones and arenites), Db2 (conglomerates, limestones, and thick mudstones), and Db3 (sandstones and limestones laterally equivalent to the Dosey Limestone and Phar Lap Member). These units intertongue with the Bracteata Mudstone to Dosey Limestone sequence to the south and west.

Interpretation. The massive mudstone-minor arenite lithofacies is interpreted as muddy slope deposits, probably deposited by turbidity currents, the coarser deposits representing channel lags derived from both terrigenous and carbonate sources up the slope. This lithofacies may be the most distal of the Mixed Siliciclastic/Carbonate Slope Facies Association.

Considering that the main limestones are flanked in places by aprons of slope deposits (some recording easterly-directed palaeocurrents), and that the Burges Forma-

PLATE 20:

a. **Calcirudite and polymictic conglomerate, with large, angular limestone clasts (granules to boulders), mixed with terrigenous clasts (mainly subrounded pebbles and cobbles). The limestone clasts are mainly bioclastic calcarenites and calcirudites which contain corals and other fossils common in the Carbonate Shelf Facies of the adjacent limestone units. The calcirudites and conglomerates range from being poorly-bedded and disorganised, to being well-bedded and crudely graded. The top of the unit is to the left. The outcrop is interpreted as a gravelly submarine channel deposit with detritus derived from both a terrigenous and local carbonate source. Mixed Siliciclastic-Carbonate Slope Facies Association, Lithofacies SL.1, polymictic conglomerate-calcirudite-arenite. Burges Formation. 7859-686503, Gorge Creek crossing on Greenvale-Broken River track.**

b. **Slump block of limestone (calcarenite to calcilutite; wackestone to packstone) approximately 0.7 m wide, in calcareous mudstone. Note stromatactoid voids under pen. Mixed Siliciclastic-Carbonate Slope Facies Association, Lithofacies SL.2, thinly interbedded mudstone-limestone-arenite. Burges Formation. 7859-647456, Broken River, 500 m upstream of Jack Hills Gorge.**

c. **Detail of calcite-filled stromatactoid void in the slump block of limestone in (b). The origin is uncertain, but it appears to be associated with dilation structures, such as veins and injectate resulting from post-depositional deformation and metamorphism.**

d. **Poorly sorted calcirudite (packstone), typical of many of the debris flow deposits in Lithofacies SL.2 (thinly interbedded mudstone-limestone-arenite) of the Mixed Siliciclastic-Carbonate Slope Facies Association in the Burges Formation. Same locality as (b).**

e. **Cleaved, bioturbated and graded siltstone to mudstone (younging to the left). Mixed Siliciclastic-Carbonate Slope Facies Association, Lithofacies SL.4, massive mudstone - minor arenite. Tributary of Diggers Creek.**

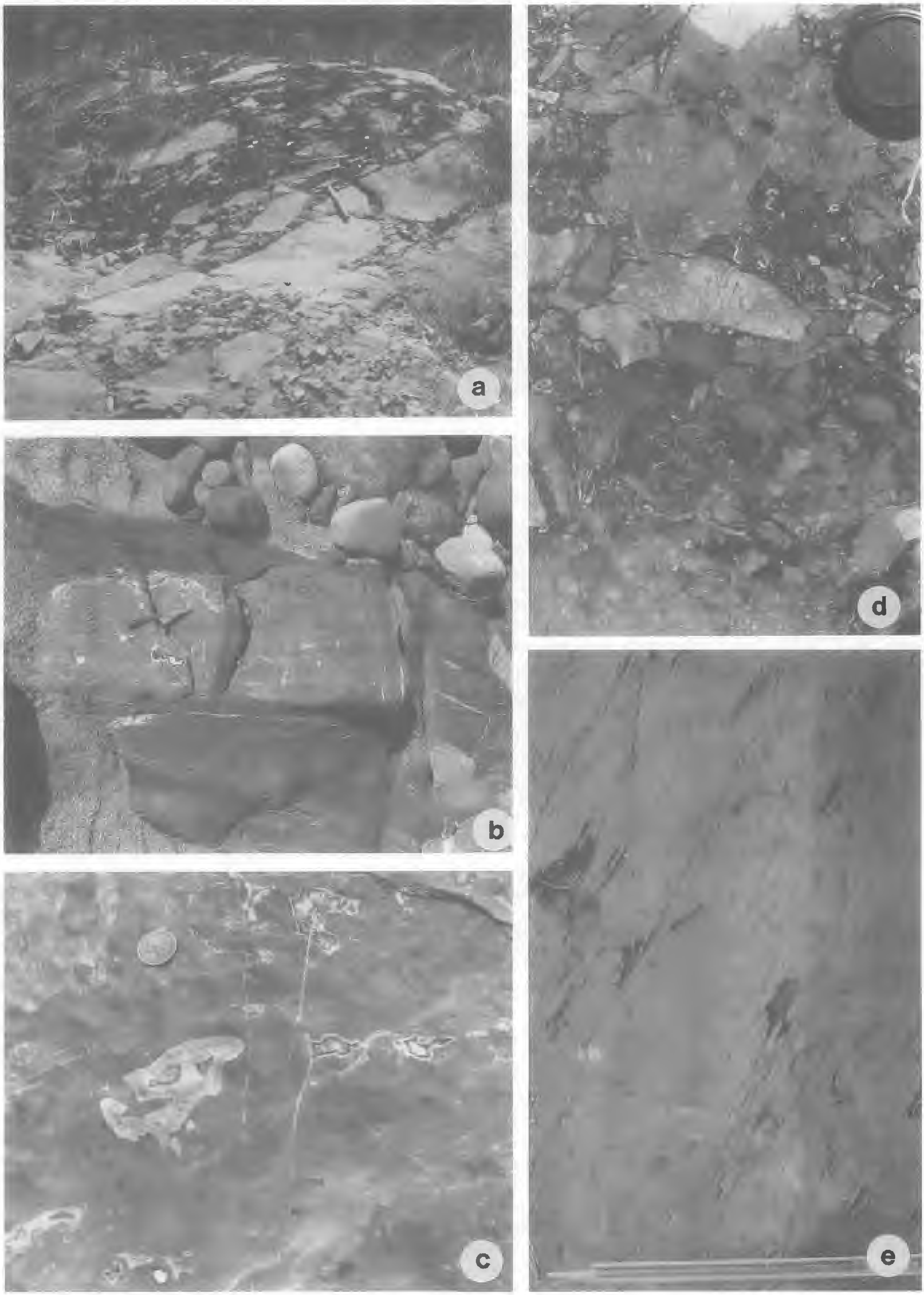


Plate 20. Burges Formation.

tion becomes steadily sandier and more conglomeratic to the west and southwest, it seems likely that the slope dipped easterly, approximately down the axis of the Graveyard Creek Subprovince. The apparent lack of true rock-fall deposits, and the presence of slumping, debris flows, and turbidites, indicate a modest slope, more like a ramp. In order to promote the shifting of the conglomeratic detritus, a relative sea-level lowering is implied during the deposition of the Burges Formation.

Therefore, the Burges Formation probably represents a gentle, ramp-like, slope environment, which rimmed a variety of shelf facies, and down which both carbonate and terrigenous sediments were deposited by slumping, debris flows and turbidity currents. In the middle of the formation, the slope deposits (and locally the carbonates) were cut by channels during lowstand episodes, along which a large amount of conglomeratic material was transported and deposited, including large boulders of pre-lithified limestone. The formation is grouped into Mixed Carbonate-Terrigenous Slope/Submarine Channel Facies Association (Table 3), and the microfacies are described in Table 4.

UNDIFFERENTIATED WANDO VALE SUBGROUP

Catfish Creek area

The Corner Creek-Catfish Creek area contains a 190 m thick sequence of undifferentiated Wando Vale Subgroup north of 'Gregory Springs' homestead. A thick bedded, poorly sorted, pebble conglomerate, dominated by very angular clasts of schist, mylonite, and granitoid, unconformably overlies the granitoid-metamorphic basement 7758-299249 and 313243). The conglomerate is overlain by 100 m of poorly sorted, sandy red mudstone and medium to coarse-grained, feldspathic sandstone. A 40 m thick unit of trough and low-angle cross-bedded, fine to very coarse-grained, feldspathic sandstone and minor green mudstone overlies these redbeds, and in places, contains rare, poorly preserved, disarticulated shelly fossils. This is overlain by calcareous, muddy redbeds and thin reddish limestones containing abundant branching *Thamnopora* and *Disphylum*, hemispherical stromatoporoids encrusted by corals (including *Alveolites*), bivalves, gastropods, and rare conodonts (313241). Along strike, thin bedded, dark grey to reddish, laminated calcilutites (Plate 18d) (303240 and 317243) contain very rare, disarticulated shelly fossils, and are extensively bioturbated in places. The regularity of the laminations, where preserved, and small, laminated, domelike features on the upper surfaces of the otherwise flat laminae may suggest algal-assisted limestone deposition. Local, mud-filled, V-shaped cracks on the upper surfaces of these thin beds may be desiccation cracks. Thin, tabular, laminated calcilutite rip-up-clasts, many with curved edges, may represent torn-up desiccation flakes. The laminated limestones are interbedded with greenish grey to reddish, bioturbated calcareous mudstones containing plant fragments, and abundant small gastropods. This sequence is overlain by drab, trough cross-bedded, pebbly, feldspathic sandstones of the Siliciclastic Shelf Facies Association.

The conglomeratic and redbed sequence is interpreted as an alluvial fan/fan-delta sequence along the basin margin. The laminated, desiccated, unfossiliferous limestones are interpreted as algal laminites deposited in the intertidal zone of a tidal flat. The interbedded reddish to greenish grey mudstones probably represent subtidal to intertidal deposits, with the fossiliferous limestones being deposited farther offshore.

This sequence has previously been referred to both the Bundock Creek Group and the Broken River Group (White & others, 1959a; White, 1965; Wyatt & Jell, 1980; Withnall & others, 1986), but conodonts recently recovered from the fossiliferous limestones indicate an Early Givetian age (*ensensis* zone) (R. Mawson, unpublished data) and it is now considered as part of the Broken River Group. The Corner Creek-Catfish Creek area was probably the southwestern margin of the basin at this time, being marked by alluvial fans/fan-deltas shedding off the Lolworth-Ravenswood Block, probably in response to movement along the Clarke River Fault Zone. Tidal flats along this margin may have extended northeastward towards 'Craigie', marginal to the Muddy Shelf Facies Association, and adjacent to the Siliciclastic Shoreline Facies Association.

Trough cross-bedded, pebbly, feldspathic sandstones of the undifferentiated Wando Vale Subgroup overlie the reddish carbonates north of 'Gregory Springs'. No shelly fossils and only rare plant fossils have been recovered from this sequence. Sandstone similar to these, and conglomerates, occur in the Storm Hill Sandstone, east and north of Top Craigie Bore, in the headwaters of Bull Creek.

Craigie area

Flat laminated, low-angle planar and trough cross-bedded, well-sorted, fine to coarse-grained, quartzose sandstone and minor conglomerate similar to the Storm Hill Sandstone, occur 1.5 km northeast of Top Craigie Bore in a tributary of Craigie Creek (7858-668365). Rare crinoid and brachiopod remains occur within these sandstones north of 'Craigie' outstation (7858-706365). These sediments are also interpreted as possible shoreline facies. In the Bull Creek area they interfinger with mudstones of the Muddy

PLATE 21:

a. **Slump folding in Lithofacies S.7 (thinly interbedded arenite and mudstone) of the Siliciclastic Shelf Facies Association. 110 m above the base of the Mytton Formation, Broken River type section.**

b. **Hummocky cross-stratification in 5 to 15 cm thick sets, in the upper part of a 10 m-thick, well-sorted, fine-grained arenite succession. Siliciclastic Shelf Facies Association, Lithofacies S.6, hummocky cross-stratified arenite. 187 m above the base of the Mytton Formation, Broken River type section.**

c. **Streaming lineation and flute marks at the base of a flat laminated arenite bed overlying mudstone. Siliciclastic Shelf Facies Association, Lithofacies S.4, flat laminated arenite. 25 m above the base of the Mytton Formation, Broken River type section.**

d. **Sinuous-crested, current ripple marks on the top of a very fine-grained, micaceous arenite bed. Muddy Shelf Facies Association, Lithofacies M.9, thinly interbedded mudstone and fine arenite. Floater block, approximately 400 m above the base of the Mytton Formation, Broken River type section.**

e. **Top of a very fine-grained arenite bed, showing sinuous-crested, ripple-marks on which are superimposed miniature, irregular ripple-like features similar to wrinkle marks ('Runzelmarken'). Muddy Shelf Facies Association, Lithofacies M.9, thinly interbedded mudstone and fine arenite. 200 m above base of the Mytton Formation, Broken River type section.**

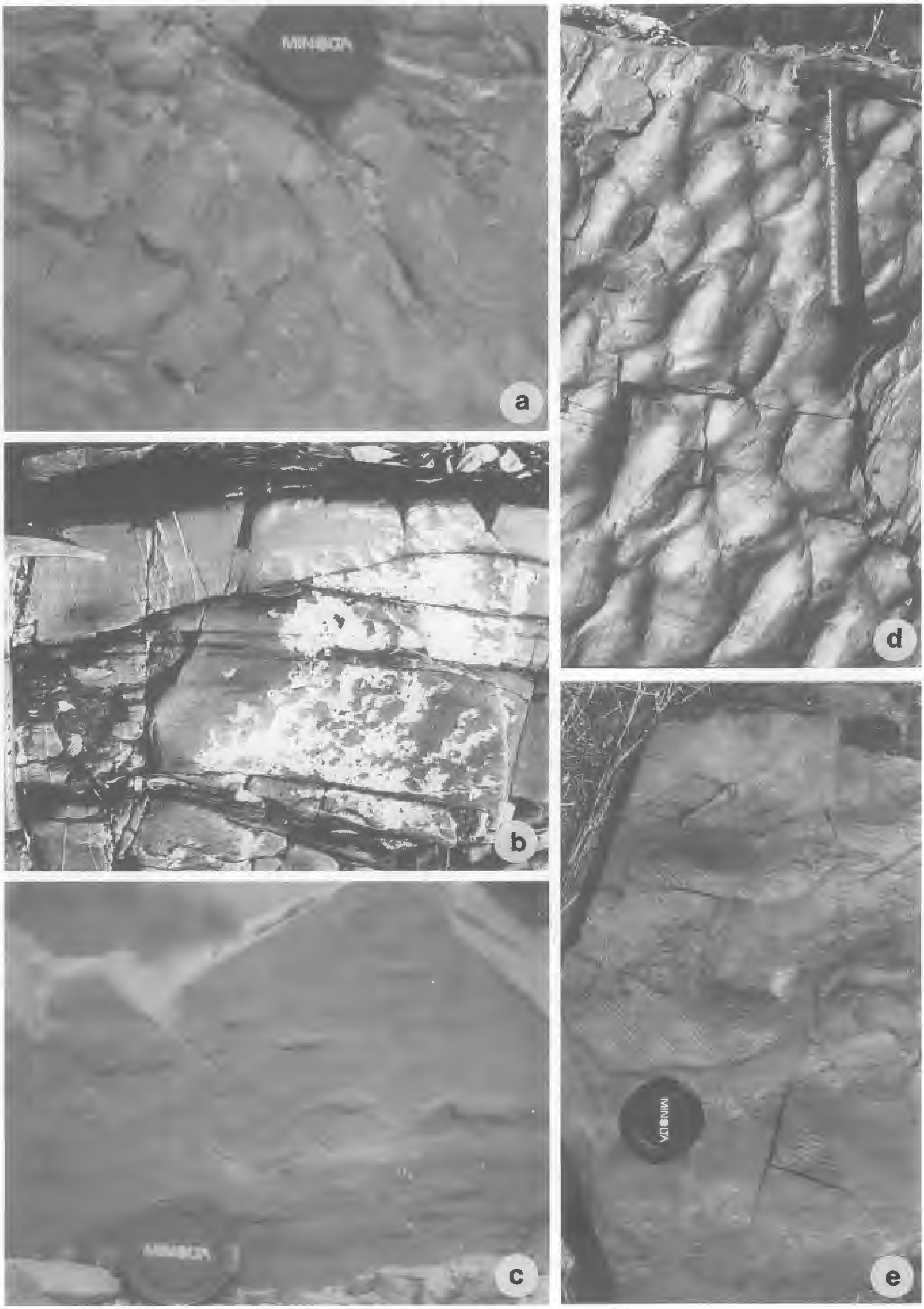


Plate 21. Mytton Formation.

Shelf Facies Association; north and northeast of 'Craigie', limestones occur within the sequence, and these probably represent the southern limit of the Carbonate Shelf Facies Association at the height of the transgression.

The Bracteata and Papilio Mudstones pass into undifferentiated Wando Vale Subgroup in the Bull Creek area, north of Top Craigie Bore (7858-659390). Thick sequences of massive, laminated and ripple cross-laminated, bioturbated mudstones and thinly interbedded, fine-grained calcareous arenites typical of the Muddy Shelf Facies Association, are intercalated with thick sequences of coarse to very coarse-grained, trough and low-angle planar cross-bedded, quartzose to feldspathic sandstone and pebbly quartzose conglomerate. The only fossils in the muddy rocks are plant fragments, and the lack of marine fossils, in association with the intercalated sandstone-conglomerate sequences suggests that the southern limit of the muddy shelf facies occurs in this area, and that it interfingers with the Siliciclastic Shoreline to Shelf Facies Associations described above.

Northern area

Thin-bedded mudstones and very fine-grained arenites containing plant fragments and rare *Lingula* overlie the Chinaman Creek Limestone north of 'Pandanus Creek'. These may represent tidal flat deposits.

Lithic arenite, polymictic conglomerate, mudstone and minor limestone occurs north of the Chinaman Creek Limestone and in fault blocks adjacent to the Teddy Mount Fault. These are mapped as undifferentiated Wando Vale Subgroup, and are tentatively interpreted as shelf deposits accumulated behind the Pandanus Platform.

MYTTON FORMATION

'Lower' Mytton Formation

Description. The lower 340 m of the Mytton Formation in the type section in the Broken River (Figure 26) is a sequence of medium to very thick-bedded, well-sorted, fine-grained arenites, which are either interbedded with grey bioturbated and ripple cross-laminated mudstone and thin-bedded, graded arenite, or amalgamated into multistorey units several metres thick. These thick sandy units form the prominent range of hills in the area. The arenites are typically laminated or massive, contain well-developed dish structures and convolute lamination (Plate 21a) in places, and commonly contain grey, angular, mudstone rip-up-clasts. Towards the upper part of the sequence, hummocky and swaley cross-stratification is well developed; upper surfaces of beds are clearly moulded into hummocks and swales with average heights of 10-20 cm, wavelengths of 0.8-1.7 m, and in sets 5-20 cm thick. Some of the sets have a well-developed basal storm lag, consisting of quartz and lithic granules, rip-up-clasts, and rare shelly debris. Most hummocky sets are amalgamated sequences, although some do show normal grading, planar tabular cross-bedding, and ripple cross-lamination in the upper parts of the sets, indicating waning flow conditions as the storm conditions faded. Hummocky cross-stratified beds occur throughout the lower Mytton Formation, being recognised in Diggers and Gorge Creek and as far north as 7859-679574 and 657594 .

The interbedded mudstones and thin-bedded arenites contain well-developed lenticular bedding (Plate 21c), lesser wavy and flaser bedding, and abundant current ripple marks. Invertebrate fossils are extremely rare in this lithofacies, and bioturbation, other than some sinuous grazing trails, is generally also rare. However, graded bedding with intense bioturbation in the upper muddy parts of beds, is well developed in sequences in the Diggers Creek area (7859-643488). Some beds have delicately preserved sole markings, such as flutes (Plate 22a) and a variety of tool marks.

Interpretation. The thick arenite beds are interpreted as storm influenced sandy shelf deposits. Supporting this interpretation are the dominance of flat-lamination with parting lineation, indicating high flow regime conditions (Allen, 1980), and the presence of hummocky cross-stratification, indicative of high energy storm conditions, (Dott & Bourgeois, 1982). The composition (Figure 22) and well-sorted, fine grain-size suggests that the sediments were derived from the recycling of older sedimentary rocks (probably Judea or Wairuna Formations); the uniformly fine grain-size is possibly the reason why the sediments were so subject to liquefaction and consequent soft-sediment-deformation during loading or rapid deposition.

The interbedded mudstone-arenite beds may be storm-generated turbidites, similar to those described by Walker (1984) because they are associated with hummocky cross-stratified, sandy storm beds, and were probably deposited on a shallow shelf.

Stanley Limestone Member

Description Humphries (1990) studied the sedimentology and coral faunas of the Stanley Limestone Member in detail, and confirmed most of the interpretations previously advanced by Withnall & others (1988b) based on reconnaissance mapping. Facies are summarised in Table 4.

The lower 30 m of the Stanley Limestone Member of the Mytton Formation consists of coarse to very coarse-grained, well-sorted oolitic/oncolitic limestones (Plate 23). They contain well-developed, small to medium-scale, planar tabular and trough cross-bedding (Plate 21d). The limestones include excellent examples of grainstones

PLATE 22:

a. Lenticular to wavy bedded, very fine-grained arenite interbedded with grey mudstone. Muddy Shelf Facies Association, Lithofacies M.9, thinly interbedded mudstone and fine arenite. 340 m above the base of the Mytton Formation, Broken River type section.

b. Thin, dominantly quartzose granule conglomerate bed in massive fine-grained arenite. Siliciclastic Shelf Facies Association, Lithofacies S.1, polymictic conglomerate and S.5, massive arenite. Uppermost part of the Mytton Formation. 7859-574445, 1.5 km southeast of Red Range Gorge.

c. Large fish plate, 10 cm wide in polymictic pebble conglomerate comprising a mixture of angular quartz and ferruginised shale clasts. Siliciclastic Shelf Facies Association, Lithofacies S.1, polymictic pebble conglomerate. Uppermost part of the Mytton Formation. 7859-658593, 1.5 km north of GSQ Clarke River 1.

d. *Stringocephalus* biomicrudite (floatstone to packstone) Carbonate Shelf Facies Association, Lithofacies C.11, *Stringocephalus* biomicrudite. Upper part of the Stanley Limestone Member. In tributary of Page Creek.

e. Planar cross-bedded sandy oolitic/oncolitic grainstone. Carbonate Shelf Facies Association, Lithofacies C.21 oosparite. Lower part of the Stanley Limestone Member. 7858-545420 in the type section.

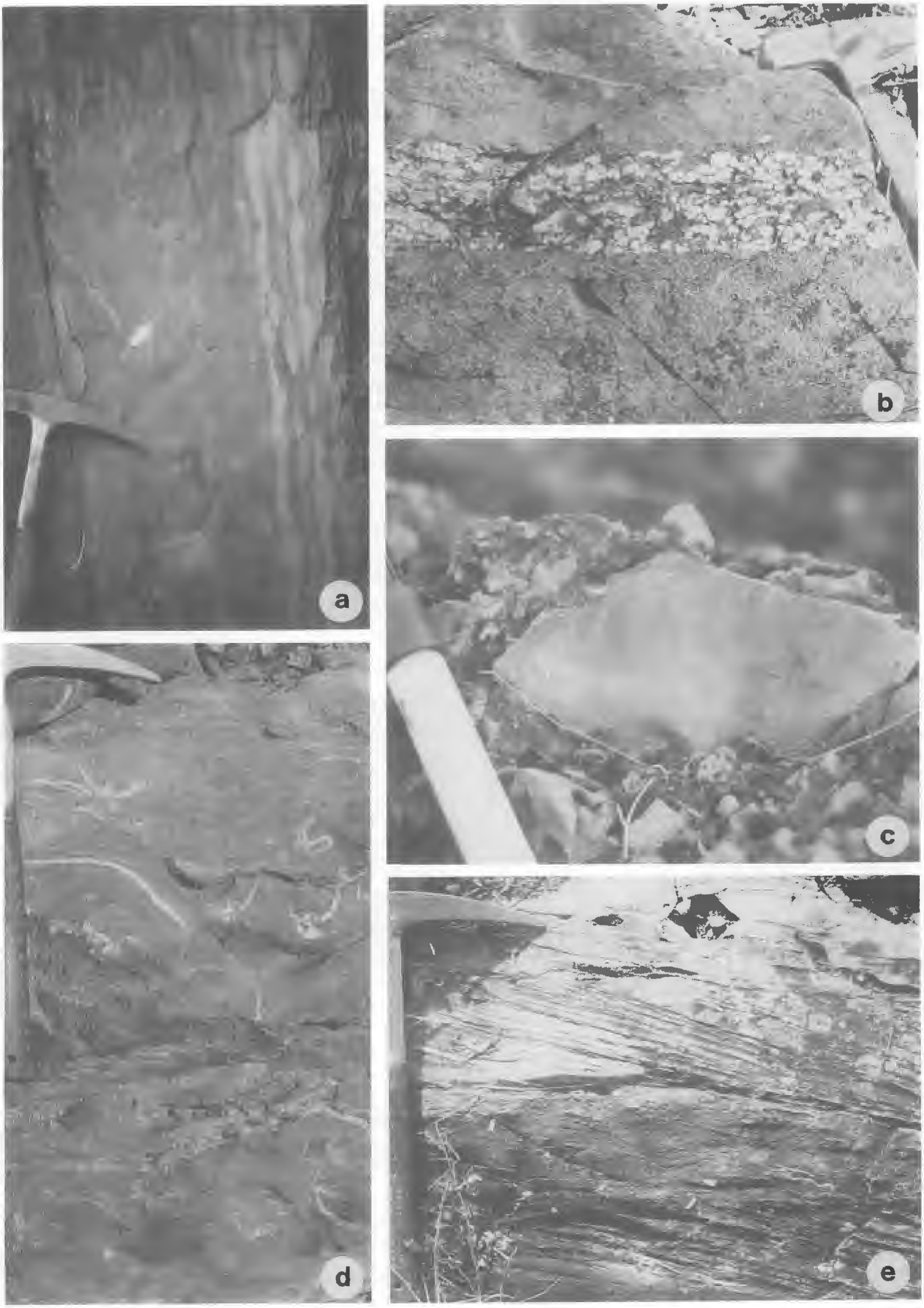


Plate 22. Upper part of the Mytton Formation and Stanley Limestone Member.

(Plate 23a,b), although in places they grade into packstones.

Well-rounded, singular and multiple ooids and pisoids are mixed with fine sand to pebble-sized oncoids. The ooids and pisoids have both a concentric and radial structure, the nucleus usually being a skeletal grain, or more rarely a quartz grain. The oncoids contain both ooids and pisoids (Plate 23), bound together by abundant algal cell remains, particularly *Girvanella* (Plate 23c). Crinoid, coral, brachiopod, stromatoporoid, gastropod, and bivalve debris also occur within these beds, which have been traced for several hundred metres along strike. In the north they grade laterally into muddy, calcareous, fine-grained arenite, in places containing abundant crinoids and rare trilobites. These beds appear to pass laterally into the hummocky cross-bedded sandstones of the Siliciclastic Shelf Facies Association. In the southwest, the limestones grade laterally into sandy oolitic limestone, and calcareous muddy arenite containing locally abundant *Thamnopora* debris, with lesser globular stromatoporoids. These overlie calcareous, fossiliferous mudstone and fine arenite of the lower Mytton Formation, which is faulted against underlying units along a branch of the Jessey Springs Fault.

The upper 50 m of the Stanley Limestone Member is distinctly different from the underlying oolitic and oncolitic limestones. The lower part (30-60 m) consists of thick-bedded wackestones, packstones and grainstones, and includes a rich fauna of lamellar, globular, and branching stromatoporoids, large massive and branching tabulate and rugose corals, small to large solitary rugose corals, abundant crinoidal material, fish bone and scale remains, and brachiopods. Conodonts are very rare. Massive stromatoporoids are particularly abundant at the top of the main limestone outcrop. One bed underlying bioclastic rubble consists of lamellar encrusting stromatoporoid boundstone (Plate 21e) up to 1.0 m thick and over 100 m wide. The upper 20 m of the Member (60-80 m) consists of thin-bedded limestone and calcareous mudstone, with an abundant brachiopod, crinoid and bivalve fauna. Solitary corals are common, and other corals and globular stromatoporoids also occur here. Plant fragments become common up the sequence. The mudstones are heavily bioturbated in places.

Interpretation. The lower part of the Stanley Limestone Member probably formed in a shallow marine, high energy environment, such as oolitic and oncolitic carbonate shoals or banks. The upper part of the member was probably deposited on a carbonate shelf lagoon, and possibly on the seaward side of the underlying oolitic/oncolitic carbonates. It is most likely that the buildup was a wave resistant structure, since the massive stromatoporoids at the top of the unit are laterally extensive and encrust rubble.

'Upper' Mytton Formation

Description. The upper 100 m of the Mytton Formation is typified by a dark grey, massive mudstone lithofacies and thinly interbedded mudstone and very fine arenite lithofacies. The massive mudstone lithofacies contains problematic, fan-shaped burrows, rare bivalves, brachiopods, and crinoids, and common plant fragments including simple dichotomising forms and lycopod stems. The thinly interbedded mudstone and arenite lithofacies contains abundant ripple marks, associated with lenticular and wavy bedding (Plate 22b). Interference micro-ripples are common on the ripple marks, particularly in the intercrest areas (Plate 22c). In places miniature irregular ripple-like features identical to 'runzelmarken' (wrinkle marks) as illustrated by Reineck & Singh (1975, p. 56) are developed.

Thin pebbly beds (Plate 22d) in several places near the upper part of the Mytton Formation contain quartz sand and pebbles, mixed with shale clasts and a variety of fossil fragments including fish bones (Plate 22e), corals, stromatoporoids, brachiopods and plant debris. In GSQ Clarke River 2, the uppermost part of the formation consists of mudstones and silty sandstones containing bioturbation and rare bivalves, gastropods and brachiopods. These rocks are not appreciably different to those immediately above the basal conglomerate of the unconformably overlying Bulgeri Formation.

Interpretation. The dominance of mudstone containing lenticular bedding, bioturbation and rare fossils, and proximity to hummocky cross-stratified beds, indicates a relatively shallow muddy shelf environment, possibly grading to intertidal in places. The thin conglomerates probably represent minor channel-fills deposited during storms.

DIAGENESIS OF THE LIMESTONES

The following brief description of the diagenetic products in limestones of the Broken River Group is based on examination of thin-sections and hand specimens as well as field observations, mainly of the Lomandra Limestone (Jorgensen, 1990) and the Dip Creek Limestone (Law, 1985, 1986a).

Micrite Envelopes (algal bored rims)

These are a common phenomenon and are present in many lithofacies, particularly C.1, C.4, C.5, and C.8. Although mainly developed around the margins of crinoid ossicles, they are also associated with many other skeletal elements. The envelopes were mainly produced by the repeated boring of endolithic algae into skeletal fragments, combined with infilling of these bores by micrite (Bathurst, 1966, 1975). This is illustrated in many samples by the close association of filaments of the blue-green algae

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PLATE 23:

- a. **Oncolitic pisolith containing *Girvanella*. Note core with radial structure, encapsulated by a delicate lamellar calcite structure. *Girvanella* tubules are particularly well developed in the top part of the oncolite, indicating that at some stage this oncolite was stationary during less agitated periods, such as between stormy seasons. Carbonate Shelf Facies Association, Lithofacies C.21 oosparite. 7858-545420, 100 m west of Page Creek. Magnification x 7.5.**
- b. **Oncolitic pisoliths surrounded by a sparry cement. Note the *Girvanella* in the core of the lower pisolith. Locality as above. Magnification x 7.5.**
- c. **Detail of *Girvanella* in the core of the pisolith illustrated in (b). Locality as above. Magnification x 25.**
- d. **View of part of a large composite oncolite. Note the lamellar carbonate rims around grains trapped within a larger oncolitic envelope. The outer rim of the oncolite is bored in places. Other grain types set in a sparry calcite matrix include gastropods, crinoids, and ?peloids. Locality as above. Magnification x 5.**
- e. **Oolitic grainstone with clean sparry calcite matrix. Locality as above. Magnification x 7.5.**

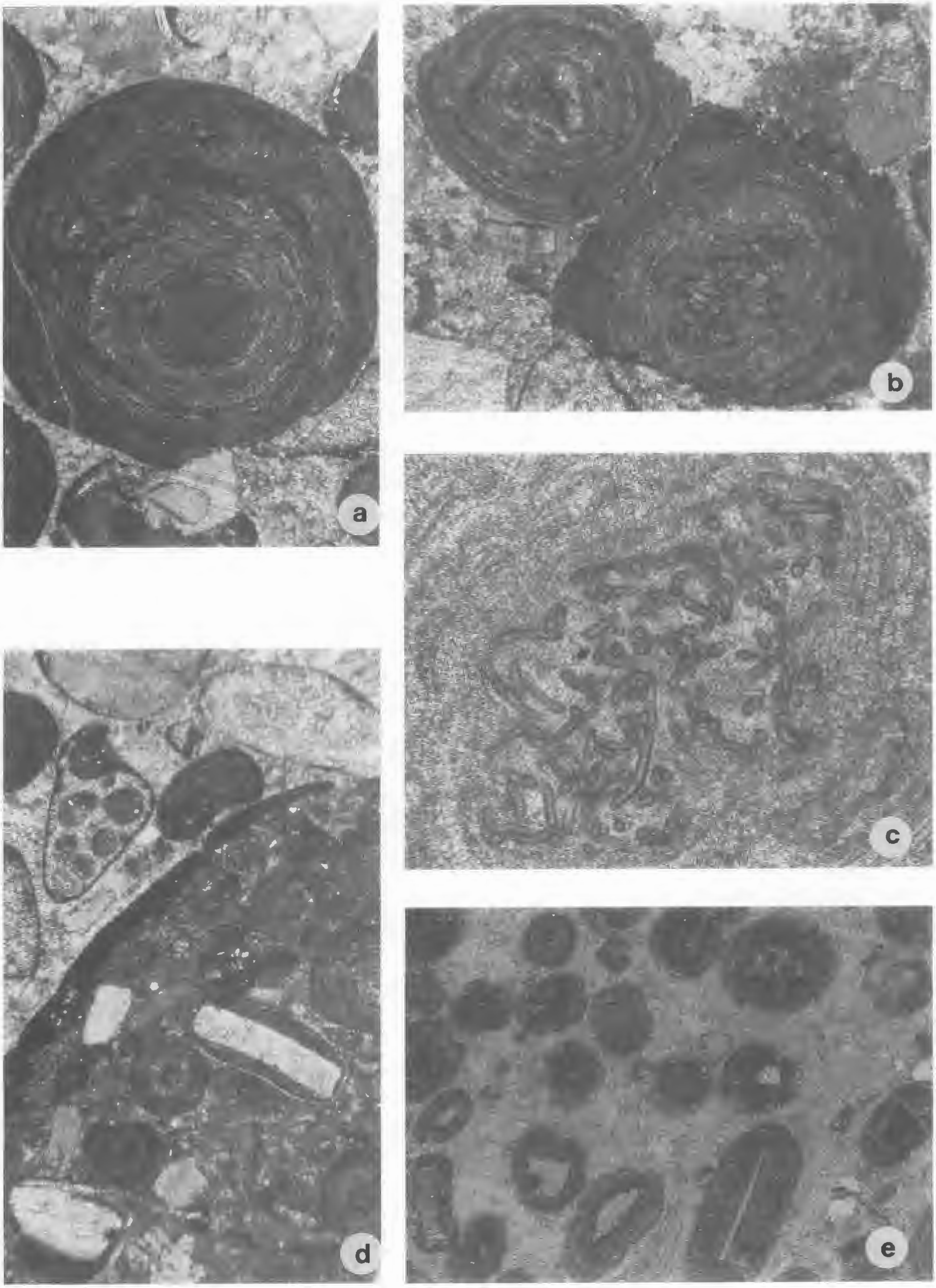


Plate 23. Photomicrographs of oncolitic pisoliths from the lower part of the Stanley Limestone Member.

Girvanella with partially developed envelopes. Skeletal grains show a complete gradation from partially bored to completely degraded (peloids).

Cementation

Sparry calcite cement is present in various quantities in many lithofacies, but is best developed in C.1, C.4, C.6, and C.12. Three types of cement are recognised in the samples: (1) spar cement, (2) syntaxial rim cement, and (3) fibrous calcite cement.

Volumetrically, spar cement is the most common type, occurring between grains and infilling original cavities in allochems. It consists of clear, usually equant calcite grains, occupying the pore-spaces not filled by the other cements. It commonly overlies these first generation cements and is interpreted as having formed during a second stage of cementation.

Syntaxial rim cement is exclusively developed around crinoid ossicles. The cement forms a single crystal around and in lattice continuity with the skeletal grain, and the whole area is commonly crossed by continuous cleavages (Evamy & Shearman, 1965; Bathurst, 1975).

Fibrous calcite cement is the least common type. It occurs in pore spaces as a thin (usually less than 0.2 mm) fringe of "fibrous" crystals, partially or wholly surrounding skeletal grains.

Neomorphism

Examples of both aggrading neomorphism (formation of coarser crystal mosaics) and degrading neomorphism (formation of finer crystal mosaics) are present. Of the two processes, aggrading neomorphism was dominant. Aggrading neomorphism is a collective term describing those processes that result in the formation of a coarser mosaic of crystals. It includes coalescive neomorphism, porphyroid inversion and porphyroid recrystallisation (Folk, 1965).

Coalescive neomorphism is the most common form of aggrading neomorphism present in the studied samples. It is the mechanism by which original micrite matrix was replaced by coarser neomorphic spar. The products of this process are most prominent in the micrite-dominated lithofacies (C.2, C.3, C.5, C.7, C.8, C.10, M.3 and M.4), but it has also affected the poorly washed specimens of lithofacies C.1 and C.4.

Porphyroid inversion affects those skeletal grains originally composed of aragonite. The grains have undergone a polymorphic transformation whereby the metastable aragonite has been replaced by calcite. The end product of this process is a skeletal fragment partially or wholly replaced by a crystal mosaic of sparry calcite. Most molluscan fragments in lithofacies C.1 and C.2 have undergone this inversion.

Porphyroid recrystallisation is the process leading to the replacement of original micrite matrix by the outward syntaxial growth of crystals in the walls of allochems (Bathurst, 1975). Its two main products are syntaxial replacement rims on crinoid ossicles and the syntaxial growth of neomorphic spar in molluscan shell walls. Only scattered syntaxial replacement rims were observed in this study.

Evidence of degrading neomorphism is present in scattered samples and is not restricted to any particular lithofacies. It can be seen in crinoid ossicles which have undergone partial recrystallisation. Patches of microspar have replaced parts of the original unit crystals of the ossicles.

Pressure Solution

Within the studied samples, the primary results of pressure solution are seen as sutured grain boundaries, microstylolites and stylolites. Stylolites are common in most of the lithofacies, whereas the sutured grain boundaries and microstylolites are restricted to scattered samples.

All stylolites are characterised by concentrations of dark, insoluble residues, and many have dolomite crystals associated with them. Some specimens have only one stylolite, but in others, stylolites are abundant and may be concentrated in complex anastomosing patterns.

Sutured grain boundaries are best developed between crinoid ossicles; the suturing is of low amplitude and some insoluble residue is concentrated at the contacts. Microstylolites are developed around the margins of some larger grains. They also contain dark coloured, insoluble residues, but generally do not have sutured surfaces.

Dolomitisation

Dolomitisation does not appear to have been restricted to any specific lithofacies. Various amounts of dolomite are present in many of the studied samples as two styles: (1) concentrated within areas of stylolitisation, and (2) replacing original matrix and/or cement. The latter style is extremely well developed in some samples, replacing almost the entire original groundmass and partially replacing some fossils.

Calcite Veins

Calcite veins are present in almost all lithofacies, but do not comprise a volumetrically significant feature of any of them. Law (1985, 1986a) recognised two generations of calcite veins in the Dip Creek Limestone and a similar subdivision was recognised in the Lomandra Limestone.

The first generation veins are very thin (less than 1 mm) and filled with fine granular spar. These are the most abundant type and are best observed in thin section. They have complex cross-cutting relationships. Most were emplaced before stylolitisation and are disrupted by the stylolites. However, some veins are incorporated into the stylolites, and others cut across them. These relationships indicate that the thin veins formed throughout the time that the limestones were being stylolitised.

The second generation veins are larger (0.2 to 10 mm thick) and composed of either fibrous or medium to coarse granular calcite. These veins cut across the stylolites and overprint the thin veins.

Silica Replacement

Silica replacement is not extensive in the samples studied. In most examples, the calcite skeletons of corals and brachiopods were replaced, although in a specimen from lithofacies C.7, calcispheres were infilled by silica.

STRATIGRAPHY AND SEDIMENTOLOGY OF THE BUNDOCK CREEK GROUP

(S.C. Lang)

Late Devonian to Carboniferous sedimentary rocks in the Graveyard Creek Subprovince crop out in a roughly rectangular area of about 1 000 km^2 in the headwaters of the Einasleigh and Broken Rivers. They were first described as the Bundock Creek Formation by White (1959, 1965).

As a result of regional mapping by Minatome (Australia) Pty Ltd and Urangesellshaft (Australia) Pty Ltd during uranium exploration activities in the late 1970's, Guillebert & others (1979) and Wyatt & Jell (1980) subdivided the Bundock Creek Formation into 'lower' and 'upper' parts, each containing four informal units. Lang (*in* Withnall & others, 1985) proposed that the formation be raised to group status, and Lang (1985, 1986a) gave detailed descriptions of the constituent units.

Formal definitions of the Bundock Creek Group and its constituent formations and members were published by Lang & others (1989b). A further revision recognised the Jamieson Member, a distinctive, partly marine sequence forming the upper part of the Bulgeri Formation (Lang & Blake, 1992). The constituent formations and members are shown in Figure 12 and are as follows:

Harry Creek Formation

Boroston Formation

Teddy Mount Formation
(including the Dyraaba Member)

Turrets Formation

Bulgeri Formation
(including the Rockfields Member, Stopem Blockem Conglomerate Member, and Jamieson Member).

The Bundock Creek Group is at least 5 965 m thick in the centre of the basin (Broken River, Montgomery Creek and Mount Brown Creek areas). A generalised section is shown in Figure 34. The Bulgeri Formation, which comprises more than half the thickness of the Group, accumulated during a series of regressive and transgressive phases. Accumulation of the overlying Turrets and Teddy Mount Formations followed during a transgressive phase spanning the Devonian-Carboniferous boundary. The Dyraaba Member, in the upper part of the Teddy Mount Formation, marks the beginning of a final regressive phase, culminating in the deposition of the Boroston Formation. The Harry Creek Formation was deposited during the onset of a major volcanic episode, which resulted in the intrusion into the sequence of the Montgomery Range Igneous Complex, before and after folding of the Bundock Creek Group in the mid to Late Carboniferous.

In this chapter, the lithology, general sedimentological features, and stratigraphic relationships of the individual units are discussed. However, the Bulgeri Formation has been the subject of much more detailed facies analysis, and the results of that analysis are described in a separate chapter. For completeness, a summary of the sedimentology is included here in this chapter.

Ternary plots of composition are shown in Figure 35, sorted by formation or member. A more detailed lithofacies analysis of the formation is presented in the following chapter. The colour scheme used is based on the Munsell system as published by the Geological Society of America (1979). The general facies distribution of the Bundock basin is illustrated in Figure 36.

BULGERI FORMATION

Introduction

The unit mainly crops out in a sinuous folded belt, generally 2 to 4 km wide, from the Clarke and Gregory Rivers in the south, to near 'Pandanus Creek' in the north. In the north, the formation has also been mapped in isolated fault blocks on the northern side of the Teddy Mount Fault. Several outcrops occur as windows in Cainozoic basalts west of the Kennedy Development Highway. Sporadic, partly fault bounded outliers of probable Late Devonian age in the southeastern part of the Georgetown Province (Withnall, 1989b) are lithologically equivalent to the Bulgeri Formation. The largest outcrop is about 80 km^2 in the Maitland Creek area (Plate 31c) between 'The Lynd' and 'Lyndhurst' homesteads.

The formation forms a thick wedge, thinning to the north and northeast (Figure 34). The unit is 3 660 m in the type section along the Broken River, and thins to approximately 1 700 m on the northwestern limb of the Rockfields Syncline. The unit is locally absent on the limbs of the Dip Creek Syncline, but thickens again to at least 1 200 m in the Six Mile Syncline northwest of 'Pandanus Creek'. Faulting and Cainozoic cover prevent an accurate assessment of the true thickness in the south, but the formation is at least 3 800 m thick southwest of Pages Dam, and possibly greater than 4 000 m adjacent to the Clarke River Fault Zone.

The unit is expressed as a series of low strike ridges, traversed by a characteristic trellised drainage pattern. Most of the unit is covered by sparse grassy cover and stunted, broad silver-leaved ironbarks. These grow mainly on the quartzose to feldspathic sandstones and conglomerates. The interbedded fine-grained redbeds commonly support quinine bush. On colour aerial photographs, the unit appears mainly as pale tones, with the fine-grained redbeds forming reddish tones. A prominent feature is the Red Range, a wall-like strike ridge formed by resistant red conglomerate and pebbly sandstone of the Stopem Blockem Conglomerate Member. Numerous gorges cut through the range, the largest being the Red Range Gorge, the site of a permanent waterhole on the Broken River.

Type sections

Bulgeri Formation. The type section (Figures 34, 38, 42, 52 and 53) lies in the Broken River between 7859-578447 (base) and 530460 (top). The section consists of 3 660 m of grey to greenish grey, fine to coarse-grained quartzose, lithofeldspathic and feldspathic sandstone. Fine-grained intervals are dominated by greyish red siltstone and fine-grained sandstone, although several intervals are grey to greenish grey mudstone and siltstone. Greyish red to reddish purple polymictic conglomerate and pebbly lithic sandstone occur in the lower half of the formation. Olive green, silicified, volcaniclastic siltstone and fine-grained sandstone (reworked tuff), and minor rip-up-clast conglomerate occur throughout the formation. The type section includes the type sections of all three constituent members.

Rockfields Member. The type section (Figure 38) forms the lower 795 m of the Bulgeri Formation type section in the Broken River between 7859-578447 (base) and 560444 (top). The section begins with a light grey, polymictic, pebble to cobble conglomerate overlain by grey, fine to medium-grained, sublabile feldspathic (arkosic) to quartzose sandstone. Fine-grained intervals include mainly grey

TABLE 5. DISTRIBUTION OF LITHOLOGICAL ASSOCIATIONS OF THE BULGERI FORMATION								
Subunits	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Northern area (undifferentiated)	A	A		C		R	A	R
Southern area (undifferentiated)	A	R	R	R		R		
Subunit Q	C	R	C		C	C		C
Subunit P	A	C			A			
Subunit O	C	R			C			C
Subunit N	A	C	C		A	C	R	
Subunit M	R	C		A				
Subunit L	C	A		C		R	R	
Subunit K	A	C						
Subunit J		C		A			R	
Subunit I		A		C			C	
Subunit H	A	R						
Subunit G		C	A				R	
Subunit F	A	R						
Subunit E	A	R						
Subunit D	C	A	C		R			
Subunit C	R	R	A		A	C		
Subunit B	C	C	A		C	C		
Subunit A		A	C					C

A = abundant; C = common; R = rare

Lithological Associations

1. Drab (light grey to brown), coarse to very coarse-grained, sandstone and conglomerate.
2. Fine-grained redbeds (greyish red siltstones and fine-grained sandstone), and minor intra-formational conglomerates.
3. Drab (light to grey brown), well sorted, fine to medium-grained sandstones.
4. Red (greyish red to purple) polymictic conglomerates and fine to very coarse-grained lithic sandstone.
5. Drab (light to dark grey, greenish or bluish grey) or variegated (brownish grey to greyish red) fine-grained sandstone, siltstone and mudstone.
6. Green volcaniclastic fine-grained sandstone and siltstone (reworked tuff).
7. Calcirudites (limestones clast conglomerates).
8. Marine influenced pebbly to cobbly conglomerate (some calcareous), fine to medium-grained sandstone, siltstone, mudstone, and coaly bands.

mudstone and siltstone, but greyish red siltstone and fine-grained sandstone occur near the base and the top of the member. Olive green, silicified, volcaniclastic siltstone and fine-grained sandstone (reworked tuff), and minor rip-up-clast conglomerate occur throughout the unit.

Stopem Blockem Conglomerate Member. The type section (Figure 41) occurs in Red Range Gorge in the Broken River between 7859-559448 (base) and 558449 (top), between 953 m and 1 220 m in the type section of the Bulgeri Formation. The member consists of 267 m of greyish red to reddish purple, pebbly to cobbly polymictic conglomerate and pebbly lithic sandstone. Interbedded fine-grained intervals include greyish red siltstone and fine-grained sandstone. Light grey, coarse-grained, sublabile feldspathic to quartzose sandstone occurs in the lower part of the member.

Jamieson Member. The type section (Figure 50) lies in the Broken River between 7859-540457 (base) and 530460 (top), comprising the upper 670 m of the Bulgeri Formation type section. The base of the member overlies a white, cobbly to pebbly, quartzose conglomerate, which forms the top of the underlying coarsening-upward sequence. The lower third of the member comprises a fining-upward sequence of grey to brown, medium to very coarse-grained, locally pebbly, labile feldspathic sandstone interbedded with greyish red to brown fine-grained sandstone and siltstone. Greenish grey mudstone containing marine fossils occurs in the middle of the sequence, interbedded with thin, gran-

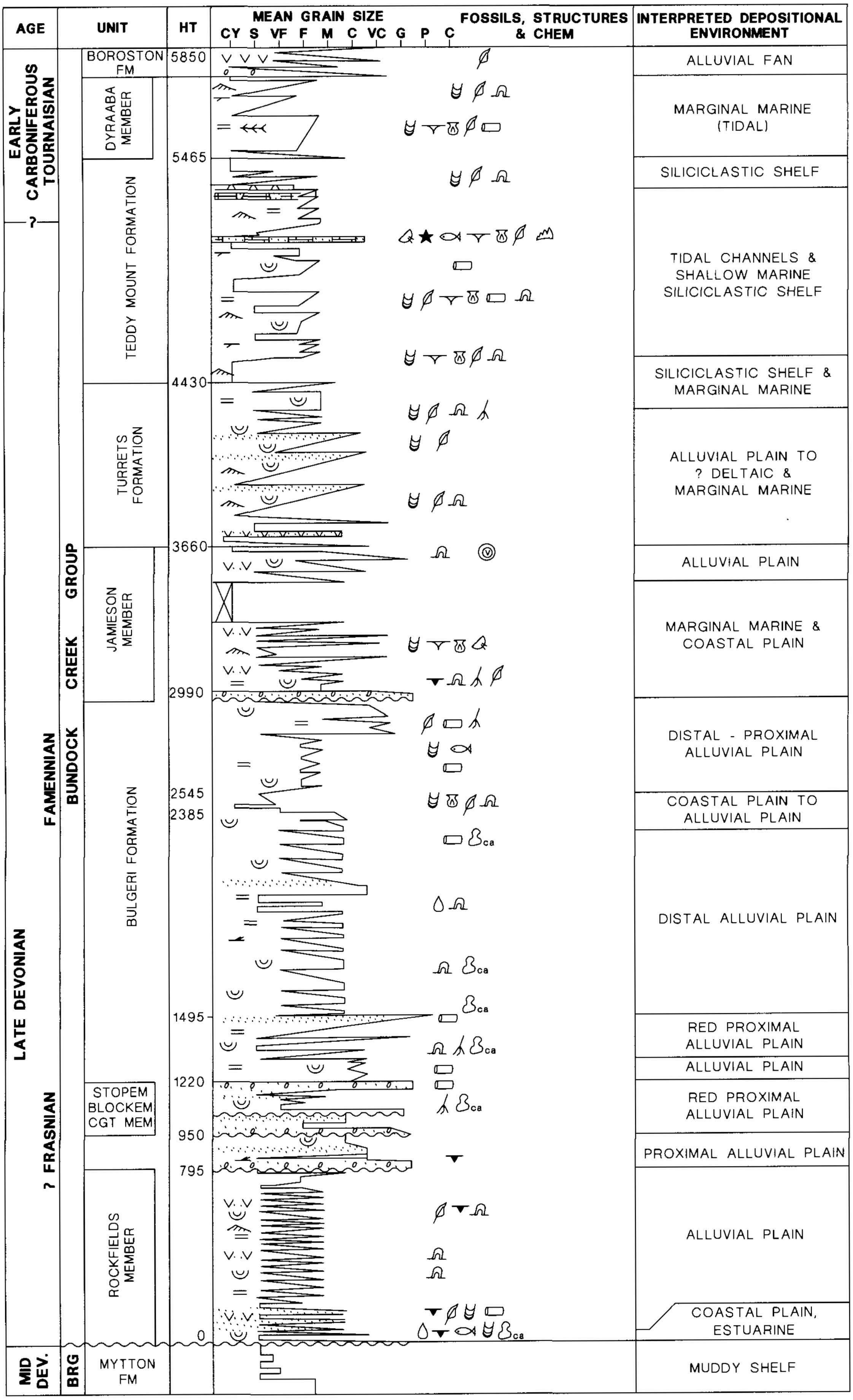


Figure 34. Generalised section, southeastern Bundock Basin. Sections are located in the Broken River or its tributaries (Montgomery Creek and Mount Brown Creek). Heights calculated from tape and compass combined with airphoto interpretation.

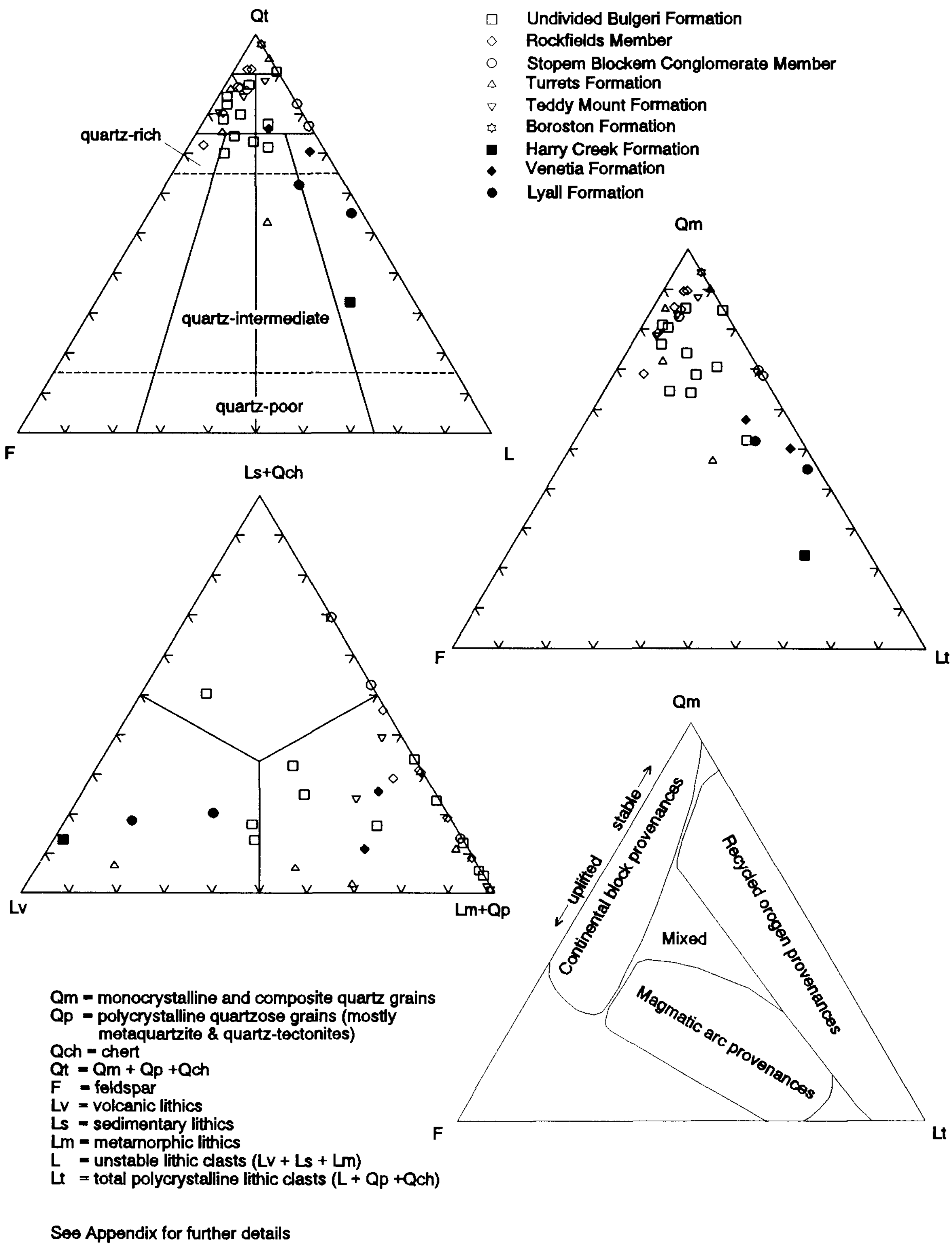


Figure 35. Plots of modal data from arenites in the Bundock Creek and Clarke River Groups. See Appendix for full analyses and more details. Compositional fields are after Crook (1960, 1974) and inferred provenance fields are after Dickinson & Suczek (1979).

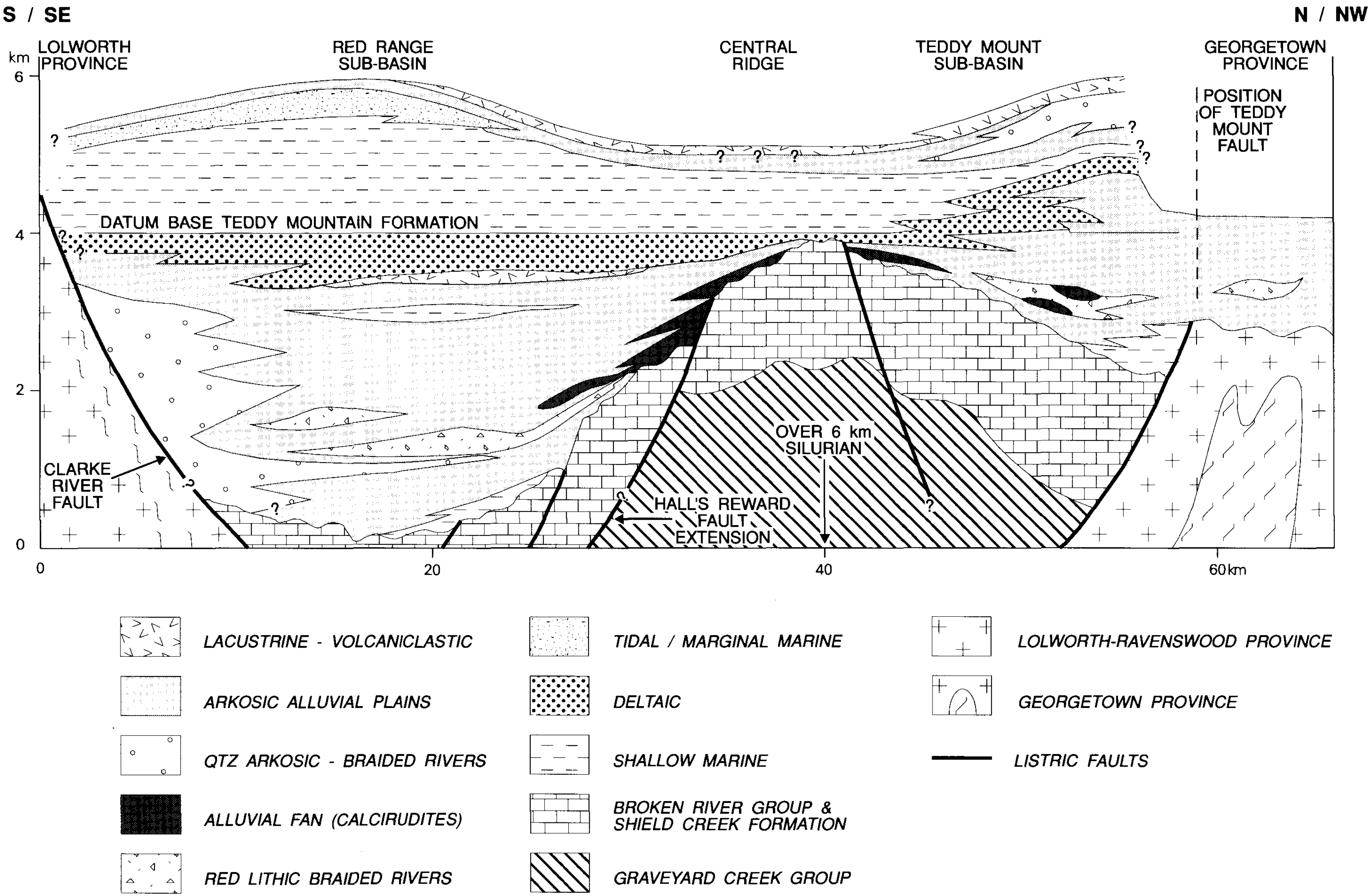


Figure 36. General facies distribution for the Bundock Creek Group.

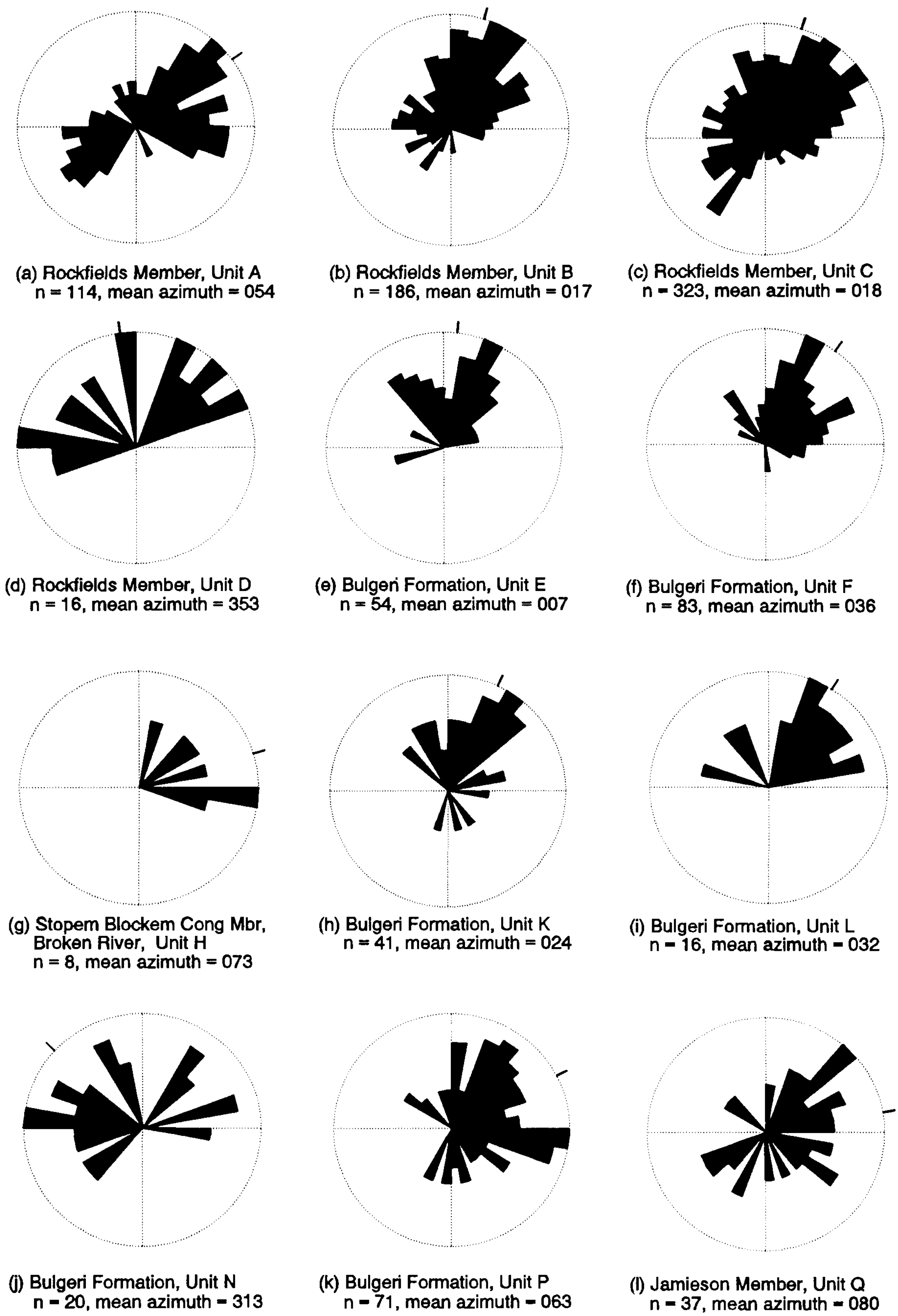
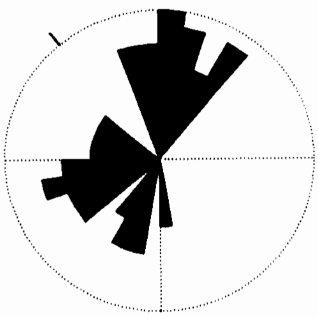
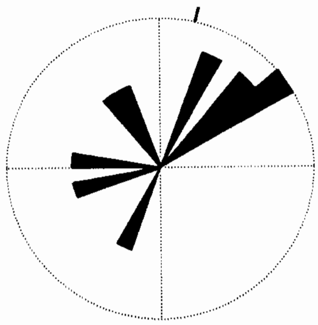


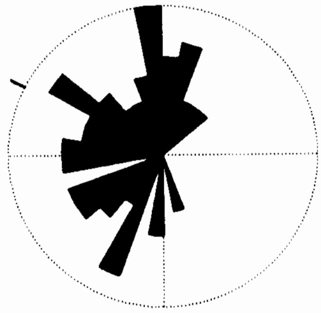
Figure 37. Palaeocurrent distribution for the Bundock Creek Group (plotting by 10° intervals - area of segment proportional to number of readings).



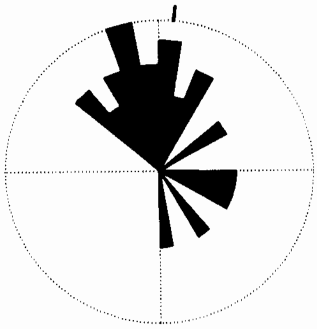
(m) Stopem Blockem Cong Mbr, Broken River, Units G, I & J
n = 135, mean azimuth = 323



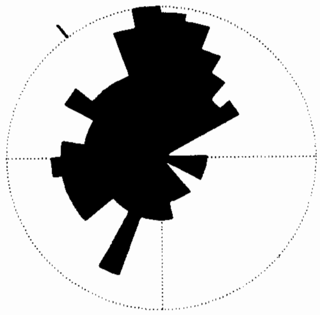
(n) Bulgeri Formation, Unit M
n = 14, mean azimuth = 013



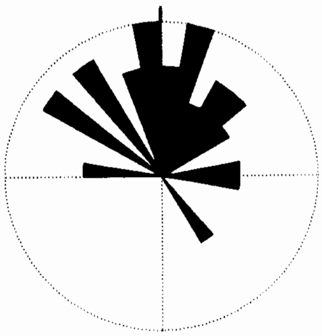
(o) Stopem Blockem Cong Mbr, Gorge Ck-Diggers Ck area,
n = 55, mean azimuth = 297



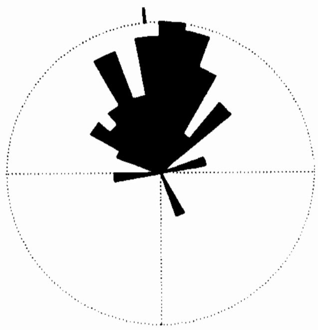
(p) Bulgeri Formation, Six Mile Syncline, all red conglomerates
n = 23, mean azimuth = 006



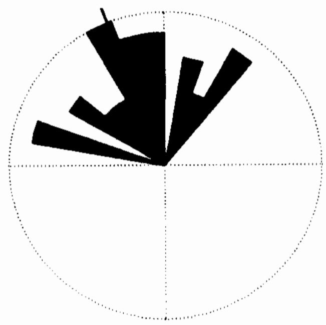
(q) Bulgeri Formation, whole area, all red conglomerates
n = 135, mean azimuth = 323



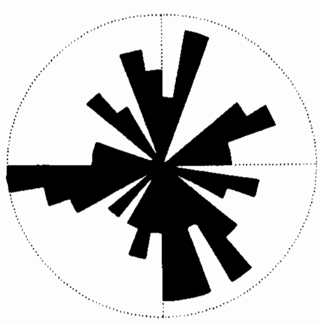
(r) Undiff. Bulgeri Formation,
n = 28, mean azimuth = 360



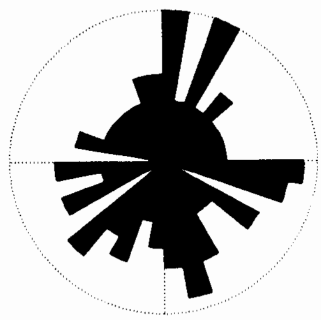
(s) Bulgeri Formation equiv., Maitland Creek area
n = 64, mean azimuth = 355



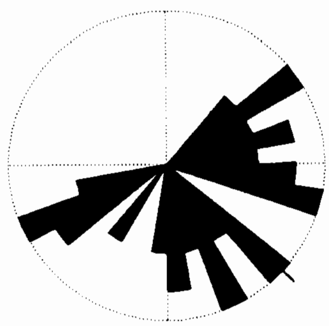
(t) Gilberton Formation, Granite Creek crossing
n = 23, mean azimuth = 339



(u) Turrets Formation,
n = 55, uniform distribution



(v) Teddy Mount Formation,
n = 34, uniform distribution



(w) Boroston Formation,
n = 31, mean azimuth = 134

Figure 37 (continued)

ule conglomerates. Olive green, silicified, volcaniclastic siltstones and fine-grained sandstones (reworked tuffs) occur mainly in the upper half of the sequence. They are interbedded with medium to very coarse-grained sandstones which contain an increasing amount of volcanic detritus. A dark grey, silicified, volcaniclastic silty mudstone containing accretionary lapilli occurs immediately under the base of the Turrets Formation.

General lithology

The Bulgeri Formation contains a variety of rock types, but for the purpose of general description they can be grouped into eight main lithological associations (Table 5). The distribution and relative abundance of these lithological associations form the basis for formal and informal subdivision of the formation. With the exception of the far southern and far northern outcrops, the formation can be readily subdivided into 17 distinctive sequences, informally labelled Units A-Q. The three members of the Bulgeri Formation are informally subdivided as follows:

Rockfields Member: Units A-D

Stopem Blockem Conglomerate Member: Units G-J

Jamieson Member: Unit Q

Undifferentiated parts of the Bulgeri Formation include Units E-F, K, and L-M (unnamed conglomerate lenses).

The eight lithological associations, described in order of decreasing abundance below, are summarised in Table 5. For further petrological details, see Lang (1985, 1986a).

1. Drab, coarse to very coarse-grained sandstone and conglomerate. These are the dominant rock types of the Bulgeri Formation, forming nearly half of the unit. They include medium to very coarse-grained sandstones, with lesser granule, pebble, and cobble conglomerate. Compositionally, most are sublabile to labile feldspathic (Figure 35), but some are almost quartzose, and a few are volcanilithic. Most of the sandstones and conglomerates have been derived from plutonic, metamorphic and sedimentary rock sources, but acid to intermediate volcanics become important in the upper part of the formation (Jamieson Member).

The drab (light grey to brown) colour commonly has a greenish tinge, which is due to epidote replacement of feldspar, and diagenetic chlorite. Minor greyish-red to purple stains on cross-bed foresets (Plate 27d) are due to intrastratal replacement of biotite by haematite, as well as haematisation of detrital clays. Reddish purple oxidation haloes commonly form around lithic grains/clasts, especially biotite schists and granitoids.

The sandstones and conglomerates generally form multistorey complexes several metres thick (Plate 30a) and extend laterally for hundreds of metres, and contain numerous erosive surfaces including scour-and-fill structures filled with a pebbly lag (Plate 30b). The sandstone bodies typically contain small to large scale trough, or planar tabular cross-bedding, particularly in the coarser-grained beds. Flat lamination or crude horizontal stratification is also common. Convolute bedding and oversteepened cross-beds occur in places. The conglomerates are horizontally stratified with weakly imbricated pebbles, or are trough cross-bedded, or massive. Medium to large scale planar tabular cross-bedding is common within Unit E.

Pebble and cobble clasts are mainly subangular to angular, but some are well rounded (mainly quartz), and sphericity ranges from fair to poor. Clasts are mainly quartz and quartzite, with lesser reddish-brown quartzose and sublabile arenite, dark greenish grey and red chert, dark grey siltstone, spotted shale, mica schist, granitoids and acid to intermediate volcanics. Angular, platy and curviplanar shale rip-up-clasts are commonly associated with the pebbly lags (Plate 27e). Rip-up-clasts are mainly greenish grey, but some greyish red to reddish purple varieties also occur.

2. Fine-grained redbeds. These are characteristic of the Bulgeri Formation, and make up about a third of the formation. They are typically greyish-red siltstone and very fine sandstone, although in places they are greyish red purple, dark reddish brown, brownish grey or may have minor greenish grey mottling, patches or spots. Most are micaceous, and range from sublabile feldspathic to labile lithofeldspathic, and some (eg. in the upper 235 m of GSQ Clarke River 1) are feldspathic, and may be tuffaceous. Stringers or thin beds of intraformational conglomerate, and coarser-grained sandstone and conglomerate, occur in places.

The red colour is due to abundant fine-grained haematite in the matrix, some of which may have formed prior to deposition, but mostly by syn- and post-depositional processes (Lang, 1985, 1986a). Many phyllosilicate grains (mainly biotite) are totally pseudomorphed by haematite. Commonly the red colouration becomes more intense towards the tops of individual laminae, where the clay fraction has been preferentially haematised. These uppermost reddened layers commonly contain mudcracks (Plate 24e) or synaeresis cracks which were infilled by overlying drab, or pale red sandstone or siltstone. Mudstone rip-up-clasts in associated sandstones and intraformational conglomerates are intensely red (Plates 27e, 29e), suggesting early oxidation within the environment of deposition.

The colour is variable, and the fine-grained redbeds are commonly mottled to greenish-grey, particularly underneath drab sandstones containing pyrite and fossil plant remains. Greenish-grey spots and irregular patches within the fine-grained redbeds are also associated with residual organic matter. In parts of Units B, C, N, and Q, some fine-grained redbeds are intimately associated with drab siltstone and mudstones, thus forming variegated successions, and indicating that the oxidation conditions were variable, but significantly influenced by local syn- and post-depositional environmental factors such as palaeotopography and the degree of pedogenesis (Friend, 1966; McPherson, 1980; Bown & Kraus, 1987).

Intervals of fine-grained redbeds range in thickness from a few centimetres to 10 m. Although many are truncated by overlying sandstone/conglomerate bodies, some intervals can be traced laterally for several kilometres. The common sedimentary structures include flat lamination, ripple cross-lamination and small-scale trough cross-bedding. Water escape structures, slump folds, mudcracks (Plate 24e), synaeresis cracks, raindrop impressions (Plate 24f), tracks, trails, and burrows occur in many places. Most beds however, are structureless, with only a few remnants of lamination preserved. The destratification is due mainly to bioturbation (especially plant rooting) and other pedogenic processes.

Many of the fine-grained redbeds are calcareous, usually in the form of nodules (glaebules) and carbonate-filled, tubular rhizoliths, but also as pervasive cement, veinlets, and in a few places, as massive, laminated or vuggy carbonate beds up to 1 m thick. The glaebules (Plate 29a, b, c) are especially well developed in the upper parts of thick redbed intervals. The glaebules range from 1-100 mm in diameter, but most are 5-15 mm. They are spherical, cylindrical or irregular in shape, and subvertically oriented. Good examples can be seen throughout GSQ Clarke River 1, and along the track to Red Range Gorge in a prominent fine-grained redbed sequence (Unit L). In some

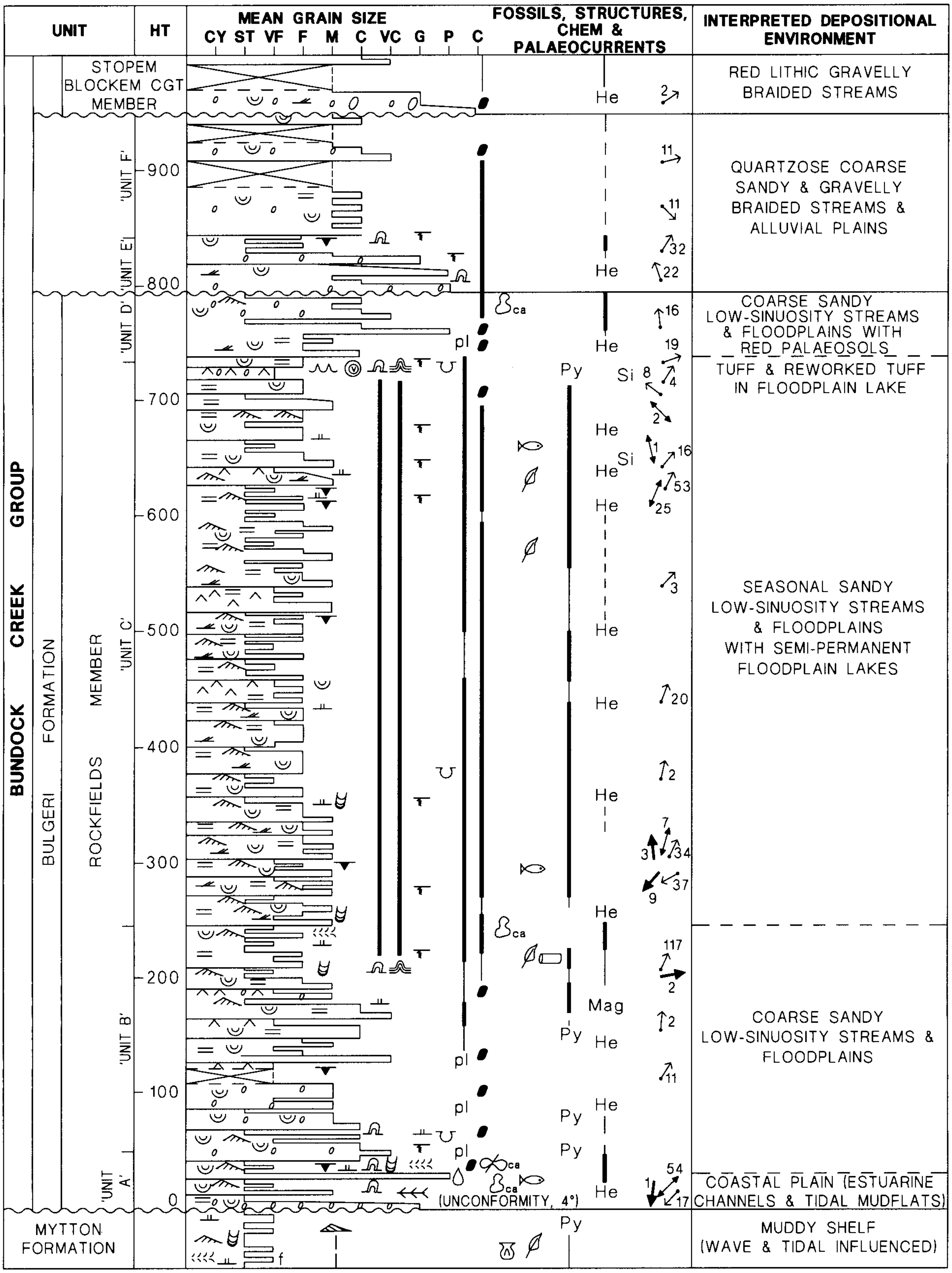


Figure 38. Lower part of the type section of the Bulgeri Formation along the Broken River from 7859-578447 to 559446, including the type section of the Rockfields Member. See Figure 14 for reference.

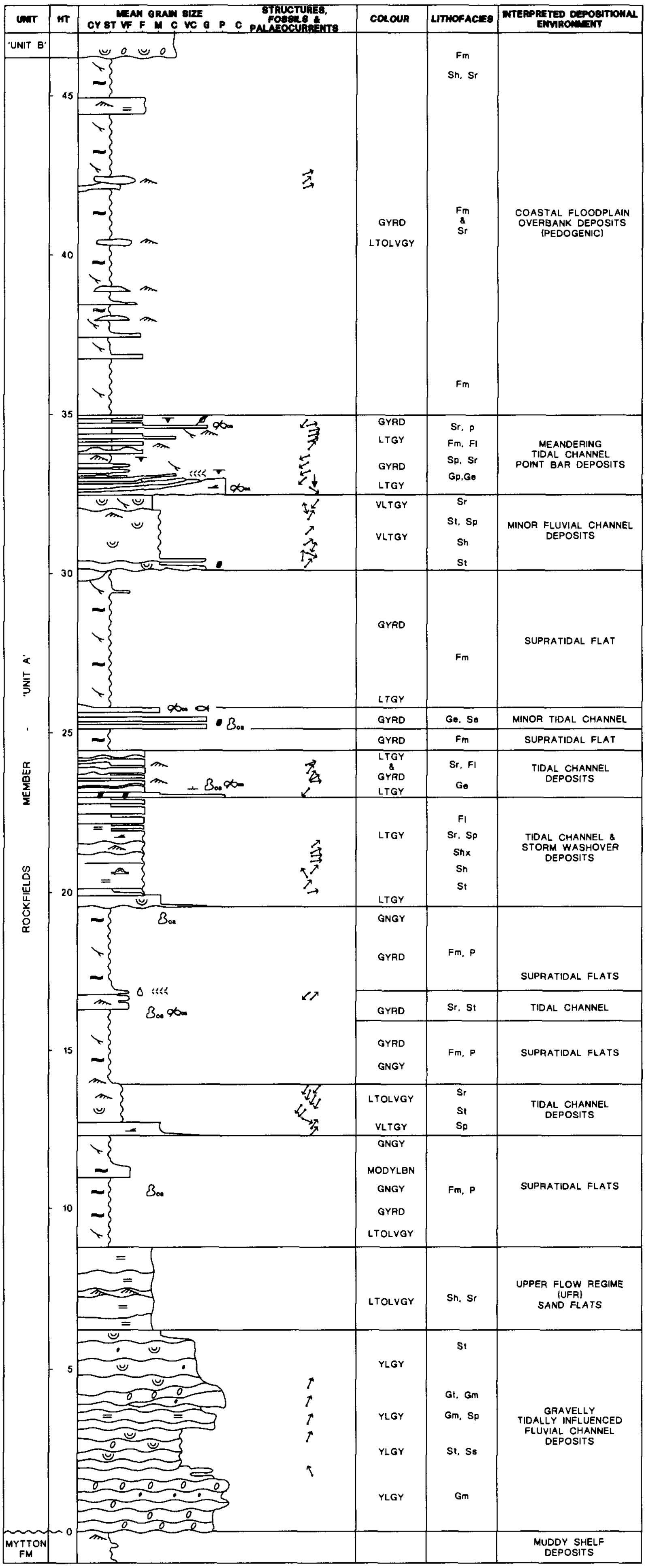


Figure 39. Detailed graphic log of the Rockfields Member (Unit A) in the Broken River at 7859-578447. See Figure 14 for reference.

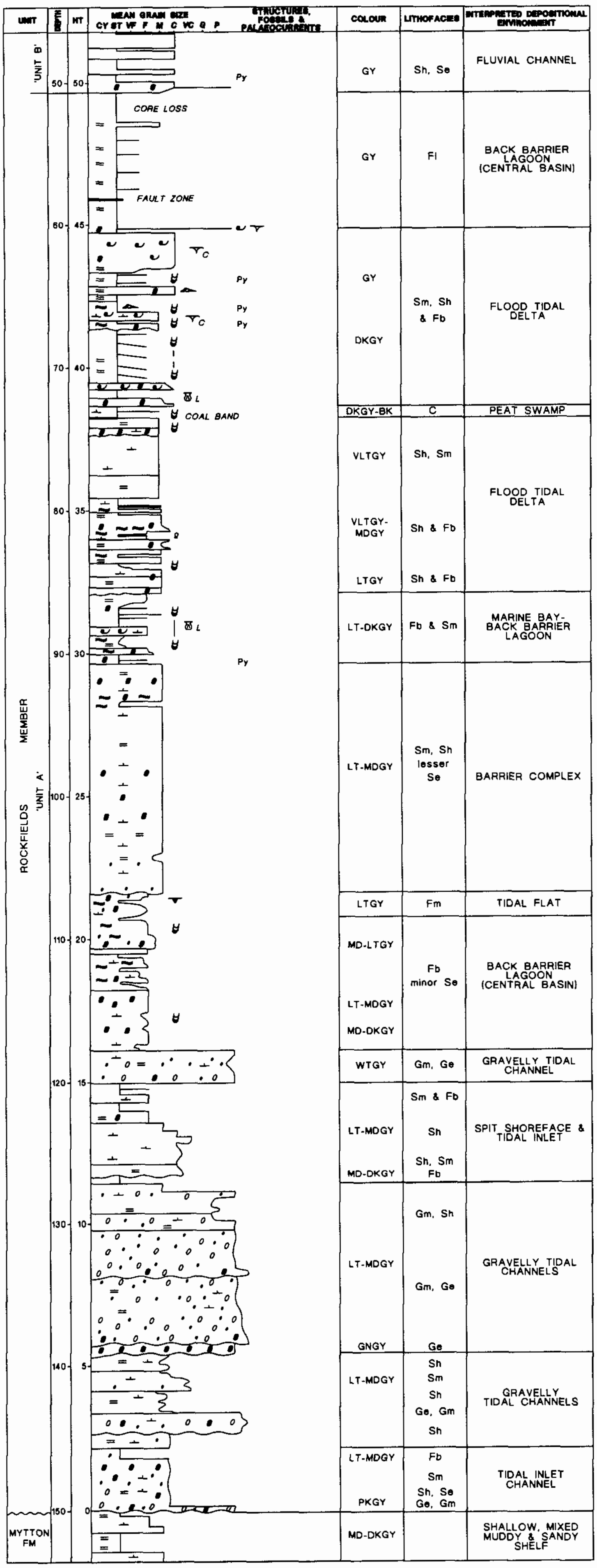


Figure 40. Graphic log of Rockfields Member (Unit A) in GSQ Clarke River 2. See Figure 14 for reference.

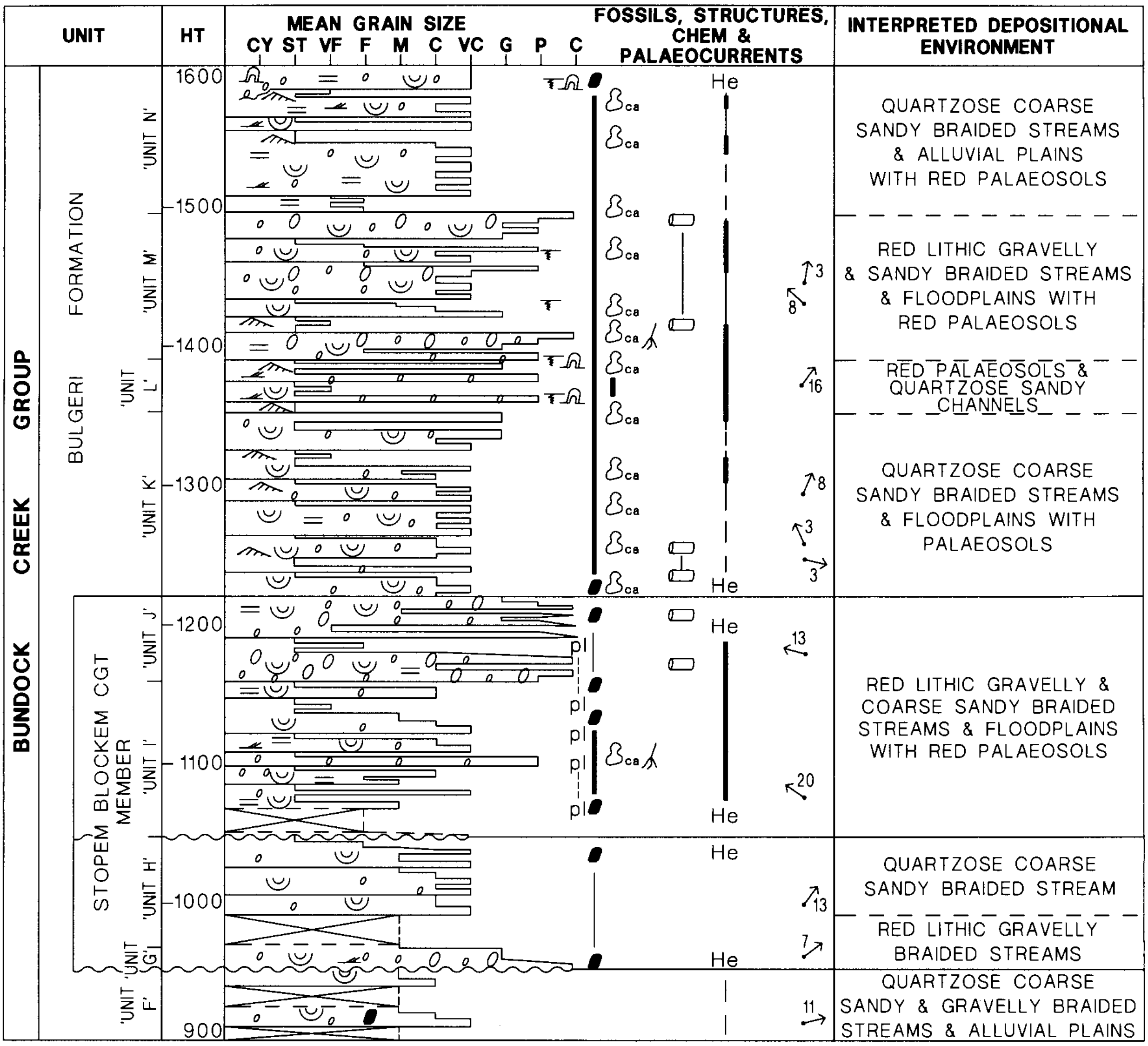


Figure 41. Part of the type section of the lower Bulgeri Formation along the Broken River from 7859-559446 (base of the Stopem Blockem Conglomerate Member) to 556451 (top of Unit M). See Figure 14 for reference.

places, the concentration of carbonate nodules becomes so great that the mudstone host is almost entirely replaced, forming a nodular to laminated limestone. Examples are: in the Craigie area at 7858-733404 (McLennan, 1986) where the host is a mottled red and green mudstone; along the 'Pandanus Creek' -'Lyndhurst' road in a prominent redbed interval at 7859-565712 and 592695; and in GSQ Clarke River 1 (Figure 47; 175 m, 434 m, 438 m, 491.5 m, 492.5 m, 508 m, 515 m).

Similar calcareous structures have been described as pedogenic calcrete (caliche) from Quaternary calcic soils by Giles & others (1966), Goudie (1973, 1983) and Machette (1985). Calcrete forms in soils where carbonate sources are present and accumulation rates are relatively low, mainly under a warm, seasonal climatic conditions (Goudie, 1973, 1983), and its occurrence in the stratigraphic record is widespread (Goudie, 1983, Table 4.2). Pedogenic calcrete in redbeds is especially common in similar Devonian sequences of Europe (Old Red Sandstone, Allen 1974, 1986), North America (Catskill magnafacies - Woodrow & others, 1973; Gordon & Bridge, 1987) and Antarctica (Aztec Siltstone - McPherson, 1979; 1980).

Skarns are locally developed in calcareous redbeds along the margins of microdiorite or dolerite sills and dykes. This is best observed in GSQ Clarke River 1, (Figure 47; 270 m, 277 m, 295.5-298 m, 407-409 m, 416-420 m, 521 m; see Lang, 1986b).

3. Drab, well sorted, fine-medium grained sandstones. This association is typical of the Rockfields Member, but it also occurs in Units N-Q in the upper part of the Bulgeri Formation. The drab sandstones range from sublabile feldspathic to quartzose (Figure 35). The sandstones are generally very fine to medium grained, and generally well sorted. They are similar to the sandstones of the underlying Mytton Formation, but they tend to contain fewer lithic grains. In some places they contain heavy mineral layers, especially magnetite (for example in Unit B, 164-184 m in the type section). Diagenetic pyrite is common, mainly as small concretions.

The sandstones form thick (0.5-10 m), laterally extensive, multistorey complexes, which contain numerous erosive surfaces which define the outlines of lenticular to sheet-like sand bodies. The surfaces are commonly load-casted where the sandstone overlies mudstone. The internal sedimentary structures are described in more detail later (Table 6), but generally they are dominated by flat lamination (and associated parting lineation), trough and low-angle trough cross-bedding, with lesser planar tabular

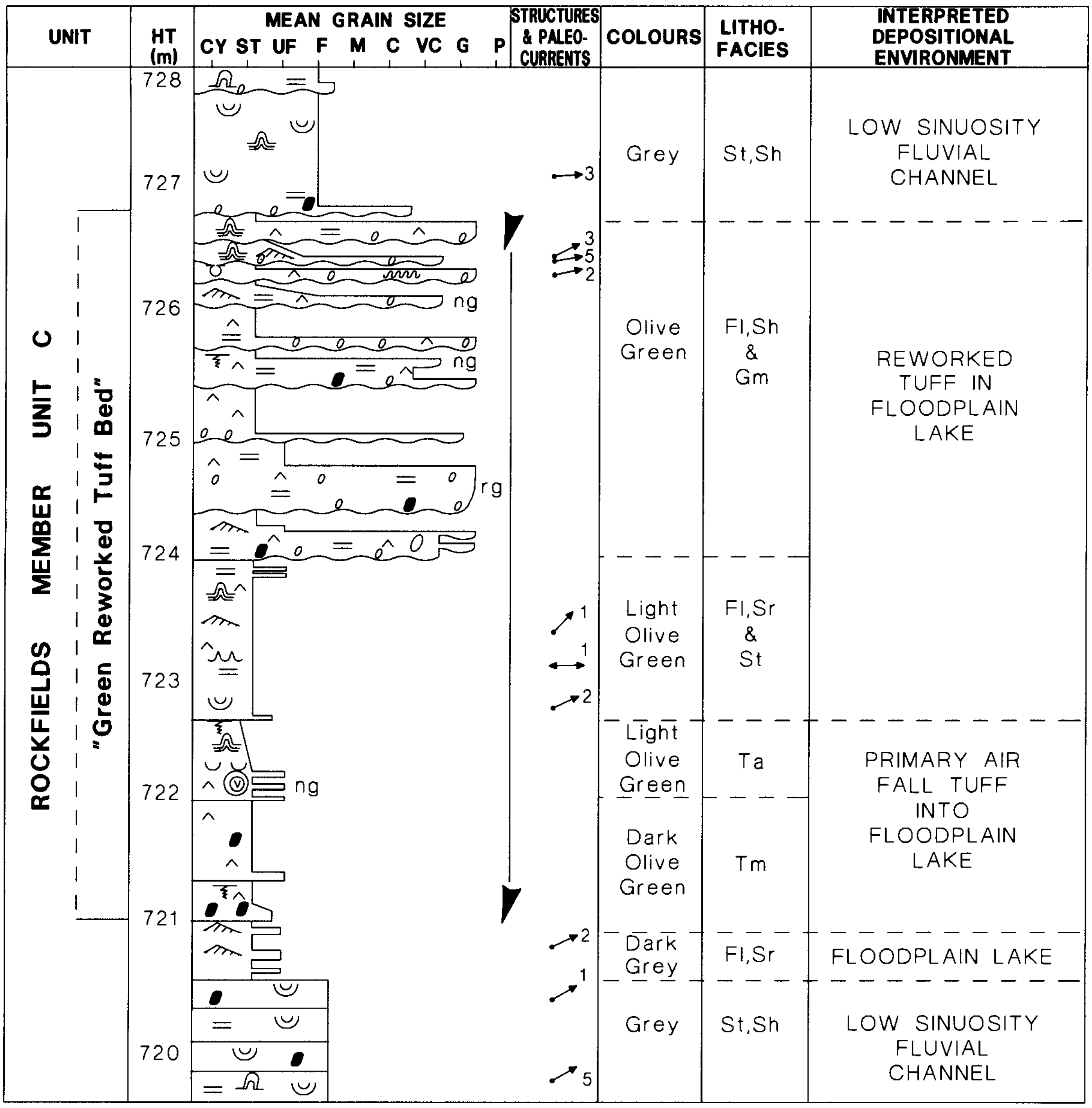


Figure 42. Section through the thick green tuff bed in the lower part of the Bulgeri Formation in the Broken River at 7859-563445. See Figure 14 for reference.

cross-bedding and ripple cross-lamination. Convolute lamination is pervasive in Units B and C (Lang & Fielding, 1991), ranging from small (less than 30 cm) to large scale antiformal water escape pipes (up to 5 m in height) which are separated from each other by broad, flat synforms up to 10 m apart).

The uniform grain size of this association appears to have been largely derived from the recycling of a fine to medium-grained quartzose sedimentary rock provenance, in addition to a direct contribution from granitic and metamorphic rocks. The most likely sources are the Ordovician Wairuna or Judea Formations or their equivalents. Palaeocurrents within this association (over 500 readings from Units B & C) indicate a southerly source area (Figure 37), which suggests that the Judea Formation (or similar rocks of the Thompson Fold Belt) may have originally lain to the south and were entirely eroded as the Lolworth-Ravenswood Province was uplifted during and after the deposition of the Bulgeri Formation.

4. Red polymictic conglomerates and fine to very coarse-grained lithic sandstone. The Stopem Blockem Conglomerate Member and Unit M comprise mainly pebbly sandstone, with lesser conglomerate intervals. The sandstones range from fine to very coarse-grained, and are typically sublabile lithic or lithofeldspathic, whereas the conglomerates are typically pebbly, but contain variable amounts of granules, cobbles and small boulders. The conglomerates have a coarse to very coarse-grained sandstone matrix, that may be micaceous and argillaceous in places. The coarsest conglomerates (maximum clast size up to 300 mm) occur in the eastern exposures of the Stopem Blockem Conglomerate Member, between Gorge Creek and GSQ Clarke River 1 (Plate 28a).

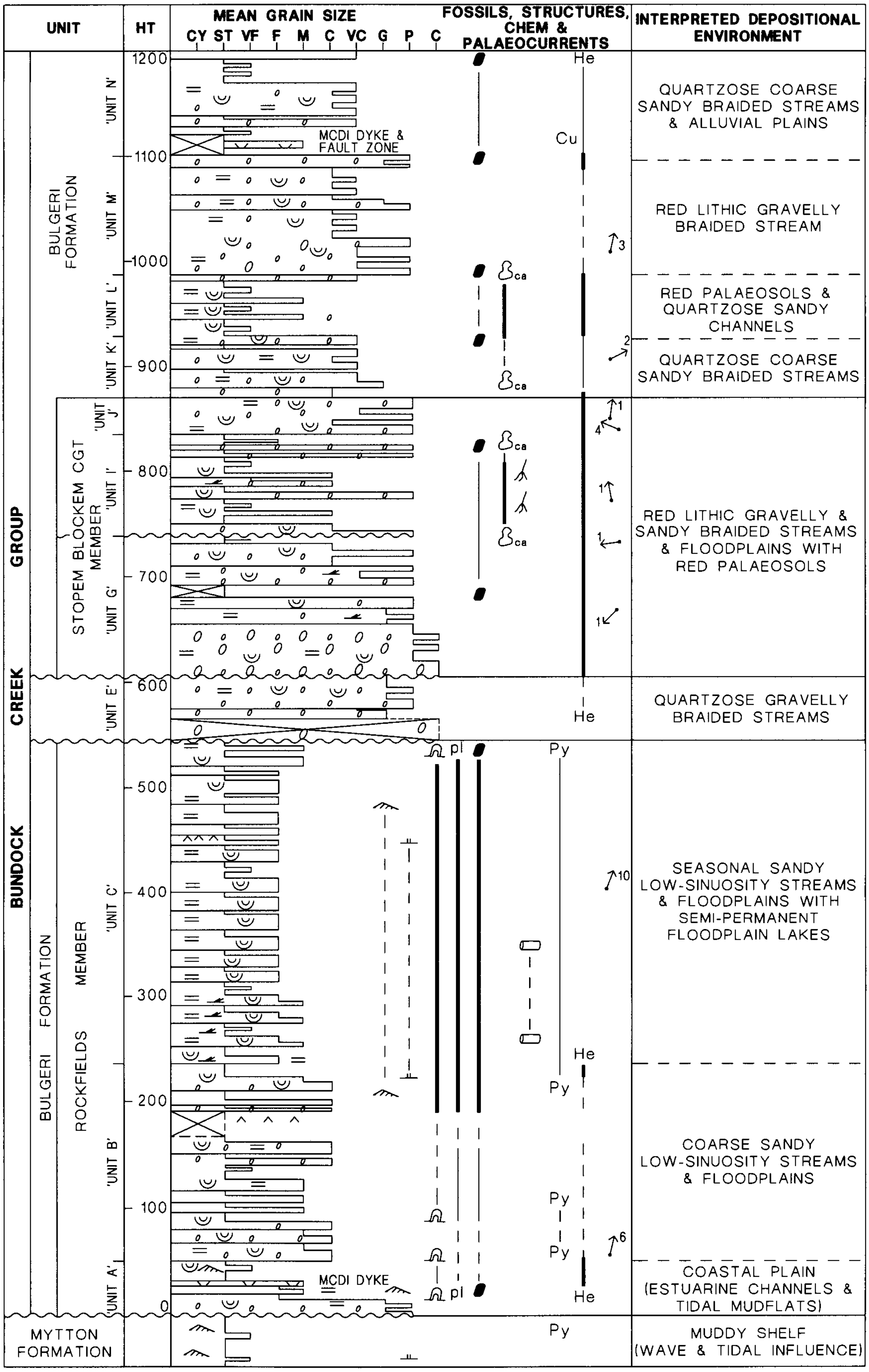


Figure 43. Section through the Bulgeri Formation in the Diggers Creek area from 7859-608501 (base) to 605500 (top of Unit M). See Figure 14 for reference.

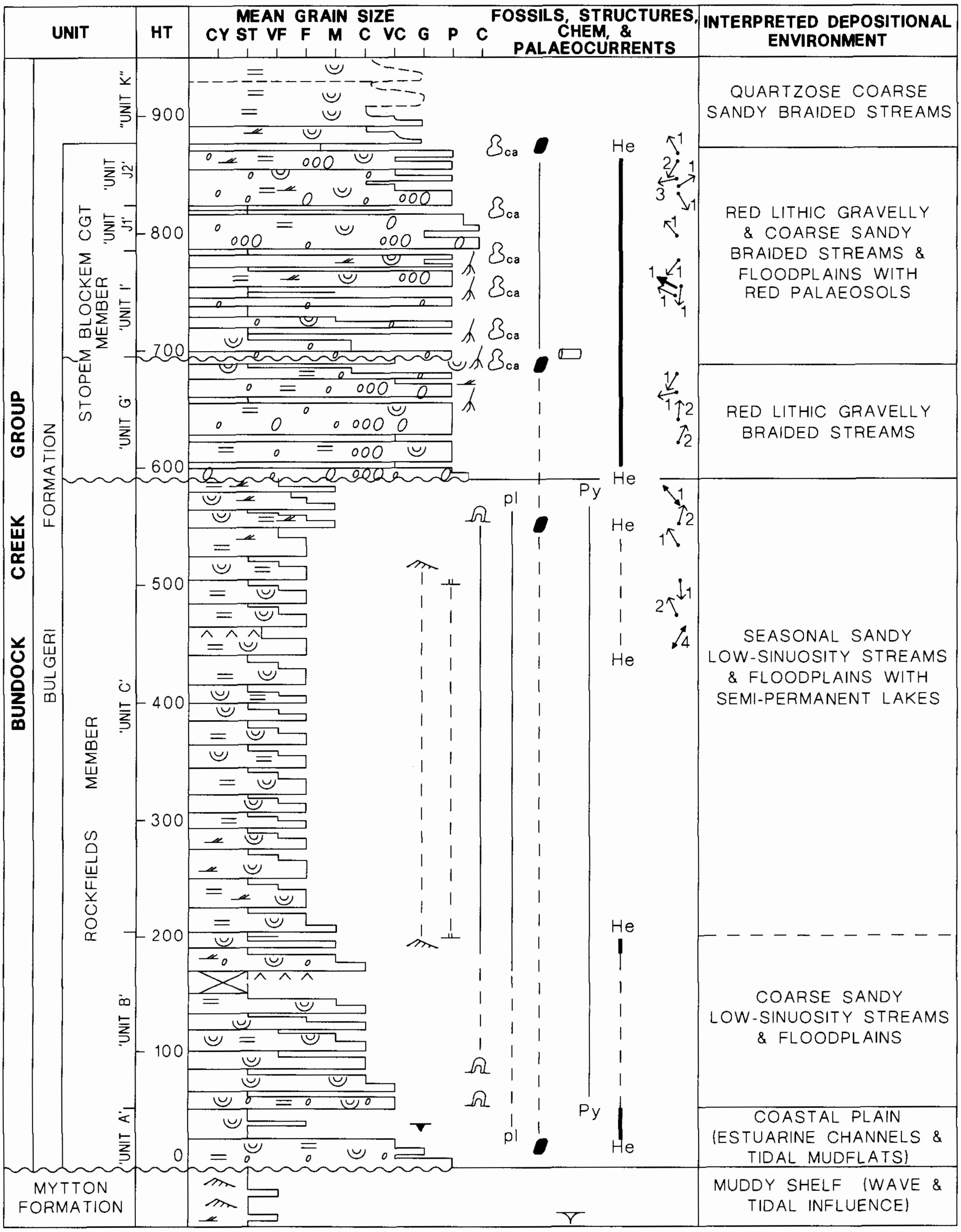


Figure 44. Section through the Bulgeri Formation in the Gorge Creek area from 7859-647536 (base) to 644548 (top of Unit J2). See Figure 14 for reference.

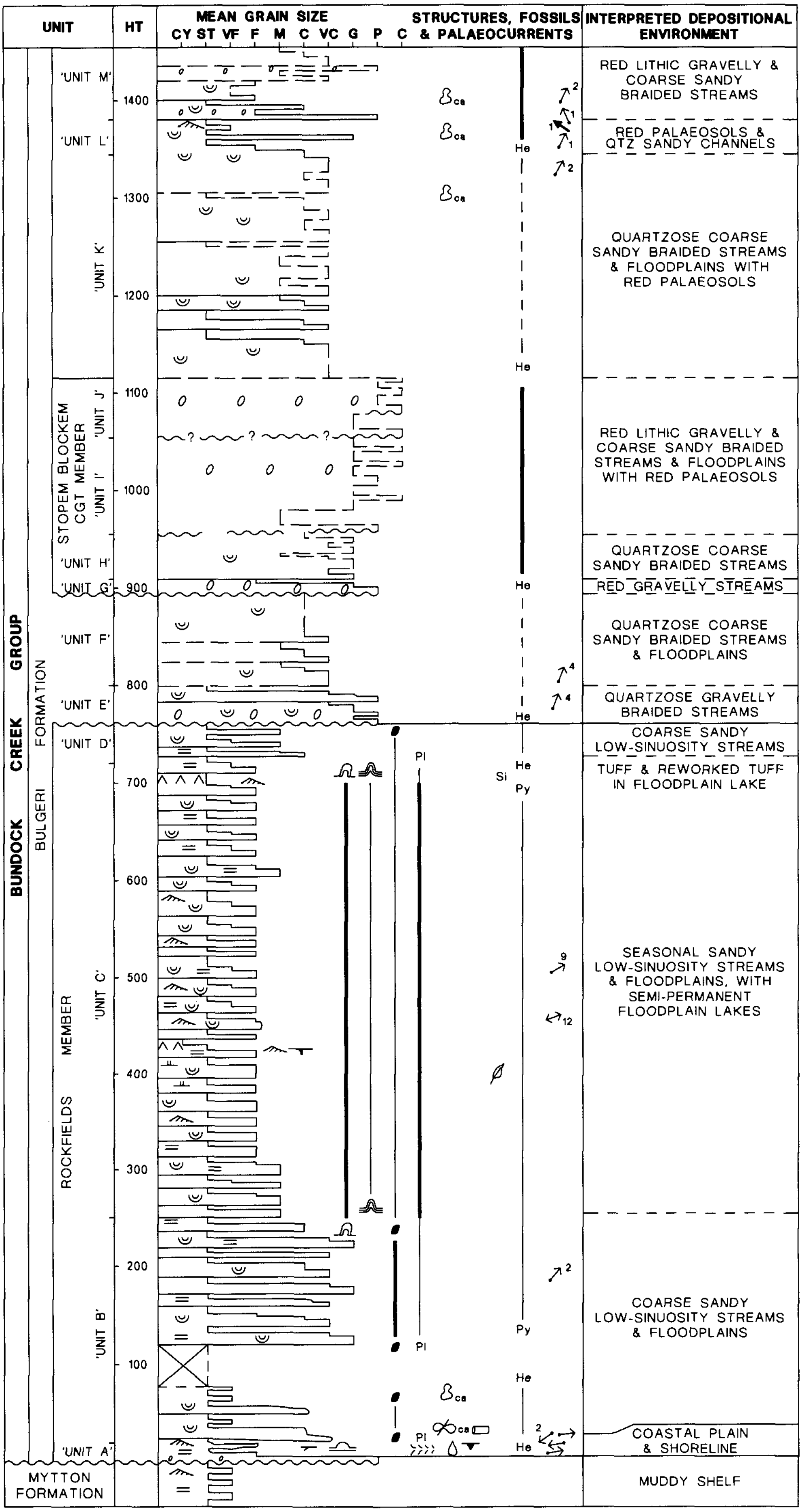


Figure 45. Section through the Rockfields Member in Pages Creek from 7859-559432 (base) to 551437 (top). See Figure 14 for reference.

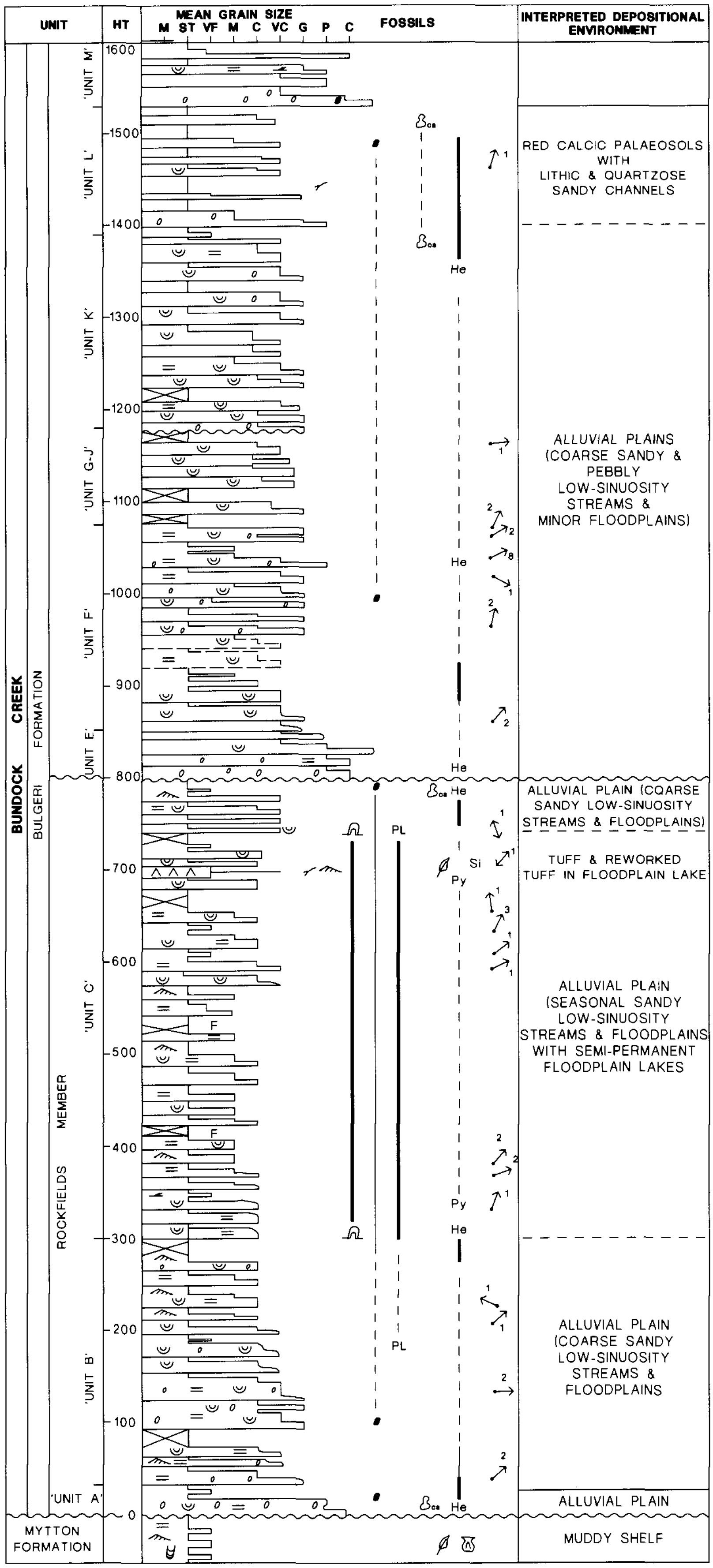


Figure 46. Section through the Bulgeri Formation in the Pages Dam/Sandy Creek area from 7859-489360 (base) to 461367 (top of Unit M). See Figure 14 for reference.

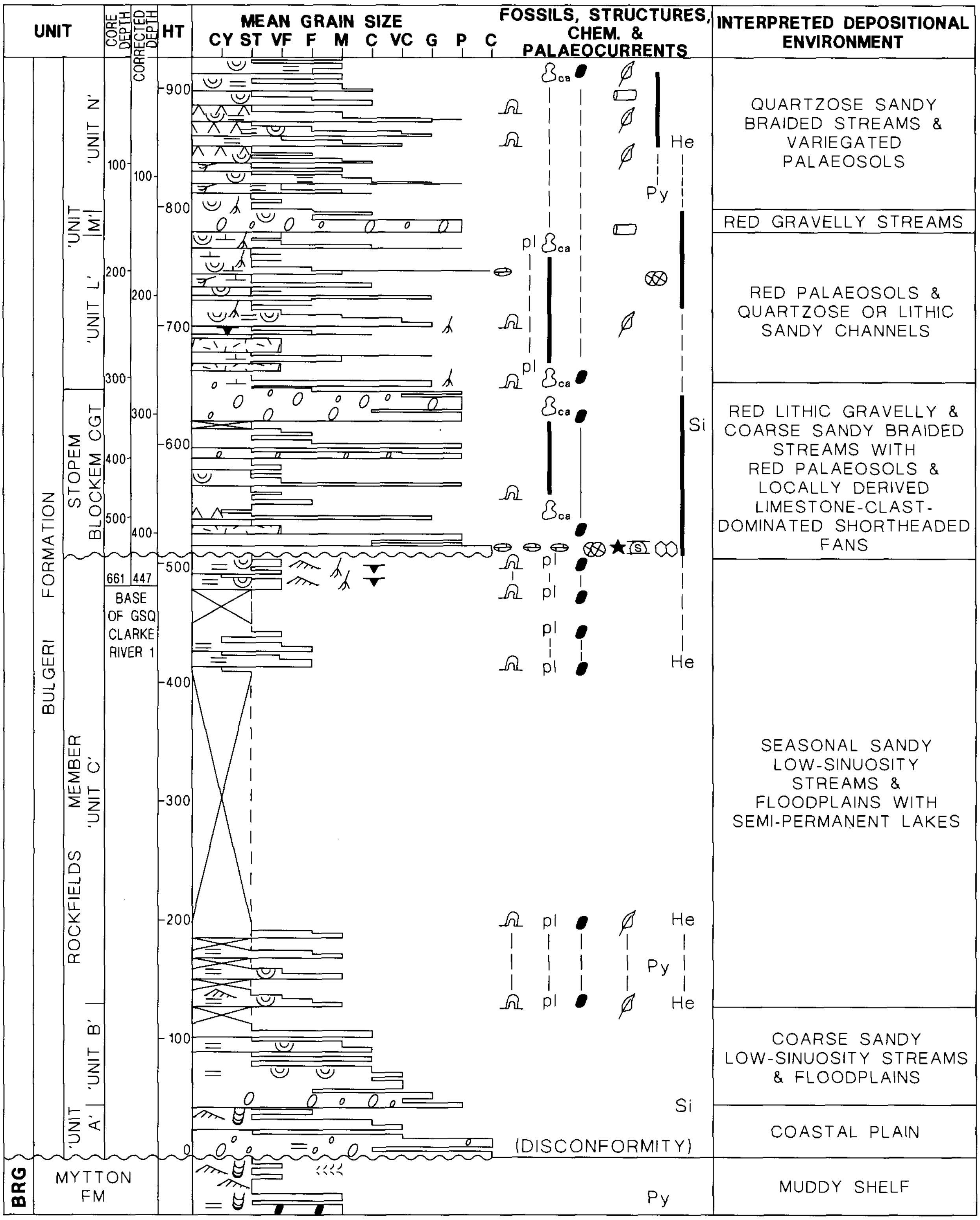


Figure 47. Composite section of GSQ Clarke River 1 (corrected for dip) at 7859-659580 combined with the outcrop section along Atherton Creek between 653599 and 658585. See Figure 14 for reference.

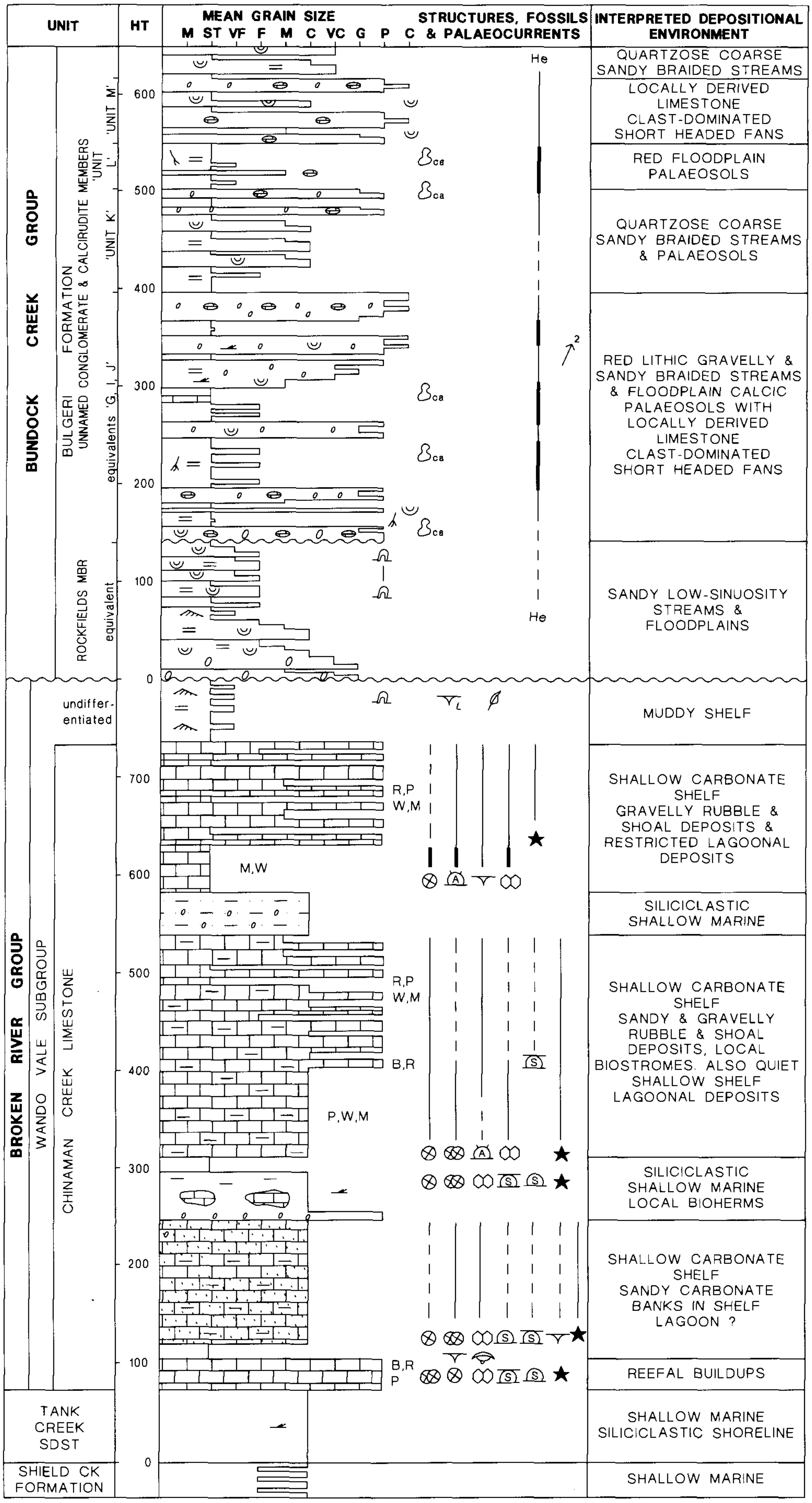


Figure 48. Section through the Broken River Group and Bulgeri Formation in the Six Mile Syncline from 7859-605689 (base of Tank Creek Sandstone in Chinaman Creek) to 588694 (top of unnamed calcirudite lens). See Figure 14 for reference.

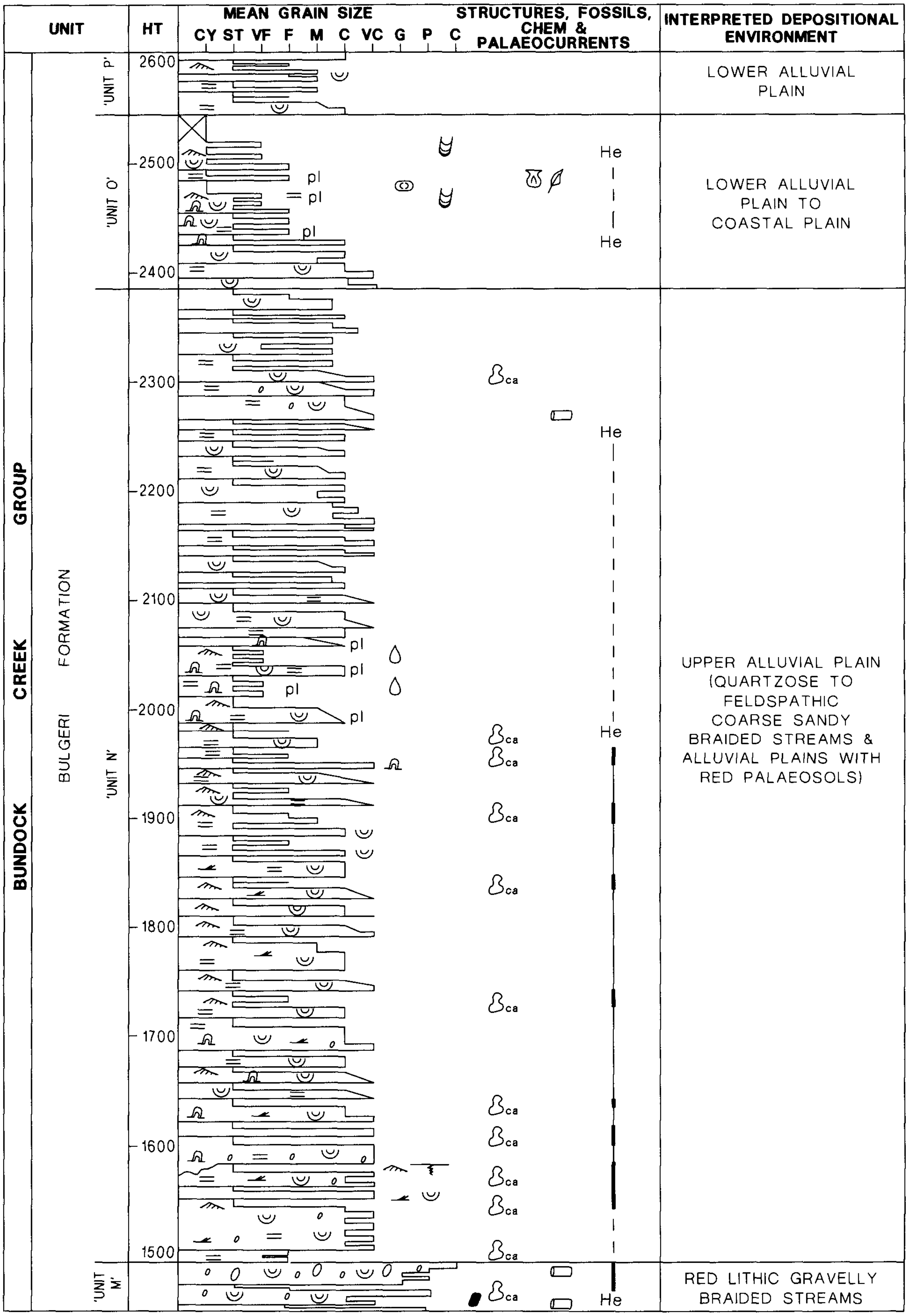


Figure 49. Section through the middle part of the Bulgeri Formation in the Broken River between 7859-556451 (base of Unit N) and 551454 (top of Unit O). See Figure 14 for reference.

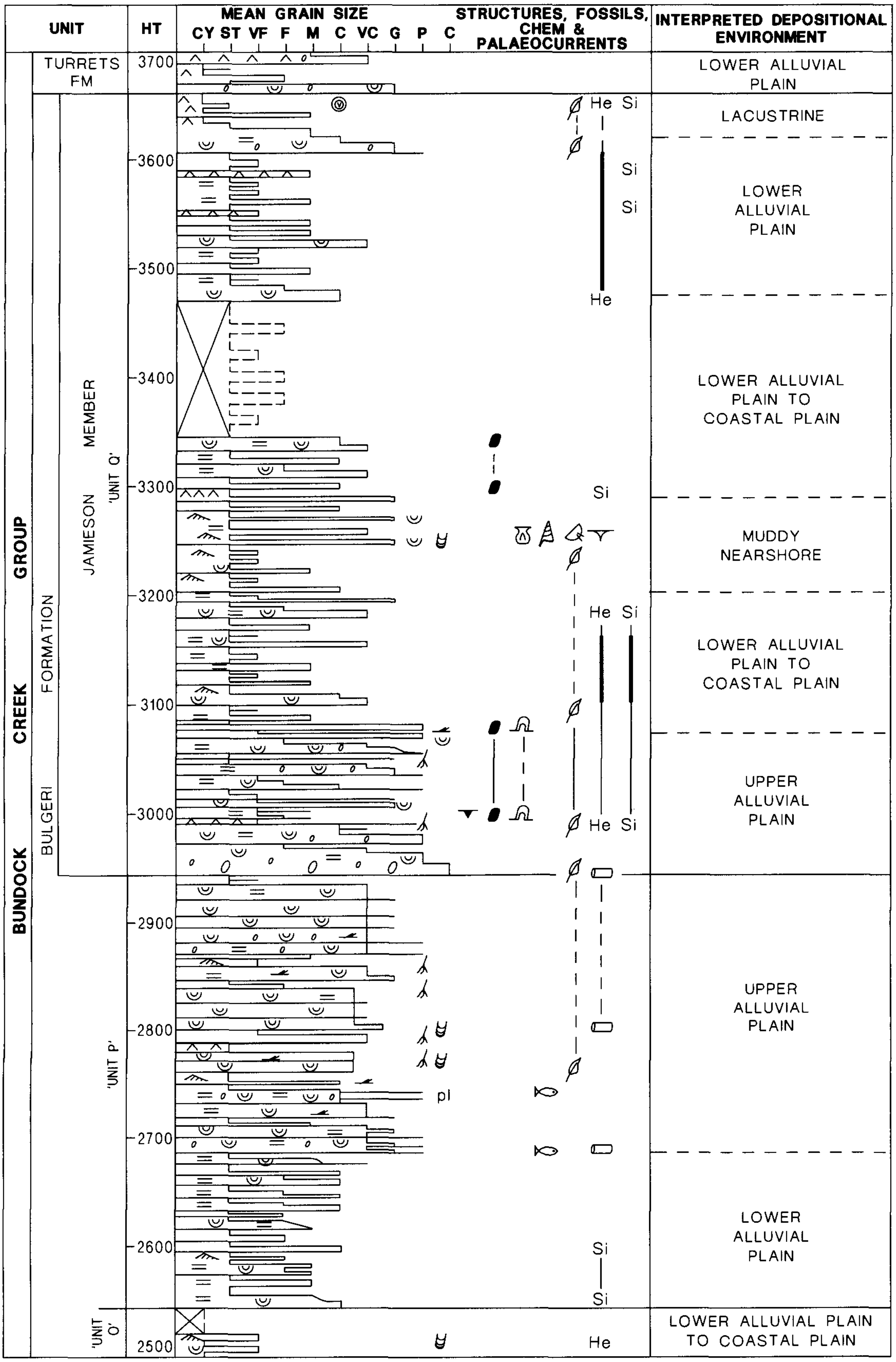


Figure 50. Section through the upper Bulgeri Formation including the type section of the Jamieson Member, in the Broken River, between 7859-546450 (base of Unit P) to 533451 (base of the Jamieson Member) and 530460 (base of the Turrets Formation). See Figure 14 for reference.

The red colour is mainly due to a combination of pre-depositional haematisation of lithic grains or clasts (especially chert), and post-depositional authigenic haematite replacement of phyllosilicates (mainly biotite, but also muscovite) and detrital clays (Lang, 1985, 1986a).

The conglomerates are commonly medium to thick bedded and locally massive. However, imbricated pebbles and large scale low-angle trough cross-bedding are also common. Erosive structures with pebbly lags abound. Pebbly sandstones commonly have horizontal stratification, or trough, low-angle trough, or planar-tabular cross-bedding (Plate 28c). Sparry calcite cement occurs in some places in the conglomerates (eg. 7858-470374), and calcified tubules occur in some of the sandstones. They represent void-filling calcrete and calcretised rootlets respectively, and are probably related to the pedogenic processes which formed calcrete nodules in the fine-grained redbeds (Lang, 1985, 1986a).

Clasts are dominantly extrabasinal in origin, most being derived from sedimentary rock sources (40-70%) and include quartz-veined fine-grained quartzose arenite or siltstone, red to green chert or jasper, and minor limestone. White vein quartz is also common (5-20%), with lesser metamorphic and igneous clasts (mica schist and acid volcanics). Reddened mudstone rip-up-clasts, derived from the erosion of intrabasinal fine-grained redbed intervals, are locally abundant (Plate 29e).

The principal and most obvious source area indicated by the dominant sedimentary clast compositions (and possibly some of the vein quartz and volcanics) is the Wairuna Formation (Lang, 1985, 1986a) which presently lies mainly to the east, or the Judea Formation at the base of the Graveyard Creek Subprovince. The coarseness of the clasts indicates a relatively proximal source area, and the palaeocurrents in Units G, I-J and M (Figure 37) indicates the source area lay to the southeast or south. Equivalents of the Wairuna Formation could originally have overlain the Lolworth-Ravenswood, but have since been completely eroded after substantial uplift during the Devonian. The limestone clasts indicate a more local source was active during deposition, probably derived from faulted blocks of the underlying Devonian carbonate sequence (see Calcirudites, below). The metamorphic clasts and associated mica were probably derived from the Lolworth-Ravenswood Province.

5. Drab or variegated fine-grained sandstone, siltstone and mudstone. This group of rocks includes all non-marine, fine-grained rocks which are within the colour range of light to dark grey, brownish grey to greenish grey.

In the Rockfields Member (Unit B & C), these rocks form intervals up to 2 m thick between drab, multistorey sandstone complexes. In places (mainly Unit B) they are intimately associated with fine-grained redbeds, forming variegated intervals of red and drab fine-grained rocks, up to 10 m thick that can be traced for 4 000 m laterally (Lang & Fielding, 1991). Parallel lamination, ripple cross-lamination and associated ripple marks (both current and wave ripples) are the most common sedimentary structures, but some mudstone intervals are massive. Desiccation cracks

PLATE 24:

a. **Unconformity between conglomerate and pebbly sandstone of the Bulgeri Formation and the Mytton Formation in the Broken River. Dip of conglomerate - 75° to 318°; dip of shales - 85° to 330°. Slight angular truncation of thin arenite beds immediately above hammer. The conglomeratic beds contain horizontal stratification, normal and reverse grading, weakly-developed imbrication and bimodal trough and planar cross-bedding (similar to that in (b)) indicating palaeocurrents trending mainly northeast. Lithofacies Gm, Gt, minor St. These gravelly deposits are interpreted as dominantly fluvial channel-fill (CH) influenced by strong tidal currents in an estuarine distributary system. Unit A, 0-2 m, in the type section (refer to Figure 39). 7859-578447, Broken River, 2 km downstream of Red Range Gorge.**

b. **Bipolar, planar cross-bedding in pebbly sandstone (Lithofacies Sp) in the upper part of the lower conglomeratic interval of the Rockfields Member, indicating strong tidal currents. Unit A, about 6 m above unconformity, eastern bank of the Broken River, 95 m northeast of the locality shown in (a).**

c. **Flat laminated and low-angle inclined to weakly hummocky cross-stratified, very fine-grained sandstone (Lithofacies Sh and Shx). Ripple cross-lamination and small-scale trough cross-beds and parting lineation trend dominantly northeast. These rocks are enclosed within redbeds of pedogenic origin and are interpreted as storm wash-over deposits preserved within a supratidal mudflat sequence behind a sandy barrier shoreline system. Unit A, 20-21 m in the type section (refer to Figure 39). Locality as in (a).**

d. **Outcrop of steeply dipping strata (75° to 318°) showing grey, trough and planar cross-bedded, and flat laminated and ripple cross-laminated, medium-grained sandstone (Lithofacies St, Sh, Sp and Sr) at the base. Palaeocurrents trend dominantly northeast, but are weakly bipolar near the top. This is overlain by a heterolithic interval of low-angle, inclined, master foresets comprising reddened and desiccated interbeds of intraformational conglomerate, silty sandstone and mudstone with pedogenic structures (Lithofacies Gp, Ge, Sp, Sh, and Sr interbedded with Fm, Fl, Fr and minor P). The master foresets trend south but contain bipolar ripple cross-lamination trending southwest and northeast. This outcrop is interpreted as high-sinuosity, tidal and supratidal channel deposits comprising a sandy channel element (CH) at the base overlain by a lateral accretion element (LA). Unit A, 30-35 m in the type section (refer to Figure 39). Locality as in (a).**

e. **Mudcracks in reddened, muddy siltstone (Lithofacies Fm) at 33.4 m indicating desiccation within the heterolithic lateral accretion element shown in (d).**

f. **Raindrop impressions on reddened, muddy siltstone laminae (Lithofacies Fm) interbedded with the desiccated beds shown in (e), further indicating subaerial exposure.**

g. **Burrowed fossiliferous sandstone and mudstone (Lithofacies Sm and Fb), containing a *Cyrtospirifer* mould, indicating a definite shallow marine origin for this part of the Rockfields Member during the Late Devonian (probably Frasnian). Note the subvertical burrows into the mudstone, perhaps indicating a period of non-deposition allowing the development of a 'hard ground' before the accumulation of storm-deposited 'shell-hash' in a back-barrier lagoon. Core from GSQ Clarke River 2 at 66.42 to 66.59 m.**

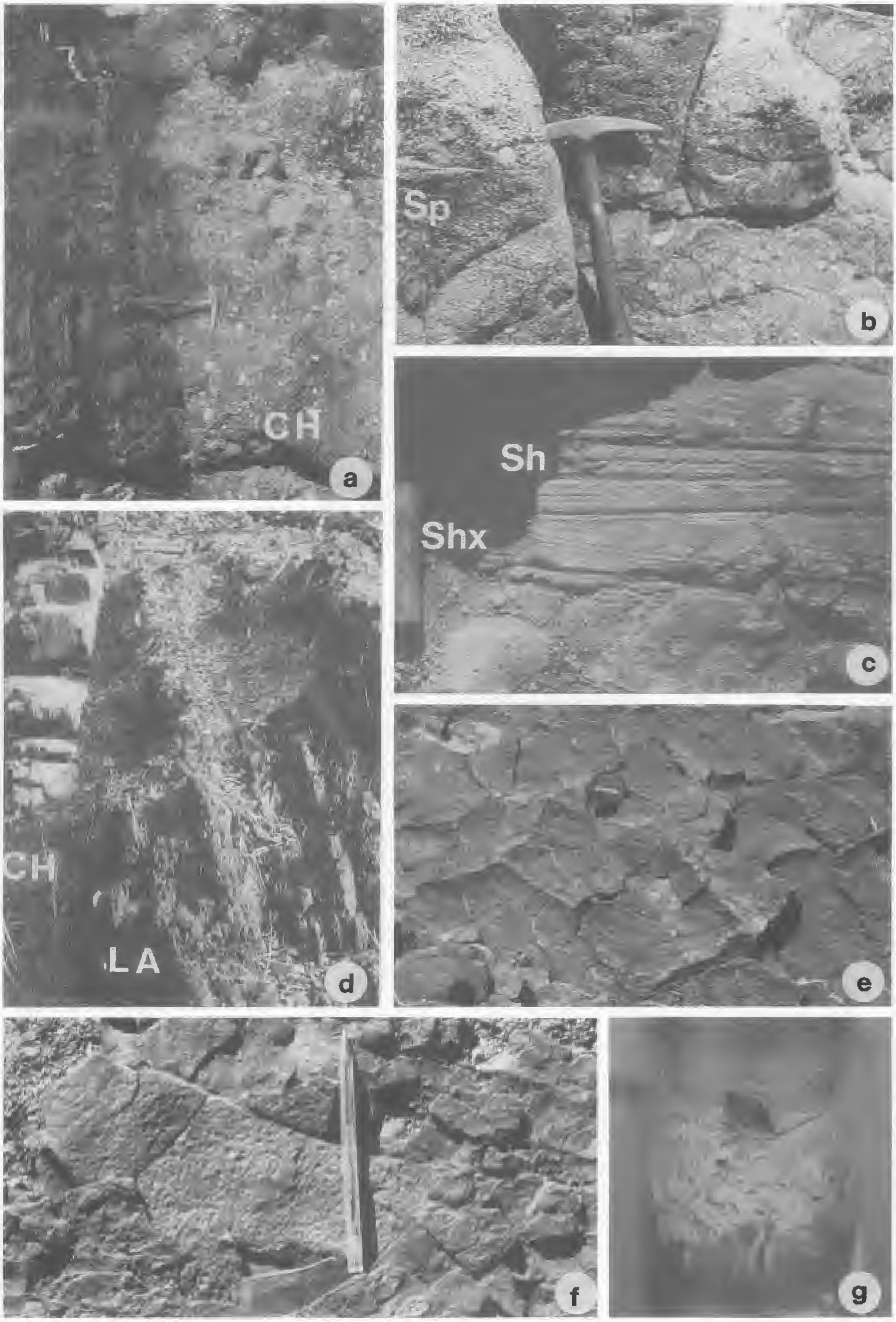


Plate 24. Rockfields Member, Unit A, Bulgeri Formation.

occur rarely. Sandstone dykes and convolute lamination occur in some places. Fossil remains include plant fragments and rare fish bones.

Similar drab to variegated fine-grained intervals occur throughout Unit N, O, P and the lower and upper parts of Unit Q. Representative examples in Unit N, in the upper 100 m of GSQ Clarke River 1 (Lang, 1986b), consist of fine-grained intervals up to 5 m thick overlying erosively-based, drab sandstones and conglomerates; together they form fining-upward cycles 1-12 m thick. In a few places, dark grey carbonaceous mudstone contain carbonised palynomorphs and dichotomous plant fragments.

Many of these fine-grained intervals may be partly tuffaceous, and grade into the green volcaniclastic fine-grained sandstones and siltstones described below. In the upper part of Unit Q, a laterally extensive, dark grey, silicified, silty mudstone with variable amounts of volcaniclastic debris occurs near the top of the Jamieson Member (7859-584501), and contains rare to common plant debris. Cellular remains can be seen in thin sections, and indeterminate fungal remains have been recovered from palynological samples (Lang, 1985, 1986a).

6. Green volcaniclastic fine-grained sandstone and siltstone. Numerous intervals containing green volcaniclastic fine-grained sandstone and siltstone (reworked tuff) are known throughout the Bulgeri Formation. They are particularly common and best exposed in the Rockfields Member. They typically lie within fine-grained intervals (red or drab), and range from a few decimetres to 6 m thick, and many are laterally extensive (15 km). They are distinctive, due to their olive green colour, and pervasive silicification. When not silicified, they typically have a greasy lustre and waxy translucence typical of clay alteration (montmorillonite?). Most are fine-grained, typically ranging from fine to coarse silt-grade. However, the thickest interval in the upper part of the Rockfields Member at 721 m in the type section (Figure 42), contains coarser-grained ash and lapilli, ranging from very fine sand-grade to pebbles and cobble-sized clasts up to 70 mm in diameter (Plate 27a).

The fine-grained matrix is vitriclastic, composed almost entirely of glass shards with lesser euhedral volcanic quartz and feldspar (Plate 27b), as well as non-volcanic material such as detrital muscovite. Most of the shards and feldspars are replaced by chalcedony, calcite, and epidote (zoisite and clinozoisite). The latter apparently contributes to the green colour of the rock, although X-ray diffraction indicates that the amount is less than 5% in the very fine-grained samples (Lang, 1985, 1986a). Chalcedony-filled cavities, containing laminae which are horizontal with respect to bedding, indicate silicification occurred before folding, probably as a consequence of early devitrification.

The clasts are mainly rhyolite (Plate 27a), large feldspar crystals, fragments of green, fine-grained tuff similar to the matrix, and rare metamorphic rock clasts. The clasts are randomly distributed in the matrix, or confined to thin, graded and reverse-graded beds, or in scour fills. The volcanic clasts are commonly subrounded, but many are angular, especially the fine-grained tuff clasts. Accretionary lapilli from 1 to 10 mm in diameter occur near the base of the thickest tuff bed (Figure 42, and Plate 27b).

Many of the intervals are structureless, but others are laminated, thin bedded, and in places graded. The latter at least were deposited from suspension in a body of water, possibly as air fall tuffs. However, nearly all beds contain sedimentary structures indicating action by traction currents and waves in relatively shallow water, and therefore they represent reworked tuffs. Plant fragments and rhizoliths occur in places within the intervals, indicating the presence of *in situ* vegetation, as well as drifted plant remains.

A striking feature of these reworked tuffs is the pervasive soft-sediment deformation, and this is especially the case with the thickest reworked tuff interval in the Broken River. This interval contains convolute lamination, water-escape structures, flame structures, clastic dykes and sills, ball-and-pillow structures, slumping, brecciation and microfaults (Plate 27c). The slump directions are consistent with the current directions of the ripple cross-lamination. The pervasive soft-sediment-deformation structures occurred during and after deposition, but before consolidation. They were caused by a variety of factors including loading and slumping, and possibly seismic shocks.

Lang (1985, 1986a) and Lang & Fielding (1991, 1992) interpreted these green volcaniclastic sediments as mainly reworked tuffs, deposited in extensive, shallow, floodplain lakes or overbank areas.

The reworked tuff intervals of the Bulgeri Formation are evidence of Late Devonian acid to intermediate volcanism in the region. The thick intervals within the Rockfields Member are evidence of volcanism as old as the Frasnian-early Famennian, based on biostratigraphic data (Withnall & others, 1988b). This is significant, because no proven

PLATE 25:

a. **Internal mould of a large log of presumed lycopod origin in the base of a fluvial channel. Unit B, 215 m in the type section (refer to Figure 38).**

b. **Flat lamination overlain by large-scale planar (tabular) cross-beds in fine to medium-grained drab sandstone (Lithofacies Sh and Sp). This outcrop is interpreted as a sandy linguoid dune (LB element) overlying a laminated sand sheet (LS element) within a larger channel-fill complex. Unit C, between 240 and 252 m in the type section (refer to Figure 38).**

c. **Metadepositional convolute lamination (Lithofacies Ssd in Sh). Note truncation surface by low-angle trough cross-stratification (Lithofacies Sl). The overturned fold may have been caused by fluid drag (to the north) of a laminated sand sheet just prior to erosion and subsequent deposition of another laminated sand sheet. Unit C, 270-284 m in the type section (refer to Figure 38).**

d. **Cliff exposure in the upper part of Unit C, showing the typical thinly interbedded character in this part of the sequence. The thicker sandstone beds are flat laminated and trough and planar cross-bedded and contain abundant convolute lamination, indicating rapid deposition. These sandstones are interpreted as crevasse splay elements (CS), whereas the interbeds are overbank deposits (OF). At about 630 m in the type section (refer to Figure 38).**

e. **Oblique section through a convolute lamination structure (Lithofacies Ssd in Sh). This could superficially be confused with hummocky cross-stratification in fluvial strata. However, along strike this bed contains larger scale, multiphase soft-sediment deformation similar to that shown in Figure 57. Unit C, at about 500 m in the Page Creek section (refer to Figure 45).**

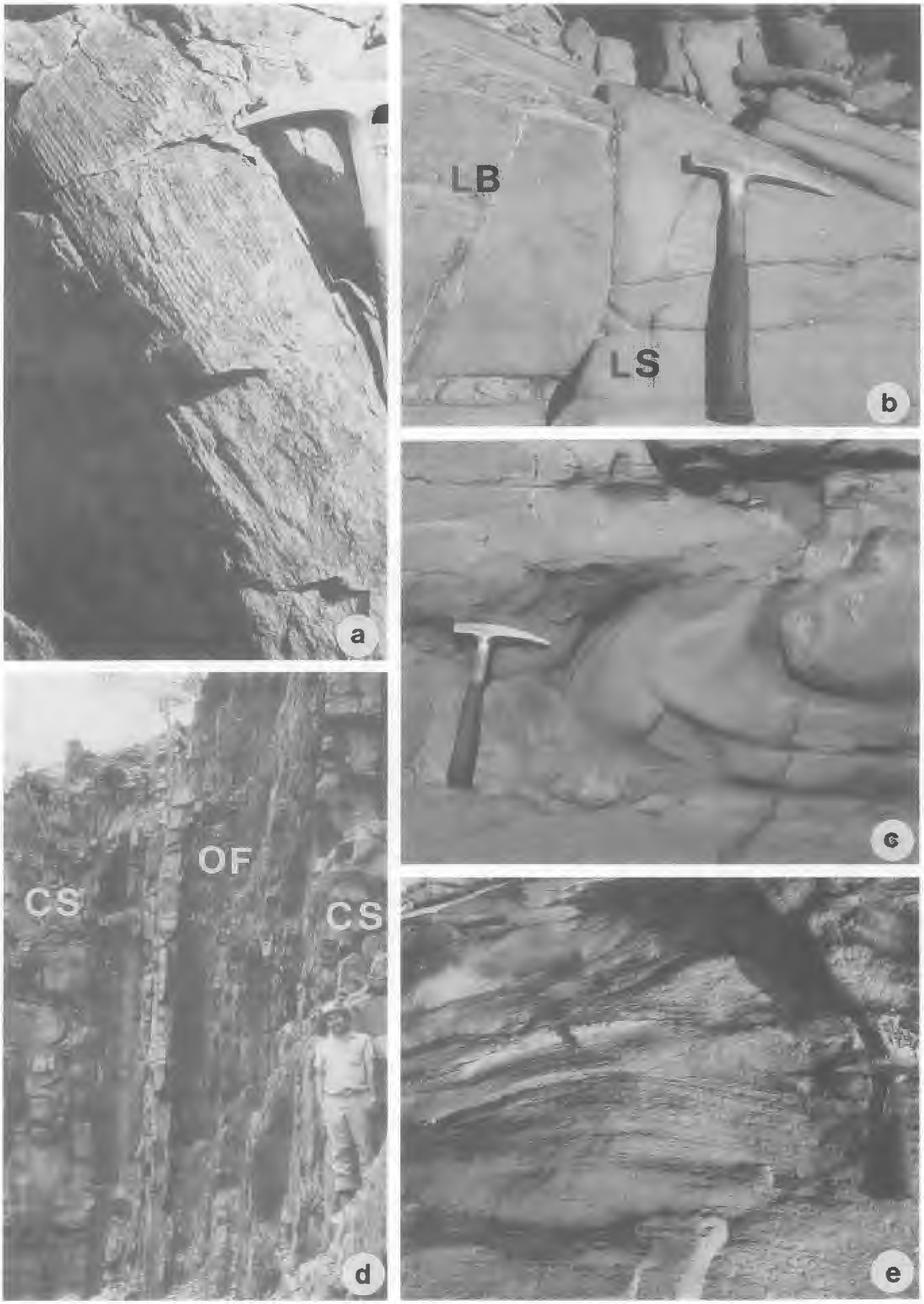


Plate 25. Rockfields Member, Units B and C, Bulgeri Formation.

Late Devonian volcanics are known to occur in the surrounding region. Igneous rocks of the nearby Montgomery Range Igneous Complex, and those in the Georgetown area to the west, are all Carboniferous or younger (Withnall & others, 1988b; Bain & others, in press). To the east, unnamed plutons intruding the Camel Creek Subprovince have been dated as latest Devonian to Carboniferous (Richards & others, 1966), and are probably also too young to have been associated with the regional volcanism.

Similar, and approximately coeval (Frasnian-early Famennian), volcaniclastic and tuff intervals occur in the Dotswood Group of the Burdekin Basin, 200 km to the east (Figure 1). Lang & others (1990a, b) suggested that these rocks may have been sourced from volcanics in the northern part of the Drummond Basin. However, recent palynological dating of strata within the basal volcanic successions of the northern Drummond Basin has resulted in the confirmation of only mid-Famennian or younger strata (G. Morrison, personal communication, 1991). These strata are therefore correlatives of the mid-Famennian-Tournaisian Keelbottom Group of the Burdekin Basin, which also has a significant volcaniclastic component.

Even if Frasnian-early Famennian volcanics are eventually discovered in the northern Drummond Basin or Connors Arch, they probably would have been too far removed to be considered a likely source for the volcaniclastic sediments in the Bulgeri Formation. Presently, these areas lie 500 km to the southeast of the Graveyard Creek Basin, and even if there were major sinistral dislocation along the Clarke River Fault Zone since the Late Devonian, the areas would still have been at least 200 km apart.

The accretionary lapilli present in the thickest reworked tuff interval in the Rockfields Member could have been delivered following rain through ash clouds emanating from volcanism anywhere in the region. However, the coarse grain-size (pebble to cobble-grade), the angular nature of some of the volcanic clasts, and the well-preserved glass shards all point to a relatively local source.

The conclusion is that the locations of proven Frasnian-early Famennian volcanics (or their sub-volcanic equivalents) are yet to be discovered in the Townsville hinterland. It is suggested however, that the source(s) for volcaniclastic sediments of the lower Bulgeri Formation, probably lay within the surrounding Lolworth-Ravenswood or Georgetown Province, and future mapping and radiometric age-dating may solve this problem.

7. **Calcirudites.** Several isolated and some continuous lenses of slightly reddened, grey calcirudite occur in the lower part of the Bulgeri Formation either as a basal conglomerate, or at the level of the Stopem Blockem Conglomerate, or slightly higher. Most lie in the eastern part of the unit, where it unconformably overlies the Dip Creek and Chinaman Creek Limestones. Jell (1967), and Wyatt & Jell (1980) included most of the calcirudites in the Dip Creek and Six Mile Synclines in the upper part of the Broken River Formation as it was understood then. However, they recognised that they were derived by subaerial erosion of the underlying limestones. The distribution and interpretation of these conglomerates was discussed in detail by Lang (1985, 1986a), who included all the reddened calcirudites, along with their enveloping fine-grained redbeds and red conglomerates and sandstones, in the Bulgeri Formation.

In the Rockfields Syncline, calcirudites occur increasingly higher stratigraphically in the Bulgeri Formation towards the southeast. They eventually interdigitate with the Stopem Blockem Conglomerate Member, as seen in GSQ Clarke River 1 and the surrounding outcrops.

Three types of calcirudite can be recognised, and examples of all three types occur in the northern and eastern parts of the Bulgeri Formation.

Type 1 range from oligomictic conglomerates composed almost entirely of reworked Devonian limestone clasts to polymictic conglomerates with up to 30% other clasts (Plate 28d). They have a quartzose sandy matrix. The best examples occur in the Six Mile Syncline (Figure 48), and a detailed map showing their distribution was given by Jell (1967). Other examples occur as basal conglomerates in the Dip Creek Syncline (between 7859-662638 and 673651), and as several lenses in the vicinity of GSQ Clarke River 1.

Type 2 are conglomerates and calcirudites, where the percentage of limestone clasts to other clasts ranges from 30% to 70%. These occur as lenses of basal conglomerate near the nose of the Atherton Creek Anticlinorium between 7859-581550 and 601567, and around 632595. They also occur north of Teddy Mount (7859-428664).

Type 3 are polymictic conglomerates, gradational with the red conglomerates and pebbly sandstones described above, and contain up to 30% limestone clasts. Where the Bulgeri Formation overlies siltstone and arenite in the Dip Creek Syncline, the basal conglomerate is quartz-dominated and polymictic, containing merely granules, pebbles, and rare cobbles of limestone (for example, 7859-621582, 596566, and 584544).

The limestone clasts range in size from granules and pebbles to cobbles, the latter being most common. Locally, boulders up to 80 cm in diameter occur. Most clasts are well rounded. The calcirudites range from being organised (horizontally stratified and clast-supported), to disorganised (unstratified and matrix- supported). The matrix supported calcirudites are rare, and limited laterally to less than a hundred metres (7859-596566). The matrix is commonly granule to very coarse sandstone, quartz- dominated, and invariably cemented by calcite. The quartz grains are generally coated by greyish red to reddish purple haematite, and many of the limestone clasts are also

PLATE 26:

a. **Small asymmetrical wave ripples overlying laminated and ripple cross-laminated, grey to slightly reddened siltstone (Lithofacies Fl and Fm) in an overbank deposit (OF). The ripples indicate standing water, probably in a floodplain lake. Unit B, 291.5 m in the type section (refer to Figure 38).**

b. **Lozenge-shaped sandstone body, showing a sharp erosive edge at left and thinning to right. The channelised base is erosive on overbank deposits, and is filled by low-angle and trough cross-bedded sandstone (Lithofacies Sl and St) with palaeocurrents trending north. The sandstone body is interpreted as a crevasse splay (CS), and is overlain by more overbank deposits (OF). Unit B, 294 m in the type section (refer to Figure 38).**

c. **Linguoid ripple marks (Lithofacies Sr) on bedding surface. Note that the trend of the parting lineation, immediately underneath the ripples (near pen) in Lithofacies Sh, is parallel to the flow of the overlying ripples (to the north). These ripples formed during waning flow conditions of a flood event in the upper part of a crevasse splay element (CS). Unit C, at about 640 m in the type section (refer to Figure 38).**

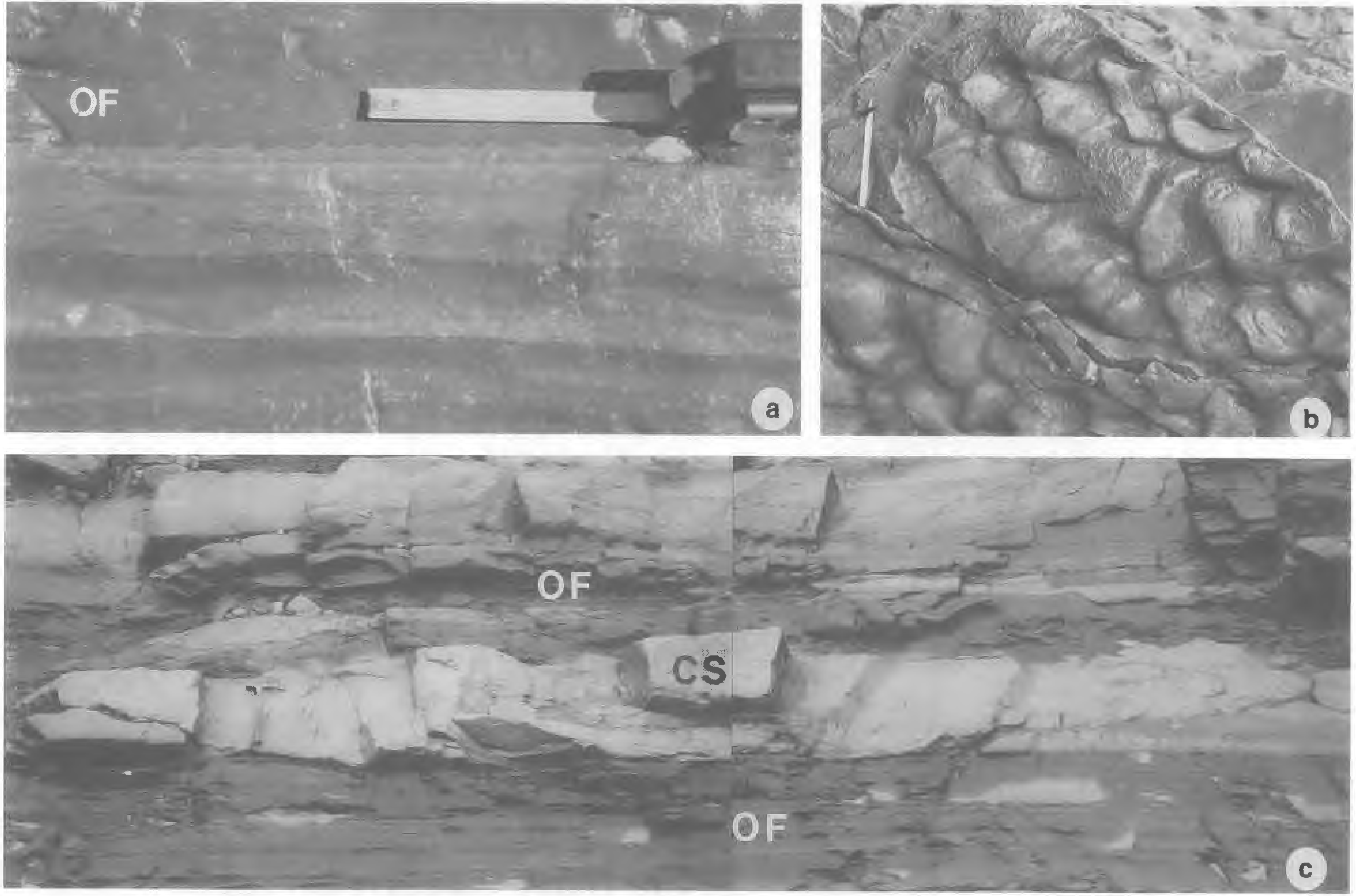


Plate 26. Rockfields Member, Units B and C, Bulgeri Formation.

reddened by haematite. Red jasper and red-brown quartzose arenite clasts occur in various proportions throughout the calcirudites, indicating a mixing with clasts typical of the Stopem Blockem Conglomerate Member.

Corals and conodonts recovered from the clasts of the calcirudites indicate an Early to Middle Devonian age for the limestone provenance (Jell, 1967; B. Fordham, unpublished data). According to Jell (1967), the coral faunas in calcirudites near the top of his Broken River Formation were all cannibalised from the underlying limestones (Chinaman Creek, Dip Creek and Lockup Well Limestone Members). In the Six Mile Syncline, this represents erosion from strata buried up to 1 600 m below the highest known occurrence of reddened calcirudite, and therefore implies considerable erosion of the Broken River Group limestones. The angular discordance between the Bulgeri Formation and the Broken River Group is regionally only a few degrees (Lang, 1985, 1986a), implying a source area many tens of kilometres up dip. Limestone gravel rarely travels more than a few kilometres from its source (Pettijohn, 1975), and therefore more proximal fault scarps of uplifted Devonian limestones were probably involved.

Jell (1967, p81) described the calcirudite lenses in the Six Mile Syncline as mound-like, with the thickest end being to the south. Given that the Bulgeri Formation is very thin or missing in the Dip Creek Syncline, and that in places Type 1 calcirudites directly overlie the Dip Creek Limestone, a fault scarp is postulated to have existed along the northwestern limb of the Atherton Creek Anticlinorium. There is also direct evidence of pre-Bulgeri Formation faulting near the nose of the anticlinorium (Lang, 1985; 1986a, p. 169). A sheared and silicified limestone is sharply truncated by non-sheared basal conglomerate of the Bulgeri Formation. The faulting appears to have truncated the Mytton Formation but does not extend into the Bulgeri Formation, and may represent part of a fault zone along which the Broken River group was uplifted. Most of the calcirudites could thus have accumulated within a few kilometres of their source. Calcirudites to the north of Teddy Mount may have been derived from the erosion of limestones originally overlying the Georgetown Province to the north.

8. Marine influenced conglomerate, sandstone, siltstone, mudstone and minor coal. Rocks containing marine fossils or evidence of marine influence occur in at least three intervals in the Bulgeri Formation, and form a distinctive lithological association.

The lowermost interval occurs in the Unit A of the Rockfields Member, and is best seen in GSQ Clarke River 2. The basal pebbly to cobbly conglomerates and pebbly sandstones of the Rockfields Member (Unit A) are overlain by calcareous, and in places fossiliferous, very fine to medium-grained sandstone interbedded with burrowed grey mudstone (Plate 24g). Desiccation cracks and thin coaly bands occur in the mudstones in places, suggesting non-marine conditions were probably involved at times. Towards the Broken River and Page Creek area, the conglomerates and sandstones of the lower part of Unit A do not contain marine fossils, but the common occurrence of bidirectional cross-bedding, flat lamination, and low-angle planar to hummocky cross-stratification suggests both tidal and wave processes were involved (Plate 24b,c,d). The fact that they are interbedded with fine-grained redbeds suggests a shallow marine to intertidal setting. Compositionally, the sandstones are sublabile feldspathic to quartzose, and are moderately to well sorted. The basal conglomerate is polymictic, but dominated by rounded quartz and quartzite pebbles and cobbles. Lesser amounts of grey chert, acid volcanics and schist are present.

The second marine influenced interval occurs in Unit O, between approximately 2400 m and 2 550 m in the type section. Outcrop is poor in the river section, but in a gully crossing at 7859-469387 (P. Blake, personal communication), a poorly preserved gastropod-bivalve-crinoid fauna occurs in a poorly sorted, burrowed, muddy, very fine to fine-grained micaceous sandstone grading to mudstone.

The third marine influenced interval occurs in the Jamieson Member (Unit Q). In the type section, greenish grey mudstones up to several metres thick containing brachiopods, bivalves, ostracodes and plant detritus, are interbedded with thin, polymictic granule conglomerates. In the Dip Creek Syncline, this interval may be represented only by a calcareous, poorly sorted, medium to very coarse-grained cross-bedded sandstone, which is interbedded with grey mudstones and poorly sorted granule conglomerates that contain disarticulated brachiopods and crinoid ossicles at 7859-597572.

PLATE 27:

a. **Crudely stratified, volcaniclastic conglomerate containing felsic volcanic clasts ranging from granules to pebbles in green vitric, very fine-grained volcaniclastic sandstone matrix (Lithofacies Gm and Fl). The dominance of large volcanic clasts set in a matrix almost exclusively comprised of glass shards suggests a relatively proximal source of felsic volcanism. The bedding structures indicate that the rock is a reworked tuff deposited in a floodplain lake. Unit C, 724.5 m in the type section (refer to Figures 38 and 42).**

b. **Photomicrograph of a specimen, from the lower part of the thick, green, reworked tuff showing accretionary lapilli in a matrix containing glass shards, indicating a relatively proximal source of phreatomagmatic volcanism. Unit C, 722 m in the type section (refer to Figures 38 and 42). Magnification X10.**

c. **Small scale soft-sediment deformation in volcaniclastic sandstone and siltstone (Lithofacies Sh and Fl), containing a partially collapsed dewatering structure, with a diapiric anticline and associated elutriation pipe. Note zone of mixing (arrowed) immediately above pipe where underlying contents have been injected, and preserved as a cloud. Also note microfaults associated with the collapse. Original layering is graded and reverse graded. Pebbles are rhyolite. Unit C, 726 m in the type section (refer to Figures 38 and 42).**

d. **Medium-scale, trough cross-stratified, grey to red sandstone (Lithofacies St). Red (dark layers) due to oxidation of biotite flakes on foresets. This shows both views, parallel and perpendicular to flow direction and is interpreted as a medium-scale sinuous dune deposit of a larger dune complex (DU element). Unit D, 740 m in the type section (refer to Figure 38).**

e. **Crudely horizontally stratified red rip-up-clast conglomerate (Lithofacies Ge). Rip-up clasts comprise both reddened and drab mudclasts up to 10 cm in diameter. The conglomerate is interpreted as a scour fill at the base of a larger channel complex (CH element). Unit D, 760 m in the type section (refer to Figure 38).**

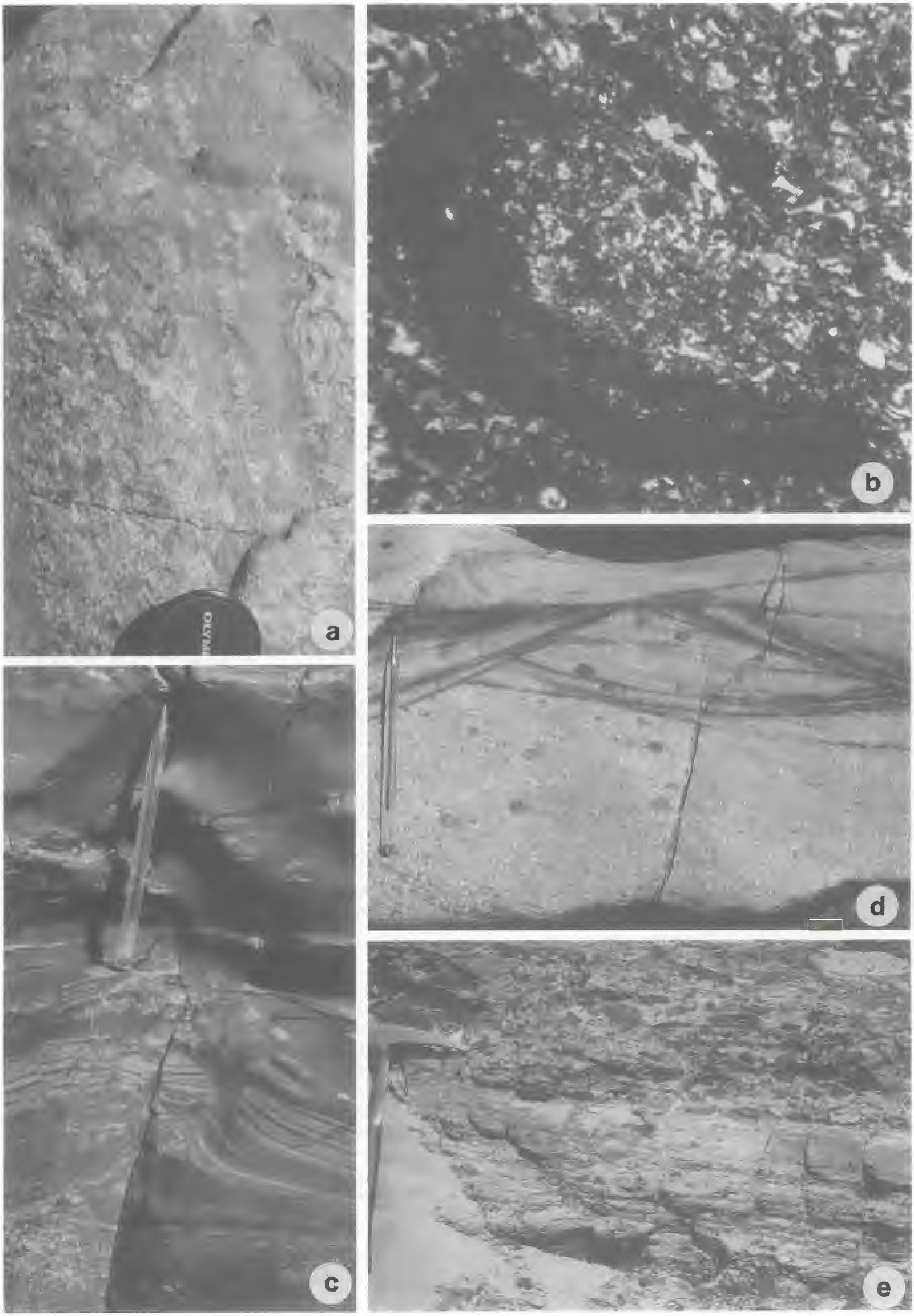


Plate 27. Rockfields Member, Units C and D, Bulgeri Formation.

Another marine interval occurs in a fault block of undifferentiated Bulgeri Formation north of Teddy Mount. Olive green, calcareous mudstone containing an abundant brachiopod fauna at 7859-405645 is overlain by pebbly conglomerates and quartzose sandstones interbedded with purple mudstones. Farther east, at 7859-424651, calcareous conglomerate contains quartz granules coated by carbonate (oncoids) and disarticulated brachiopod shell fragments. The precise stratigraphic position of this sequence is uncertain because of faulting, but it is probably in the lower half of the formation because the age has been determined by Mawson & others (1985) as Frasnian.

Relationships and boundary criteria

The Bulgeri Formation is the basal unit of the Bundock Creek Group, and overlies the Broken River Group with a slight angular unconformity (a few degrees) to disconformity. In the type section, the base is marked by a pebble to cobble conglomerate dominated by quartz and quartzite clasts, which sharply overlies pencil-cleaved shales of the Mytton Formation (Plate 24a). The boundary appears to change character between the Broken River, and GSQ Clarke River 2, approximately 18 km to the northeast. In GSQ Clarke River 2, the relationship appears almost transitional, and is probably disconformable (Lang, 1985, 1986a). The boundary in the Craigie area to the southeast also appears to be disconformable (McLennan, 1986).

The Rockfields Member is sharply overlain by pebbly to cobbly conglomerates of undifferentiated Bulgeri Formation (Unit E). This boundary appears conformable in the field, but the contact is erosional, since the upper Rockfields Member is gradually truncated to the northeast of the Broken River (Figure 56). The boundary is therefore a local unconformity, and marks the beginning of a thick conglomeratic sequence .

The abundant fine-grained redbeds, characteristic of the Bulgeri Formation, serve to distinguish the unit from the overlying Turrets Formation. The boundary appears to be conformable throughout most of the area, but the Turrets Formation oversteps the Bulgeri Formation in the Dip Creek Syncline to unconformably overlie the Dip Creek Limestone. This boundary was previously considered to be a regional unconformity by Wyatt & Jell (1980).

The formation is faulted against Proterozoic metamorphic rocks and early Palaeozoic granitoids of the Lolworth-Ravenswood and Georgetown Provinces along the Clarke River and Teddy Mount Faults, respectively. The northern outliers of the formation (eg. near Maitland Creek) unconformably overlie the Georgetown Province, although parts of the outliers are in fault contact. The formation is intruded by the Carboniferous to Permian Montgomery Range Igneous Complex.

Summary of environment of deposition

A more detailed discussion of the lithofacies within the Bulgeri Formation and their interpretation is given in the following chapter. However, for completeness, a summary is presented here.

The depositional environments of the various sequences that comprise the Bulgeri Formation include coastal plain and barrier shoreline depositional systems at the base (Unit A) followed by a major regression resulting in the accumulation of thousands of metres of alluvial plain facies.

Compositional and palaeocurrent data indicate that there was probably a major low-sinuosity trunk river system draining from the southwest (Georgetown and Lolworth-Ravenswood Provinces) towards the retreating sea. The river system, which carried very coarse bed loads in places, was probably part of a major alluvial system feeding into the Bundock Basin and nourished by uplifts along the faulted southern margin of the basin. The uplifts were associated with significant movements along the Clarke River Fault Zone, and were probably accompanied by frequent major earthquakes. The rivers were subject to flash flooding on a large scale, and extensive semi-permanent floodplain lakes developed on a broad braidplain, much like the modern fans of the Gulf of Carpentaria. In more proximal areas of the alluvial system, some of these deposits filled a broad palaeovalley (20 km wide and hundreds of metres deep), which was later used by a different alluvial system comprising 'Stopem Blockem type' conglomerates, which was largely derived from the erosion of a thick arenite-jasper sequence to the south or southeast. This source was most likely the Camel-Creek Subprovince and/or its equivalent overlying the Lolworth-Ravenswood Province and now completely removed by erosion.

In the interfluvial areas between the two systems, widespread floodplains accumulated thick calcic palaeosols under a warm, but probably highly seasonal equatorial climate (Lang & Fielding, 1991). Volcanic ash falls were a common occurrence over the region. However, the precise location of the volcanic source area is unknown, but was probably close to south or west of the basin.

This major regressional phase was probably tectonically driven, since it occurs at a time of global sea-level highs, represented by major transgressions elsewhere (eg. Canning Basin, Canadian Rockies etc.). However, during two

PLATE 28:

a. **Cobbles and boulders of quartz arenite and jasper in reddened conglomerate (Lithofacies Gm). This is the coarsest grade conglomerate in the Stopem Blockem Conglomerate and is interpreted as a very proximal channel deposit of an alluvial plain. Unit G, at 7859-609499 in the south branch of Gorge Creek.**

b. **Stem of *Leptophloeum australe* in the uppermost part of the Stopem Blockem Conglomerate Member. Unit J, 1221 m, in the type section in Red Range Gorge (refer to Figure 41).**

c. **Planar (tabular) cross-stratified, reddened conglomerate (Lithofacies Gp), interpreted as a longitudinal bar in a gravelly, low-sinuosity channel within an alluvial plain. Stopem Blockem Conglomerate Member, Unit G, 960 m, in type section, near Red Range Gorge, Broken River.**

d. **Calcirudite (Lithofacies Gm) containing clasts of slightly reddened fossiliferous limestone and reddened arenite (dark grey in photo) clasts. The presence of Early Devonian fossils indicates reworking from the underlying Chinaman Creek Limestone. 7859-588692, near Lyndhurst-Pandanus Creek road, 5 km north of 'Pandanus Creek'.**

e. **Horizontally stratified sandstone (lithofacies Sh) within horizontally stratified and imbricated reddened conglomerate Lithofacies Gm). The outcrop is interpreted as a longitudinal bar deposit in a gravelly, low-sinuosity channel within an alluvial plain. Stopem Blockem Conglomerate Member, Unit G. 7859-645543, headwaters of Gorge Creek.**

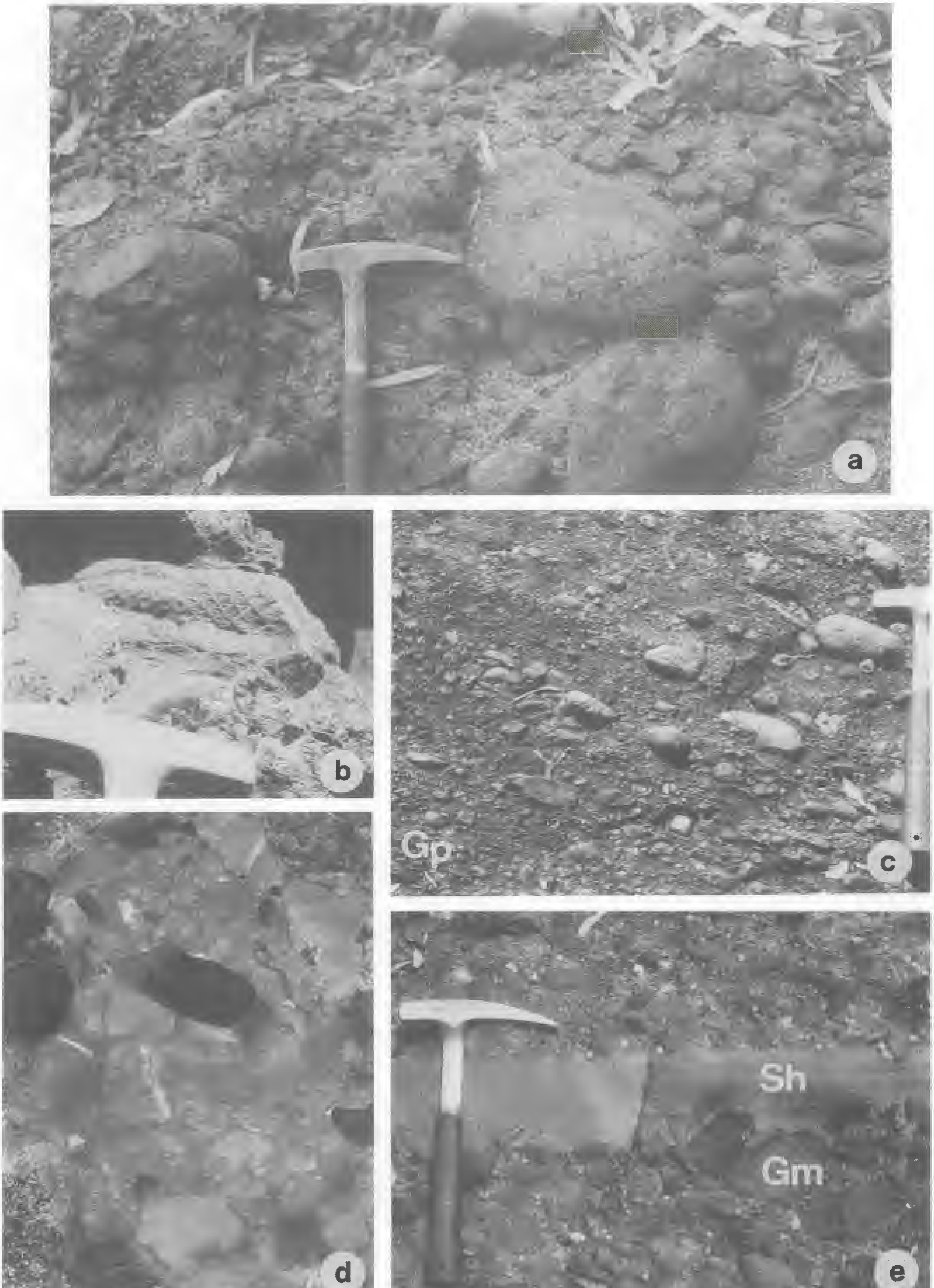


Plate 28. Reddened conglomerate and calcirudite from the Bulgeri Formation, including Units G and J from the Stopem Blockem Conglomerate Member.

periods of relatively little tectonic activity, the sea transgressed the basin (Unit O and Q). The timing of these transgressions is poorly known, but probably first occurred in the late Frasnian/early Famennian, then later in the mid Famennian. The latter transgression is widespread throughout the nearby Burdekin Basin (Talent, 1989; Lang & others, 1990a, b). The upper part of the formation returned to regression before the deposition of the Turrets Formation.

Fossils and age

Brachiopods (*Cyrtospirifer* sp.), small bivalves (*Leiopteria* sp.) and small gastropods occur in sandstones and siltstones near the base of the Rockfields Member in the hinge of the Rockfields Syncline, both in outcrop at 7859-663595 and in core from GSQ Clarke River 2 (Lang, 1985, 1986a, b; Law, 1986b; Figure 40, Plate 24g). A brachiopod-dominated fauna including *Cyrtospirifer "australis"* Maxwell, associated with atrypids and stropheodontids, occurs in calcareous sandstone north of Teddy Mount (Mawson & others, 1985; 7859-405645). Nearby, at 7859-424651, disarticulated brachiopods occur in oncoidal, calcareous sandstones and granule conglomerates.

These localities near the base of the formation are probably Frasnian in age (Mawson & others, 1985; Lang & others, 1989b). They are definitely younger than latest Givetian, based on the coral fauna from the underlying Stanley Limestone Member of the Mytton Formation (Humphries, 1990). Mawson & Talent (1989) report the occurrence of conodonts in the Stanley Limestone Member which may be as young as *asymmetricus* Zone, in the earliest Frasnian. This data implies that the hiatus between Mytton Formation and the Bulgeri Formation lies somewhere within the Frasnian.

The presence of Frasnian marine strata suggests a relatively high sea-level during this time, especially considering the enormous volume of sediment being delivered during the accumulation of the Bulgeri Formation (Lang, 1985, 1986a). It is possible therefore that this marine interval corresponds to the peak of a global marine transgression in the late Frasnian *gigas* Zone (Johnson & others, 1985; Talent, 1989).

In about the middle of the formation (UNIT O), poorly preserved gastropods, bivalves and crinoid ossicles occur in calcareous, micaceous sandstones at a gully crossing on the track from Page Creek to Montgomery Dam (7859-469387; P. Blake, personal communication).

Near the top of the formation, in the middle of the Jamieson Member, athyridid brachiopods, bivalves (*cf.Leptodesma*), and ostracodes occur in mudstones exposed near the Broken River at 7858-536458 (GSQ L2448). A fauna recorded by Hill (*in* White & others, 1959; Locality BRS 97) near the top of the Jamieson Member (7859-609536), includes gastropods, bivalves (*?Leiopteria, ?Leda,* and pectinoids), brachiopods (*Productella* sp.), pteropods (*Hyolithes*), and *Tentaculites*. At 7858-597572, also in the Jamieson Member, indeterminate brachiopods and crinoid ossicles occur in a cross-bedded, poorly sorted calcareous sandstone.

A Famennian age is inferred for the fossil localities in the upper half of the Bulgeri Formation. They occur several thousand metres above the lower Frasnian localities, and approximately 1 800 m below the Famennian-Tournaisian boundary in the middle of the Teddy Mount Formation. The marine part of the Jamieson Member may represent the extension of the mid-Famennian (*marginifera* Zone) regional transgression recorded in the Burdekin Basin (Lang & others, 1990a, b; Gunther & others, 1990). The newly recognised marine interval in the middle of the formation represents an earlier marine transgression, presumably in the early Famennian (perhaps representing marine transgressions in the late *triangularis* or *crepida* Zones; Talent 1989).

Scattered lycopod log and stem impressions, *Leptophloeum australe*, occur throughout the unit (Plates 25a and 28b). Wyatt & Jell (1980, p. 212) reported logs up to 8 m long and 10 cm across from the southwestern outcrops of the Bulgeri Formation. A simple dichotomous ?lycopod stem was recovered from GSQ Clarke River 1 (91.78-91.82 m) in a carbonaceous mudstone. A carbonised palynoflora was recovered from this interval in GSQ Clarke River 1, and included *Granulatisporites frustulentus* (Playford, in Lang, 1985, 1986a, b). Fish bone fragments occur in cross-bedded sandstones and fine-grained redbeds sporadically throughout the formation.

PLATE 29:

a. **Massive red mudstone containing calcrete glaebules increasing in abundance towards the top where two layers of concentrated glaebules occur (Lithofacies Fm and P). The nodules are interpreted as advanced calcic soil development in a highly oxidised overbank environment. This may be equivalent to pedogenic Stage III of Giles & others (1966) for non-gravelly soils. Unit K, 1324 m in the type section (refer to Figure 41).**

b. **Massive red mudstone containing large calcrete glaebules up to 4 cm in diameter (Lithofacies Fm and P). Note the overall subcylindrical to irregular shapes of glaebules. This may be equivalent to pedogenic Stage II of Giles & others (1966) for non-gravelly soils. Unit L, 1363 m in the type section (refer to Figure 41).**

c. **Massive development of large calcrete glaebules within a red mudstone (Lithofacies P and Fm). This represents a peak in the deposition of calcrete glaebules, and may be equivalent to pedogenic Stages III to IV of Giles & others (1966) for non-gravelly soils. Floater block, presumably from an equivalent of Unit N. 7858-461345, in a tributary of Sandy Creek.**

d. **Medium-scale planar cross-bed set within a lenticular unit of reddened medium-grained sandstone (Lithofacies Sp), interpreted as a straight-crested dune bar-form in a sandy part of an otherwise gravelly low-sinuosity stream. Unit I, 1175 m in the type section (refer to Figure 41).**

e. **Medium-scale, planar tabular cross-bed in coarse, pebbly sandstone containing large angular rip-up clasts of red mudstone (Lithofacies Ge and Sp). This is interpreted as a straight-crested dune bar-form infilling a scour into the underlying red mudstone. Unit L, approximately 1370m m in the type section (refer to Figure 41).**

f. **Edge of a small channel eroded into massive red mudstone and filled by flat-laminated sandstone onlapping the channel margin. It is interpreted as the edge of a crevasse splay channel (CS element) within a thick overbank succession (OF element). Unit N, approximately 1575 m in the type section (refer to Figure 49).**

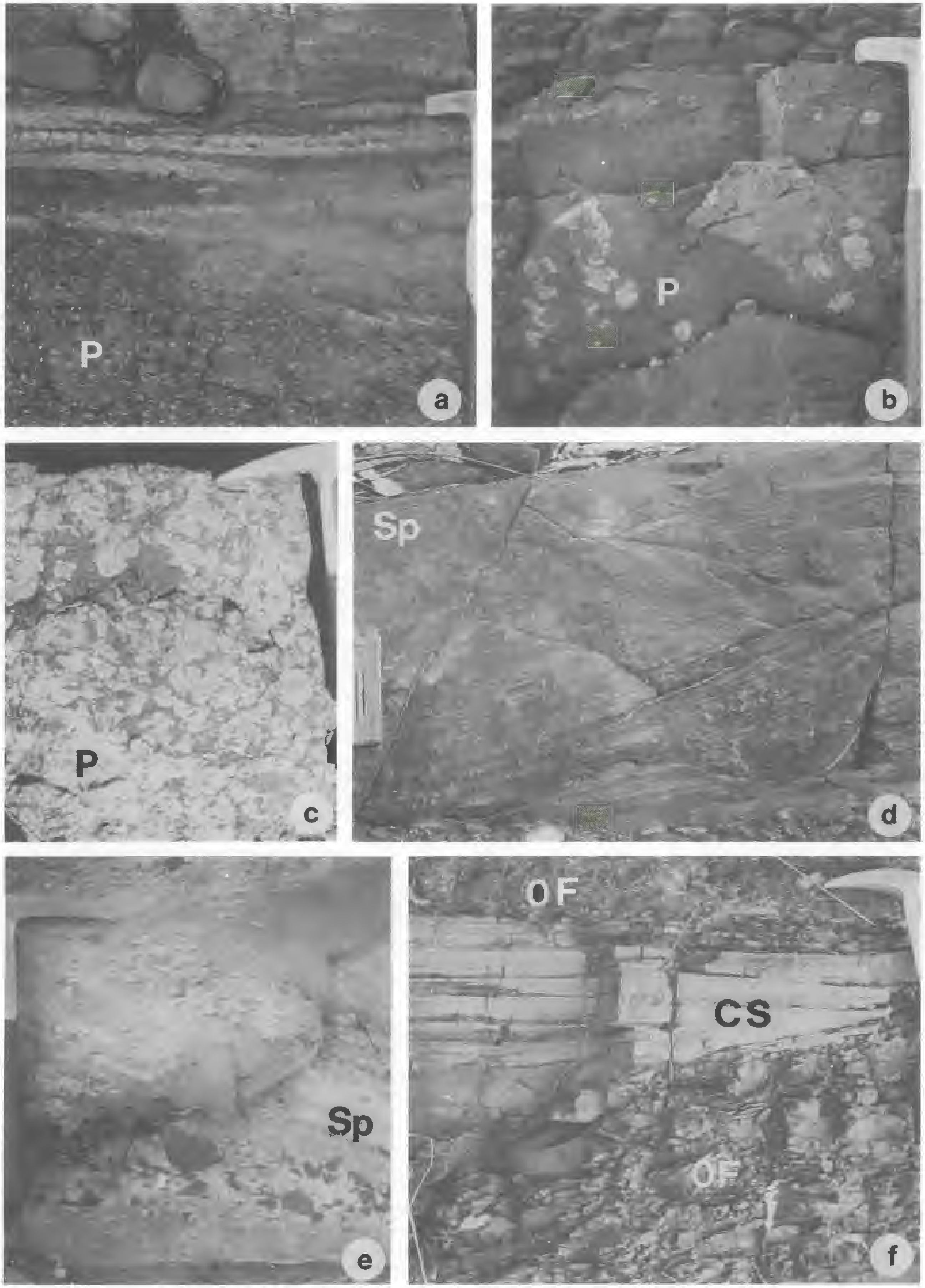


Plate 29. Sandstones and reddened mudstones from Units I, K, L and N of the Bulgeri Formation (including the Stopem Blockem Conglomerate Member).

Trace fossils (tracks and trails) occur in the fine-grained redbeds near the base of the Rockfields Member. One specimen of a large trace fossil, similar to *Beaconites antarcticus* (cf. Allen & Williams, 1981) was found in the Jamieson Member, at 7858-620544.

TURRETS FORMATION

Introduction

The Turrets Formation occurs in a sinuous folded belt from near 'Gregory Springs' in the southwest to near 'Pandanus Creek' in the northeast, and 'Oak Valley' in the northwest.

The formation thins dramatically from west to east. The thickest part of the unit is 1 400 m in the 'Oak Valley' area in the northwest. In the southwest the unit may be as much as 900 m thick - the top is faulted out in the core of the Gregory River Syncline. In the type section, about the centre of the basin, the unit is 770 m thick. The formation is 840 m thick on the northern limb of the Boroston Syncline. The formation then decreases in thickness to 560 m on the northern limb of the Montgomery Creek Anticline, and to 430 m in the Six Mile Syncline in the northeast. In the east, the formation continues to thin from 480 m to 100 m in the Dip Creek area.

Type section

The type section is 770 m thick and is along the Broken River and tributary Montgomery Creek (Figure 48).

Lithology and sequence

The dominant lithologies in the Turrets Formation are sandstone and siltstone, with lesser mudstone, conglomerate and reworked tuff. Most of the sandstones and conglomerates are lithofeldspathic or feldspathic, with an important (sometimes dominant) volcaniclastic component. The sandstones are generally more pebbly and coarser-grained in the 'Oak Valley' area.

In the type section the base is marked by a thick to very thick-bedded, pale grey, cross-bedded pebbly sandstone, which overlies red siltstone of the Bulgeri Formation. Laterally, this unit grades into quartzose pebbly conglomerate. The lower 50 m is dominated by a very thick-bedded, silicified, light green grey, very coarse to very fine grained, graded, crystal-lithic vitric tuff. The tuff contains small to coarse lapilli-sized (up to 5 cm) clasts of volcanic glass (pumice) and intermediate to acid volcanilithics, in a vitric matrix which contains abundant volcanic quartz and plagioclase crystals. Pink and white zeolites occur in alteration zones at the base of the tuff, and this makes it clearly visible on airphotos as a whitish strip which can be followed along strike throughout the central part of the area. The tuff is poorly sorted at its base, but becomes laminated and cross-laminated near the top. The tuff appears to grade into fine to very coarse-grained volcaniclastic sandstone. These sandstones, although dominantly composed of reworked tuff in which glass shards are still well preserved, also contain clasts of plutonic and metamorphic origin, as well as detrital muscovite.

The overlying 300 m is a sequence of medium to thick-bedded pebble conglomerate, and very coarse, cross-bedded labile sandstone (Plate 32a) overlain by thick mudstone intervals containing carbonaceous and fragmentary plant material. Although several cycles of cross-bedded sandstone or conglomerate fining-upward to grey mudstone are common, the overall aspect of the sequence between 150 and 360 m is that of two coarsening-upward sequences. Generally the sequence becomes thinner bedded and finer upwards, the latter reflecting the increased proportion of siltstone and mudstone over sandstone and conglomerate. Carbonaceous and fragmentary plant material still persist in the finer-grained beds, and occasionally contain *in situ* rootlets and burrows. The sandstones tend to become more calcareous up the section, and at the top of the unit are very similar to some arenites in the middle part of the Teddy Mount Formation. The sandstones in the upper half of the formation commonly contain flat lamination with associated parting lineation, and are also associated with small to medium scale convolute bedding and trough and low-angle trough cross-stratification.

In the northwest, the sequence is not known in any detail but it is considerably thicker and dominated more by pebbly sandstone and granule conglomerates, with apparently less fine-grained intervals.

Relationships and boundary criteria

In the type section the Turrets Formation overlies the Bulgeri Formation apparently conformably. Generally, the boundary is placed at the base of a thick-bedded pebbly sandstone, overlying the highest known fine-grained redbed typical of the Bulgeri Formation. The sandstones

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PLATE 30:

a. **Succession of drab, pebbly sandstone and conglomerate containing large-scale scour-fills, horizontal stratification, and trough and planar cross-bedding (from right to left, Lithofacies include Sh, Gt, and Gp, deeply eroded by more Gt at the top. Interpreted as channel-fill deposits in a gravelly and sandy low-sinuosity stream in the upper reaches of an alluvial plain. Unit E, 813 to 816 m in the type section (refer to Figure 38).**

b. **Drab, pebbly sandstone containing a scour, filled with pebbly lag and small-scale, trough cross-bedded sandstone (Lithofacies Gm, Ss and St), and overlain erosively by low-angle trough cross-bedded sandstone (Lithofacies Sl) which in turn has been eroded and filled by trough cross-bedded conglomerate (Lithofacies Gt). Interpretation as for (a). Unit E, approximately 810 m in the type section (refer to Figure 38).**

c. **Medium and large-scale, trough cross beds in pebbly sandstone (Lithofacies St), interpreted as large-scale sinuous dune bed-forms in a larger dune complex (DU element). Unit N, 7858-461340 in Sandy Creek.**

d. **Large-scale planar (tabular) cross-bedded, coarse-grained, drab sandstone (Lithofacies Sp), probably a sand wave or transverse bar deposit. It overlies a very thin pebbly sandstone conglomerate lag deposit (Lithofacies Sh and Gm). Unit P, 2775 m in the type section (refer to Figure 50).**

e. **Partially reddened cross-bedded sandstone containing a quartzose arenite pebble with a deeply oxidised rind. The pebble was derived from the Judea or Wairuna Formation. The clast underwent an extended period of weathering prior to final accumulation in the cross-bedded sandstone. Undifferentiated Bulgeri Formation, at 7858-463258 in the Clarke River.**

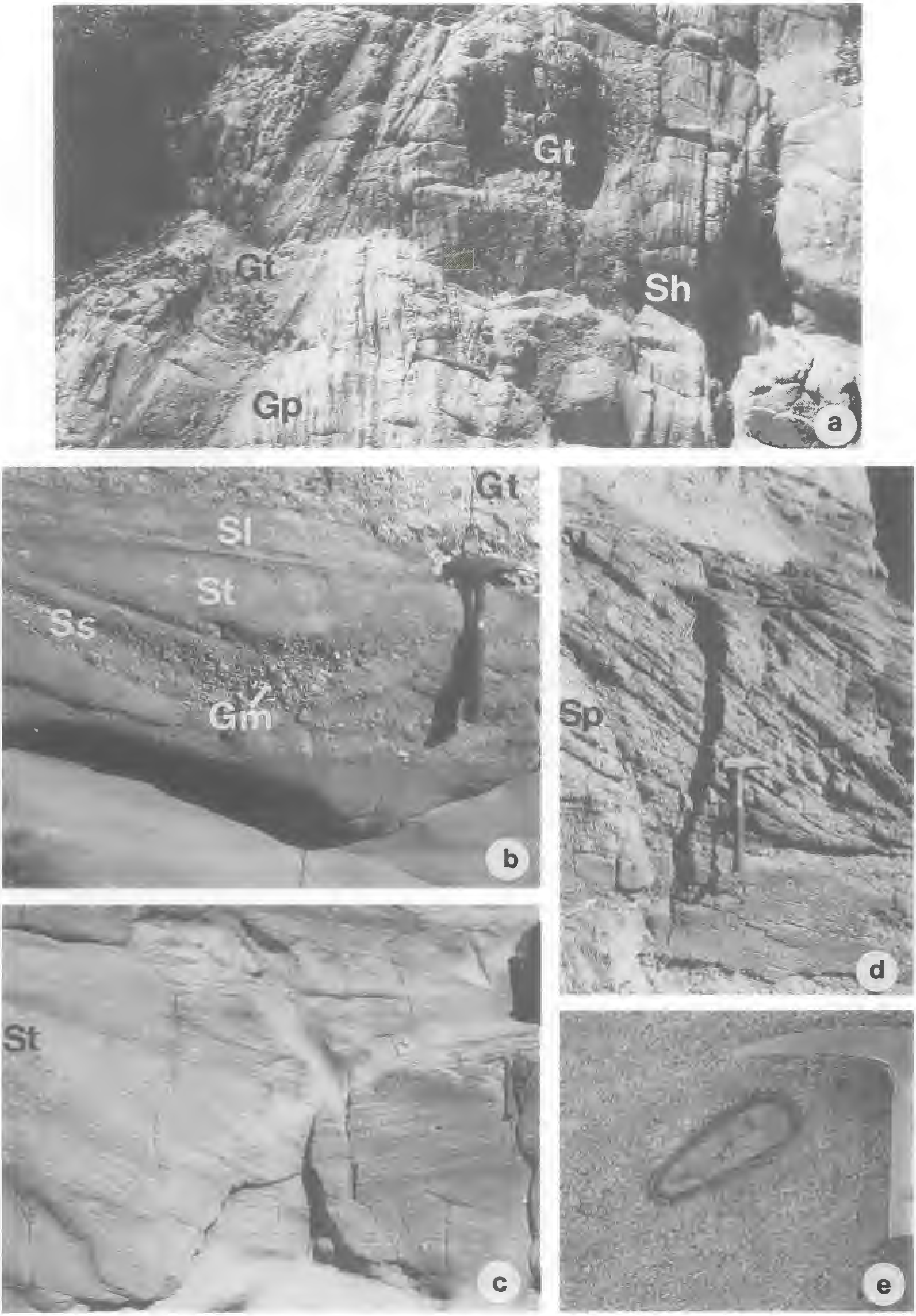


Plate 30. Bulgeri Formation, including Units E, N and P.

are generally more feldspathic than those of the Bulgeri Formation, and green tuffaceous sandstones are particularly common near the base. The top of the Turrets Formation passes conformably and transitionally into Teddy Mount Formation. The boundary is placed at the base of a thick sequence of greenish grey mudstone and lesser interbedded very fine to medium-grained arenite.

In the Dip Creek Syncline the lower boundary is placed under a white, thick-bedded, quartz-rich, pebbly, cross-bedded sandstone and conglomerate. This overlies a sequence of red siltstones, pebbly sandstones and calcirudites of the Bulgeri Formation, and between 7859-634599 and 657630 it directly overlies limestones of the Dip Creek Limestone Member. In the Six Mile Syncline the base of the Turrets Formation is apparently conformable on the Bulgeri Formation. The boundary is marked by a thick bedded, very coarse-grained, cross-bedded, quartzose and lithofeldspathic sandstone which overlies reddish-purple micaceous siltstones. The top in both areas is placed at the base of thick-bedded, partly calcareous, polymictic paraconglomerate with abundant metamorphic rock clasts. The basal contact with the Bulgeri Formation is not exposed in the 'Oak Valley' area, and the upper boundary is placed at the top of pebbly sandstones which underlie greenish grey mudstones of the Teddy Mount Formation.

Environment of deposition

The lower 150 m of the type section was probably deposited in a lower alluvial plain setting with the thick, cross-bedded sandstones and coarse-grained reworked tuffs representing fluvial channels. The finer-grained tuffaceous intervals represent overbank deposits. The bulk of the overlying sequence (150-625 m) is characterised by coarsening-upward successions.

Each sequence appears progradational, beginning with plant-rich mudstones that pass upward into fining-upward cycles of cross-bedded sandstones and conglomerates overlain by mudstones and siltstones with abundant plant remains and burrows. This is typical of deltaic sedimentation (Elliot, 1978). The thick plant-rich mudstones may represent prodelta or distributary bay deposits, and the cross-bedded pebbly sandstone horizons probably represent distributary channels or crevasse splays. The mudstones and siltstones overlying each channel sandstone probably represent delta plain facies.

The interval between 565 and 635 m, which contains occasional rootlet horizons, may represent the abandonment facies of the delta plain at the top of a major deltaic lobe. The lack of marine fossils and abundant plant remains, combined with rooted horizons indicates that the delta-system may have been fluvial-dominated, trending south to southwest. Perhaps the coarser-grained and thicker sequence in the northwest represents channel deposits of an alluvial system draining into the delta.

The upper 145 m of the formation is characterised by sandstones containing low-angle cross-bedding (bidirectional in part - see below), flat lamination associated with parting lineation, and convolute bedding suggesting a high-energy environment. The increasing amount of carbonate, the presence of burrows, the decreasing amount of plant fragments, and the overlying marine muddy nearshore facies of the Teddy Mount Formation, all point to a tidally influenced shoreface to sandy nearshore setting.

Palaeocurrent data is scarce in the Turrets Formation, but the limited data suggests the fluvial channel flow directions were mainly from the north, northwest, or west (Figure 37), which suggests that the dominant source area was probably the Georgetown Block. The compositions of the arenites as well as the eastward and southward thinning of the formation are compatible with this. In the upper half of the formation in the type section, and in the eastern exposures, palaeocurrents trend both southerly and northerly (Figure 37). These apparent flow reversals in mainly low-angle cross-bedded calcareous arenites suggest that tidal processes were important during the accumulation of the upper part of the formation.

In summary, the Turrets Formation was deposited in a paralic, fluvio-deltaic setting draining mainly from the Georgetown Block, and presumably filling a widespread bay system to the south and southeast. It represents a regressive phase between the mid Famennian marine transgression of the upper Bulgeri Formation, and the Late Famennian-Early Carboniferous transgression of the overlying Teddy Mount Formation.

Fossils and age

Plant fossils are distributed throughout the Turrets Formation and occur in abundance on some bedding planes. Most are fragmentary, and of calamitaean affinity. Invertebrates are not known.

The age of the Turrets Formation cannot be determined directly, due to the lack of diagnostic fossils. However, the unit underlies the conodont faunas of the Teddy Mount Formation in the type section, and is therefore Late Devonian (Late Famennian). The formation is thus comparable in age with the Lollypop Formation of the Burdekin Basin.

PLATE 31:

a. **Polymictic conglomerate containing subangular clasts of intermediate to felsic volcanics and quartzose arenite, siltstone and metapelite in a feldspathic matrix which also contains glass shards. The angular volcanic clasts and glass shards in the matrix suggests a proximal volcanic source. Jamieson Member, Unit Q, 3620 m in the type section (refer to Figure 50).**

b. **Poorly bedded, clast-supported conglomerate (Lithofacies Gm) containing dominantly granite, quartz and quartzite cobbles and boulders with lesser schist, amphibolite, mylonite, felsic volcanics and rare grey siltstone. The coarse grain-size indicates deposition in a high-energy channel within the proximal reaches of an alluvial system draining an igneous and metamorphic provenance. Significantly, reddened arenite and jasper, typical of the Camel Creek Subprovince to the east, are absent. Northerly-directed palaeocurrents from the enveloping sandstones (see Figure 37) indicate that the uplifted Lolworth-Ravenswood Province was the principal source. Undifferentiated Bulgeri Formation, at 7858-463258 in the Clarke River.**

c. **Black Rock, a hill of partially reddened, very thick-bedded, trough cross-bedded, conglomeratic sandstone (Lithofacies Gm, Ss and St) in the Maitland Creek outlier. Probably equivalent to the Bulgeri Formation above the Stopem Blockem Conglomerate Member. 7759-332885, 15 km northeast of Lyndhurst homestead.**

d. **Cross-bedded conglomeratic sandstone showing sporadic cobbles and a boulders of quartzite and gneiss. Interpreted as a low-sinuosity stream deposit. Locality as for (c).**

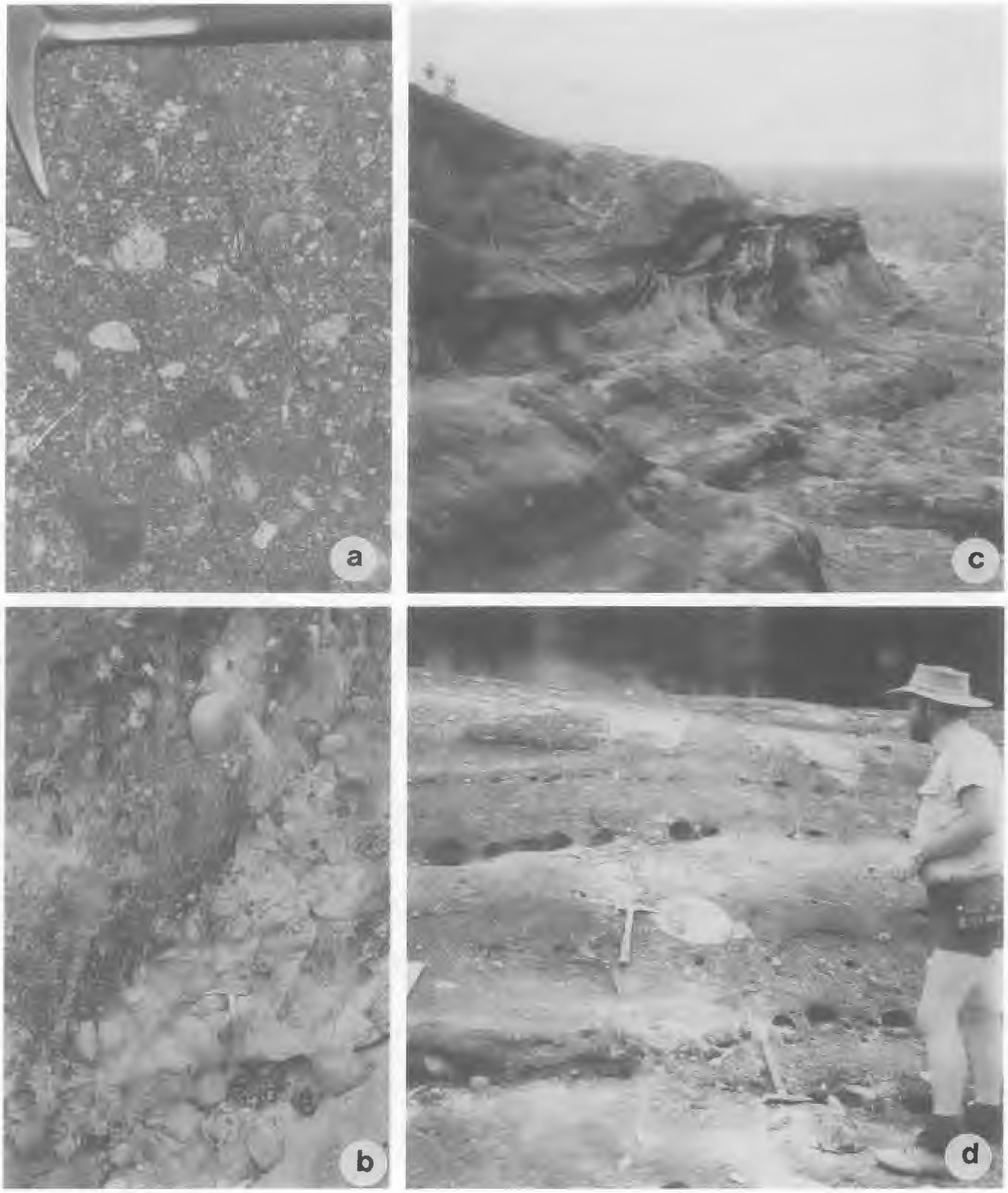


Plate 31. Bulgeri Formation (including the Jamieson Member, Unit Q) and Maitland Creek (Black Rock) outlier.

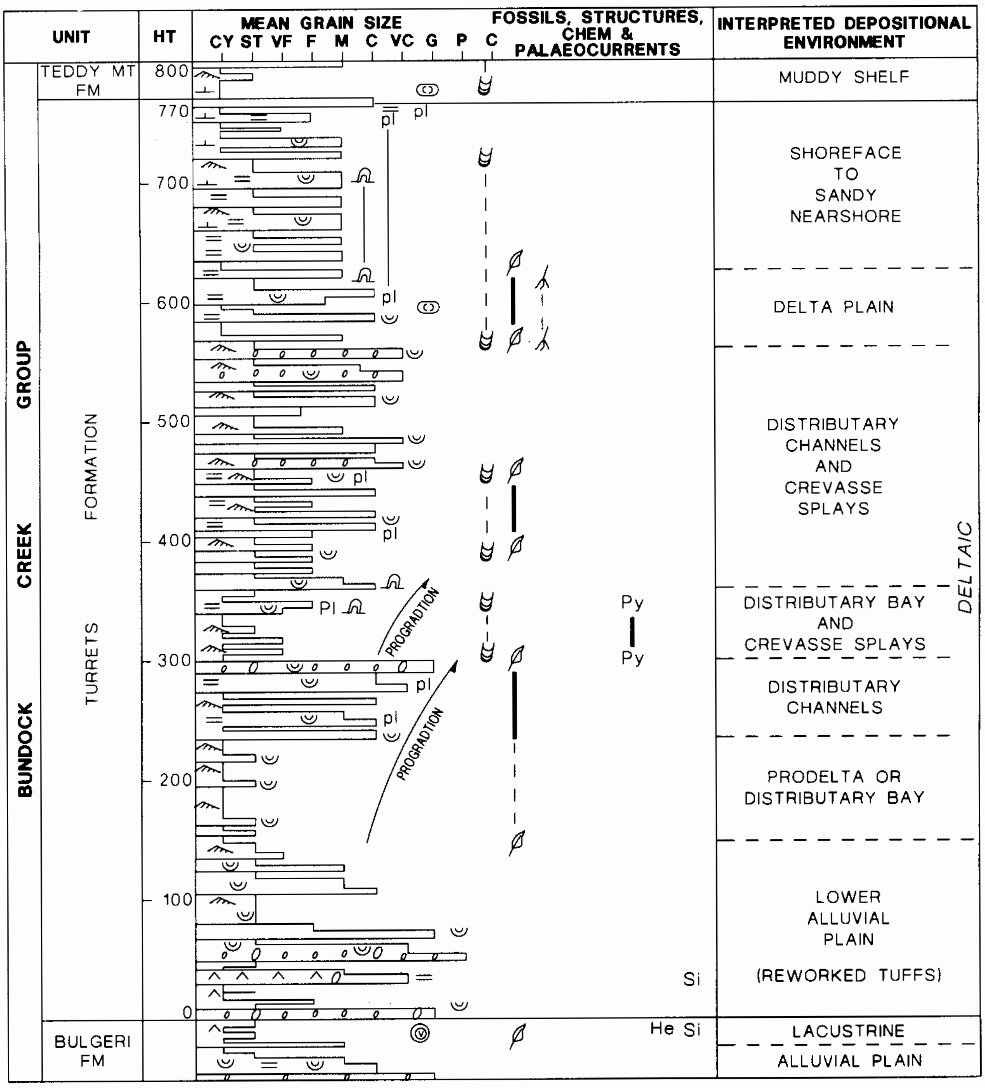


Figure 51. Type section of the Turrets Formation between 7859-530460 in the Broken River and 518463 in Montgomery Creek. See Figure 14 for reference.

PLATE 32:

a. **Trough cross-bedded, pebbly sandstone (Lithofacies St), interpreted as a sinuous-crested dune bar-form in a sandy and gravelly, low-sinuosity stream. Turrets Formation, at 7858-388262 in Dingo Creek.**

b. **Vertical and subhorizontal *Planulites* burrows in ripple-cross laminated sandstone (Lithofacies Sm), interpreted as a shallow marine, probably upper shoreface deposit. Teddy Mount Formation, 630 m in the type section (refer to Figure 52).**

c. **Trough and low-angle trough cross-stratified sandstone. Note the large wave ripples (centre), and soft sediment deformation at bottom left. Interpreted as a shallow marine, probably upper shoreface deposit. Teddy Mount Formation, 635 m in the type section (refer to Figure 52).**

d. **Photomicrograph of poorly sorted, bioclastic sandstone of shallow marine origin and showing brachiopod, coral and crinoid debris. Note the angular quartz grains. Teddy Mount Formation, 480 m in the type section (refer to Figure 52). Magnification x 10.**

e. **Parting lineation on the top of a bed of very fine to fine-grained labile sandstone (Lithofacies Sh), deposited under high-energy, plane bed, flow conditions, and interpreted as being deposited in an upper shoreface environment. Dyraaba Member, 1175 m in the type section in a tributary of Mount Brown Creek (refer to Figure 52).**

f. **Typical lepidodendroid plant fossils from the lower part of the Dyraaba Member. Floaters in a tributary of Montgomery Creek at 7859-518488.**

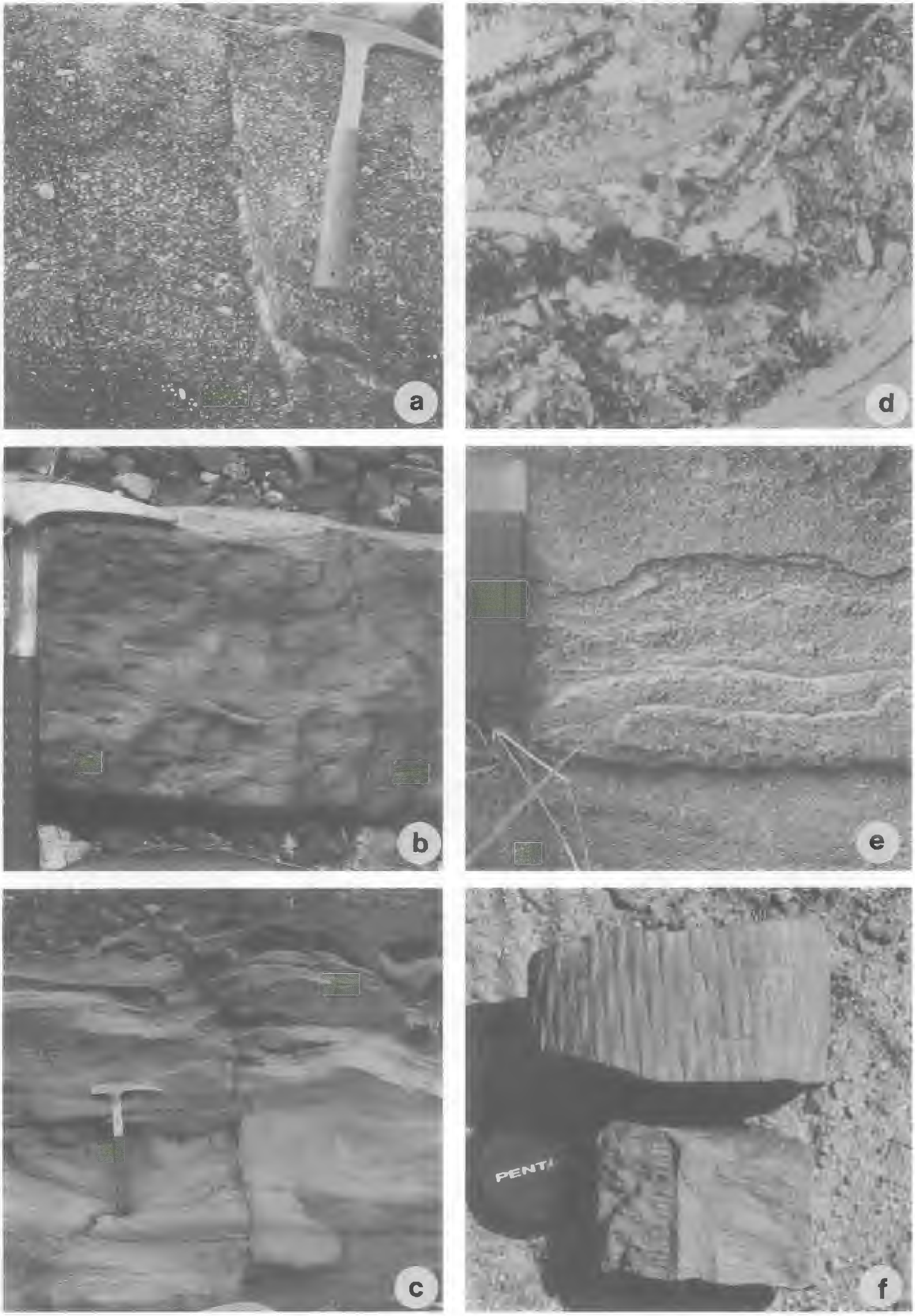


Plate 32. Turrets Formation and Teddy Mount Formation, including the Dyraaba Member.

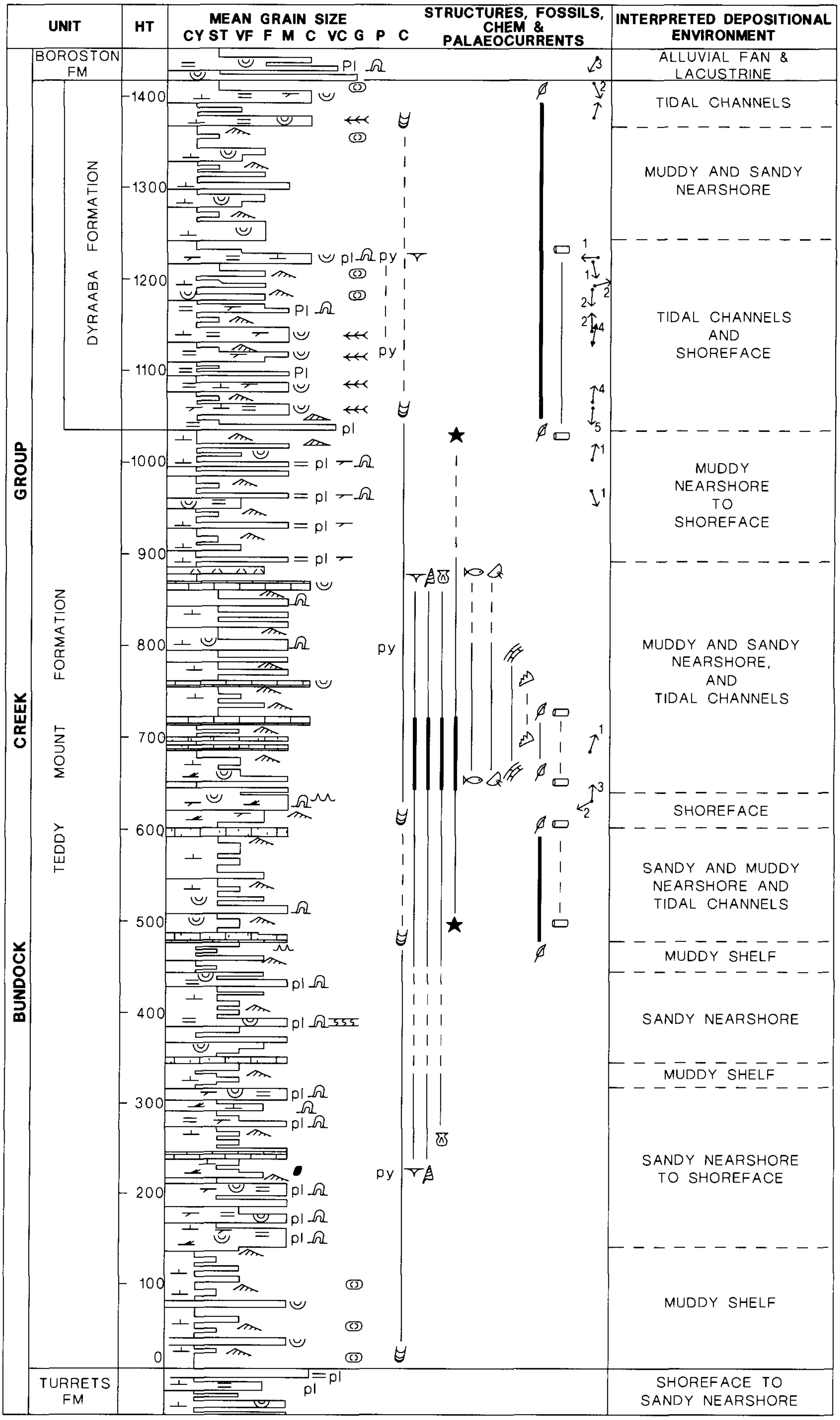


Figure 52. Composite type section of the Teddy Mount Formation; lower part from 7859-518463 to 521481 in Montgomery Creek and thence to 518488 (base of Dyraaba Member) in an unnamed tributary; upper part in Mount Brown Creek from 499462 (base of the Dyraaba Member) to 497466 (top). See Figure 14 for reference.

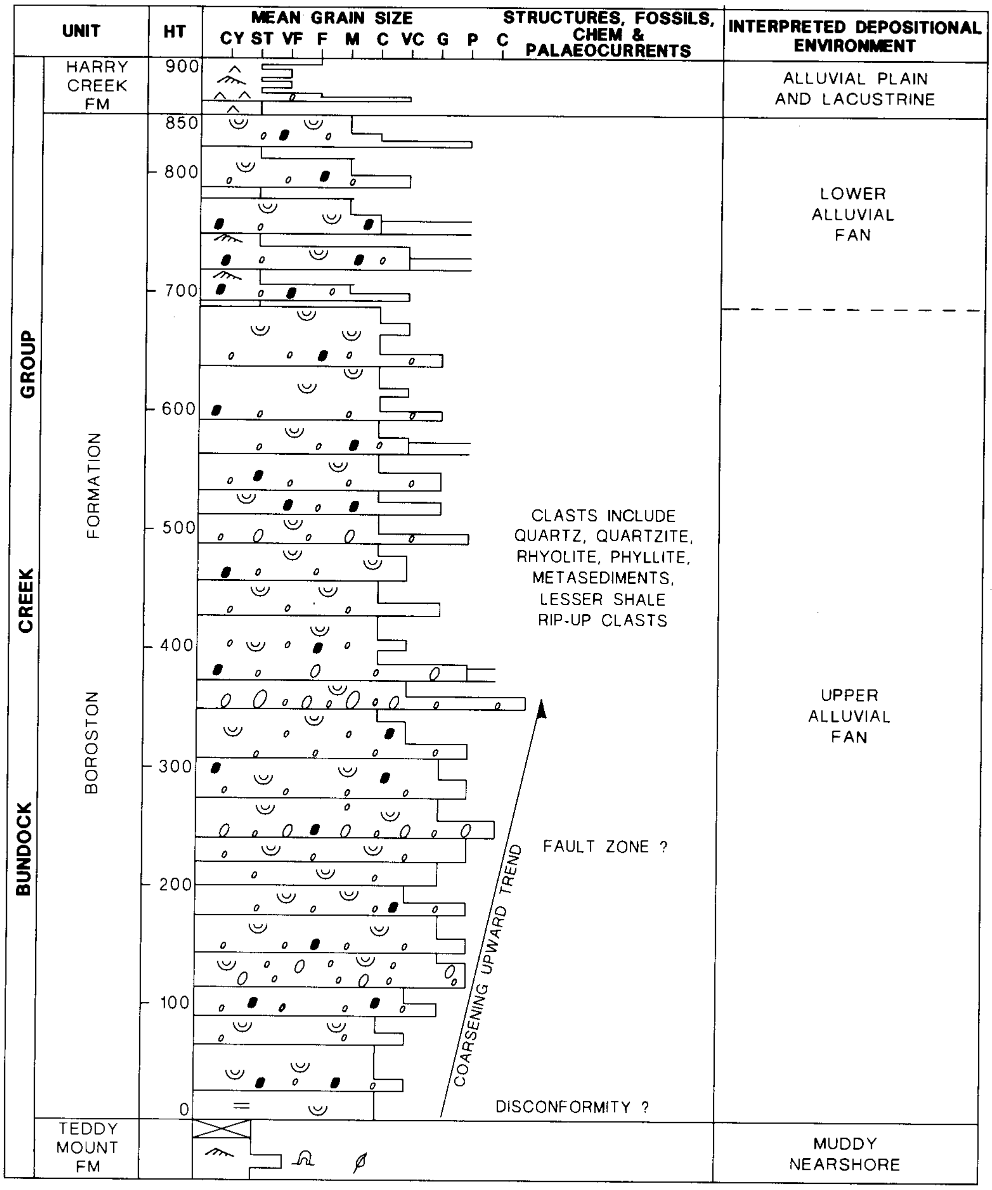


Figure 53. Type section of the Boroston Formation in the Harry Creek Syncline between 7859-375566 (base) and 7759-370577 (top). See Figure 14 for reference.

TEDDY MOUNT FORMATION (INCLUDING DYRAABA MEMBER)

Introduction

The Teddy Mount Formation is exposed on the limbs of numerous folds throughout the Bundock Basin. North of the Great Dividing Range, the formation crops out between the Einasleigh River and Bundock Creek in the northwest, to McKinnons Creek and Chinaman Creek in the north and northeast respectively. South of the divide, the formation mainly crops out in the Broken River and its tributaries, but it also occurs in the Catfish Creek area in the southwest, and in Shield Creek in the east. As mapped, the Dyraaba Member is confined to the Boroston Syncline in the headwaters of Mount Brown and Dingo Creeks and their tributaries.

The formation has a subdued outcrop pattern, being controlled largely by the dominance of mudstone, siltstone and fine-grained sandstone. Calcareous sandstone and limestone form sparse, widely spaced ridges. The unit has a smooth textured air-photo pattern reflecting the usually well grassed cover, with an open canopy of tall ironbarks and other eucalypts.

The Dyraaba Member forms low hilly topography which is strongly dissected and gullied. It is covered by low scrub, eucalypts and good grassy cover in places. The unit has a maximum thickness of 385 m in the type section, but it is difficult to determine elsewhere because of folding.

Type section

The type section is a 1 420 m thick, composite-stratotype consisting of two parts. The Dyraaba Member forms the upper 385 m, and is defined in a tributary of Mount Brown Creek, whereas the lower part is in Montgomery Creek and in an unnamed tributary (Figure 52).

Lithology and sequence

The dominant lithologies are sandstone and mudstone, with minor dirty limestone. The sandstones range from labile feldspathic to lithofeldspathic, and all are micaceous (mainly muscovite), and most are calcareous. The sources are dominantly plutonic and metamorphic, but there is a substantial volcaniclastic input. In many sandstones, feldspars and reworked glassy shards have altered to smectite clay.

The basal part of the unit in the type section consists of thick to very thick-bedded light green-grey to dark grey micaceous laminated mudstone and siltstone. Ripple cross-lamination and burrows are common. Calcareous concretions occur sporadically. The sequence is punctuated by thin to medium-bedded, pale grey, very fine to medium-grained sandstones. The top of this lower part is where a low ridge meets Montgomery Creek, 230 m above the base of the formation. It is formed by a medium to thick bedded, light grey, fine to medium, trough cross-stratified sandstone. Disarticulated brachiopods occur on some bedding planes, along with gastropods and plant fragments (GSQ L2409).

Above 230 m to approximately 1 010 m the sequence is generally coarser and consists of thick to very thick-bedded and massive pale brown siltstone and mudstone, with interbeds of thin to very thick-bedded, pale grey, very fine to medium sandstone. The finer units are typically laminated, ripple cross-laminated and burrowed (Plate 32b, c), with plant fragments and rarer stems scattered throughout. The sandstones typically have small to medium-scale, trough and low-angle cross-bedding. Low-angle planar and tabular cross-stratification (in places bidirectional), flat lamination associated with parting lineation, occur in the lower and upper portions of this interval. Small scale soft-sediment deformation and ripple cross-laminated fine sandstone are common throughout.

Several fossiliferous horizons are present in the sequence, including several sandy limestones. A very calcareous micaceous sandstone occurs at 480 m above the base of the formation in the type section (Plate 32d). It contains disarticulated and broken gastropods, brachiopods and bivalves (GSQ L2455). A similar, but thicker, calcareous sandstone occurs at 595 m. It is cross-stratified, containing numerous large eumophalid gastropods, crinoid ossicles, broken brachiopods and bivalves (GSQ L2406). It is very poorly sorted. At 690 m, a thick to very thick bedded, dark grey, tabular and trough cross-bedded, medium to very coarse-grained sandy limestone and calcareous arenite contains a fish microfauna with rare conodonts in the upper part (GSQ L2453). It is overlain by dark grey micaceous siltstone, a thin-bedded, dark grey, dirty limestone containing disarticulated brachiopods and bivalves (GSQ L2454), overlain in turn by a thick to very thick-bedded, intensely bioturbated grey micaceous sandy siltstone and dark grey muddy siltstone. A well preserved and rich, bivalve, gastropod, brachiopod, and crinoid fauna, including bryozoans and scaphopods in some layers (GSQ L2407) occurs in this finer-grained interval, which is then overlain by another thin-bedded, pale grey dirty limestone containing disarticulated brachiopods, bivalves, rare fish, and conodont microfossils (GSQ L2452). At 731 m a thick-bedded, dark grey, medium to coarse, poorly sorted dirty limestone is rich in turreted and eumophalid gastropods, bivalves, brachiopods and crinoids. The limestone contains a rich fish microfauna, with rare conodonts (GSQ L2451; Lang, 1985). A similar dirty limestone occurs at 865 m.

Above 1 010 m, marked by a ridge of fine to medium-grained sandstone, is a 25 m thick sequence of pale brown-grey mudstone. This underlies the Dyraaba Member.

The main lithologies of the Dyraaba Member are sandstone, siltstone and mudstone. The sandstones are all labile feldspathic to lithofeldspathic in composition. They contain abundant mica (mostly muscovite), and are almost invariably calcareous and muddy. Medium to thick bedded, pale brown grey, fine to medium-grained, moderately sorted sandstone, is the dominant lithology. In places, such as at the base of the unit, poorly sorted, coarse-grained sandstones are common. Interbeds of medium to thick-bedded, dark grey to pale brown-grey mudstone and siltstone occur throughout. The upper half of the unit is generally finer grained, but the sequence coarsens upwards towards the top.

The sandstones are typically cross-stratified. They contain abundant small to medium-scale, trough and low-angle trough cross-stratification. Flat-laminated sandstones with associated parting lineation (Plate 32e) are less common, and occur mainly in the lower half of the Member. Bidirectional cross-stratification (low-angle planar type) also occurs in sandstones in the lower half, and is also associated with parting lineation; interbedded sandstones contain small-scale soft-sediment deformation. Some sandstones are composed of a poorly-sorted mixture of angular quartz granules and muddy, fine to medium-grained sand. Silicified stems and logs (Plate 32f), and disarticulated shelly fossils occur in these poorly sorted sandstones, which are usually trough cross-stratified. The interbedded mudstones and siltstones are typically laminated, burrowed in places, and contain abundant carbonaceous matter and plant fragments. In places they grade into carbonaceous mudstone and coaly bands. Pyrite (oxidised to limonite in outcrop) is abundant, and rare calcareous concretions occur in these muddy and silty interbeds.

The sequence described above changes slightly between the type section and the northwest. A reference section in the upper reaches of Bundock Creek (east of 'Oak Valley'), where the formation is at least 1 260 m thick, differs from the type section in that limestones are unknown, and marine faunas are rare. Farther east, in the Box Flat Dam and Kennedy Highway area, Wyatt & Jell (1980) report the occurrence of marine fossils in calcareous sandstones near the middle of the unit.

Relationships and boundary criteria

The Teddy Mount Formation conformably overlies the Turrets Formation, the boundary usually marked by a thick calcareous mudstone interval. In the Dip Creek and Chinaman Creek Synclines however, the base of the unit is placed under a very thick-bedded, brownish grey, polymictic, pebbly, cross-bedded paraconglomerate, which overlies a distinctive white, quartz-rich, pebbly cross-bedded sandstone and conglomerate of the Turrets Formation. The lower mudstone interval is interpreted to be missing in this area. In the north of the basin, the lower part of the unit is faulted against metamorphics and granitoids of the Georgetown Block in the north of the basin by the Teddy Mount Fault. North of Teddy Mount, the base of the unit is faulted against the Bulgeri Formation, and against undifferentiated Wando Vale Subgroup.

The base of the Dyraaba Member is placed under a medium to thick-bedded, pale brown-grey, medium to very coarse-grained, calcareous, micaceous arenite. Numerous fossil logs and stems litter the ground above the boundary, and are used to differentiate the Member from the underlying rocks. The top of the unit is overlain apparently conformably by the Boroston Formation. The upper boundary is placed at the top of the highest mudstone and siltstone underlying a distinctive ridge-forming granule conglomerate. The Member is distinguished from the Boroston Formation by the fine grain size, abundance of plant fossils, and the lack of quartzose sandstones and conglomerates.

The formation is conformably or disconformably overlain by the Boroston Formation throughout most of its extent.

The top of the formation is faulted out or eroded in the core of the Dip Creek Syncline, and obscured by basalt in the Catfish Creek area. In much of the western and northern area, the Teddy Mount Formation is extensively intruded by plutons, dykes and sills of the Carboniferous to ?Permian Montgomery Range Igneous Complex.

Environment of deposition

The presence of plant remains and shallow marine fossils in a predominantly sandy and muddy sequence indicates accumulation in a shallow marine siliciclastic nearshore to shoreline depositional environment. Bioturbation is common in the sandstones, mudstones and siltstones. *Planulites* type burrows have been observed in some sandstones (Plate 32b), and usually indicate a littoral and shallow marine environment in the *Skolithos* ichnofacies (Seilacher, 1967). Many of these sandstones are ripple cross-laminated (Plate 32c).

In the type section, low-angle planar cross-stratification, with accompanying parting lineation, occurs in marine sandstones between 125 and 315 m, 600 and 645 m, 890 m and 1 240 m, and at 1 400 m near the top of the unit. These indicate deposition under high energy swash conditions, probably in a shoreface environment. The bimodal character of the cross-beds (Figure 37), especially in the Dyraaba Member, suggest that tidal processes may have been important. Disarticulated fossils in thin pebbly bands may be beach lag or tidal channel deposits.

Amalgamated sequences of trough and tabular cross-stratification occur within the unit, usually associated with soft sediment deformation (Plate 32c). The soft sediment deformation is suggestive of periods of rapid deposition, possibly in a deltaic channel complex, with relatively strong currents. The beds of cross-bedded sandy limestone, with broken shells and phosphatic fossil remains, point to a shallow marine or possibly tidal channel accumulation, deposited in migrating dunes. Locally, wave ripples are developed (Plate 32c). Coarsening-upward trends are only weakly developed in the type section (Figure 52), and may represent shoreline progradation.

In the Dyraaba Member, the presence of rare marine fossils and abundant carbonaceous matter, plant fragments, stems, and logs, in an essentially fine-grained facies, indicates a marginal-marine depositional environment. The occurrence of bidirectional cross-stratification and low-angle planar cross-stratification with parting lineation, is indicative of flow reversals under high flow regime conditions. These conditions are all met in tidal channels. Trough cross-stratified sandstones, with a poorly sorted mixture of disarticulated shells, granules, stems and logs, can therefore be interpreted as tidal channel lag deposits. The coarsening upward-sequence towards the top of the unit may indicate a deltaic influence. If there is no significant break above the Dyraaba Member, then the Boroston Formation may have been deposited in the adjacent alluvial plain facies to the Dyraaba Member.

In summary, the Teddy Mount Formation was deposited in a shallow marine to marginal marine environment, represented by muddy and sandy nearshore, muddy shelf, tidal channel and shoreface facies.

The Teddy Mount Formation was deposited at the western end of a shallow sea that probably connected with the Clarke River and Burdekin Basins to the east.

Fossils and age

The Teddy Mount Formation contains an abundant shallow marine fauna, dominated by gastropods. Brachiopods, bivalves and crinoids occur to a lesser degree, and corals, bryozoans and scaphopods are rare. Microfossils abound in the limestones, and include a rich microvertebrate (fish) fauna, and rare ostracodes, phyllocarids and conodonts. Fossils are rare in the Dyraaba Member; indeterminate, disarticulated brachiopod shells occur in the middle unit. Plant remains occur throughout the formation. They include mainly fragments of leaves, stems and logs, all of calamitaean and lycopod affinity. Lepidodendroid (Plate 32f) and calamitean type stems are particularly common in the Dyraaba Member, littering most of the outcrops. Burrows are common throughout the formation. This includes *Planulites* type burrows in sandstones (Plate 32b). Some fine-grained intervals are completely churned by burrows.

The conodonts suggest a Late Devonian (latest Famennian) age for the unit. It may, however, range up into the Early Carboniferous in places (Lang, 1985, 1986a; Withnall & others, 1988b). A latest Devonian or earliest Carboniferous age has been suggested by Turner (1982) for the fish remains.

This is a similar age to the Venetia Formation of the Clarke River Basin, and the Hardwick Formation of the Burdekin Basin.

The lepidodendroid and calamitaean plant remains suggest a Late Devonian or Early Carboniferous age for the Dyraaba Member (J. Rigby, personal communication, 1985).

BOROSTON FORMATION

Introduction

The formation was defined by Lang & others (1989b), although it was first described by Lang (1985, 1986a) and published by Withnall & others (1988b).

The unit described here is confined to the core of the Boroston Syncline, between Dingo and Mount Brown Creeks, north of the Broken River, at the base of the Great Divide, in the southwestern corner of the Burges 1:100 000 Sheet area. It is also extensively distributed throughout the centre and northwestern side of the Montgomery Range, between Harry Creek and 'Oak Valley' homestead. Lang & others (1989b) gave an exaggerated thickness of 1 050 m for the formation. However, it probably does not exceed 850 m in the type section. The unit thins rapidly to the southeast where it is only 85 m on the southwestern limb of the Boroston Syncline. The unit tends to form high strike ridges covered by stunted eucalypts including silver leaved ironbark and yellowjack.

The Boroston Formation conformably overlies the Teddy Mount Formation in synclines in the northwestern quadrant of the Bundock Creek Group, between Mount Brown and Bullock Dray Creeks and north to the Teddy Mount Fault. The base of the unit is placed under a distinctive ridge-forming granule conglomerate, which overlies the Teddy Mount Formation with apparent conformity. The formation is overlain conformably by the Harry Creek Formation, and is distinguished from both formations by the abundance of quartzose pebbly sandstones and conglomerates.

Type and reference sections

The type section (Figure 53) is defined along an unnamed tributary of McKinnons Creek between 7859-375566 (base) and 370577 (top). The base is a distinctive, ridge-forming, very coarse-grained, quartzose sandstone coarsening upward to cobble conglomerate. The remainder of the unit is cross-bedded, medium to coarse-grained, micaceous, lithofeldspathic sublabile to quartzose sandstone, conglomerate and mudstone. A reference section is exposed along the banks of Mount Brown Creek between 7899-

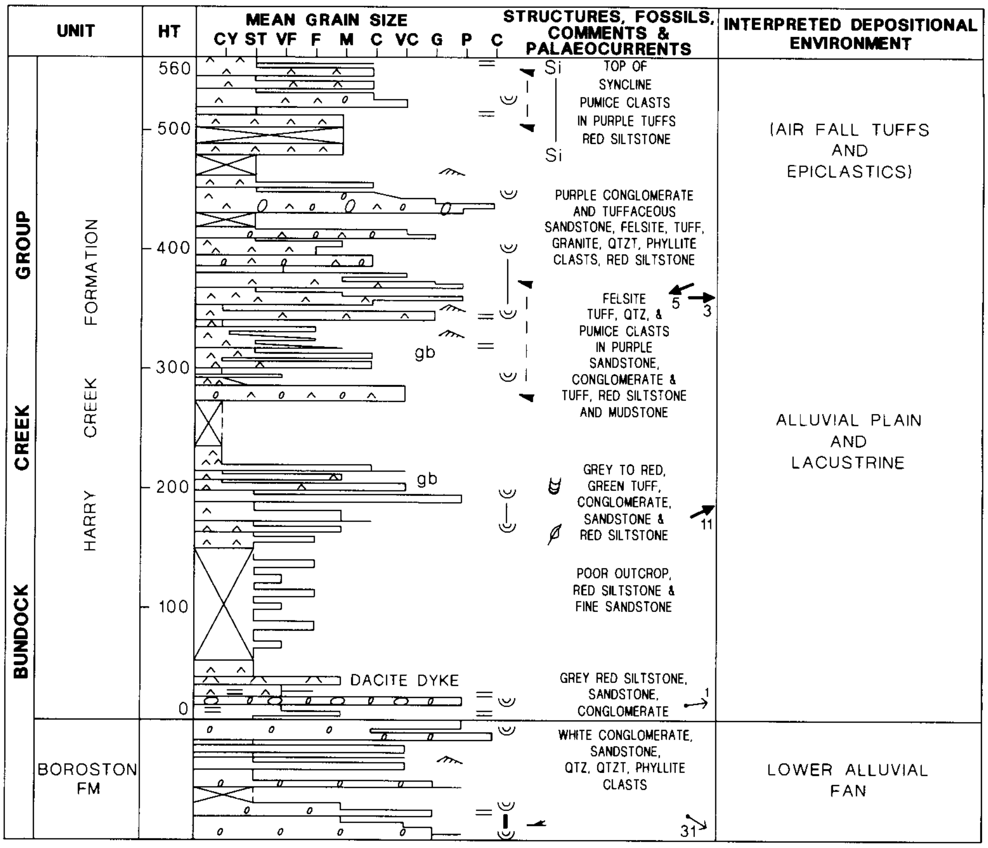


Figure 54. Type section of the Harry Creek Formation in the Harry Creek Syncline between 7759-355599 (base) and 365588 (synclinal hinge). See Figure 14 for reference.

495465 and 494466. This section includes 85 m of sandstone and conglomerate, with interbeds of siltstone, mudstone and reworked tuff in the upper part.

Lithology and sequence

The unit is composed of medium to very coarse-grained lithofeldspathic sublabile micaceous sandstone and conglomerate. The sandstones contain small to medium-scale trough, low-angle trough and planar tabular cross-bedding (Plate 33a). The lower part of the sequence usually comprises very coarse-grained quartzose sandstone to cobble conglomerate. Pebble and cobble clasts include quartz, quartzite, phyllite, metasediments, rhyolite, and shale rip-up-clasts. The sediments are mostly derived from a metamorphic or plutonic source, but a significant volcaniclastic input occurs towards the upper part of the formation. Minor greenish grey to reddish-brown micaceous siltstone, mudstone and reworked tuff occur in the upper part of the unit, especially in the southern areas.

Environment of deposition

The lack of fossils other than rare plant fragments, the dominance of conglomerates and trough cross-bedded pebbly sandstones, and the coarsening upward profile for the lower half of the unit, together suggest an alluvial fan origin for the Boroston Formation (Figure 53). The bulk of the unit was probably deposited in low sinuosity channels on a broad alluvial fan system. The palaeocurrents indicate a fan axis trending southeast (Figure 37), and this is compatible with the compositions of the sediments, which were largely derived from a plutonic/metamorphic source - probably the Georgetown Province. The volcanic detritus component becomes increasingly important in the upper part of the sequence, suggesting increasing volcanism in the region. The alluvial fan system must have been generated in response to a significant uplift event of the Georgetown Province in the Early Carboniferous. The finer-grained interbeds in the upper part of the formation may represent lacustrine or alluvial plain facies deposited as the alluvial fan system settled down to a lower energy regime represented by the overlying Harry Creek Formation.

Fossils and age

Apart form indeterminate plant remains at 7859-478465, no fossils are known from the formation.

The unit is younger than the Teddy Mount Formation in the type area, and is therefore Early Tournaisian or younger. The unit predates the main northeast trending fold event, which may be Visean. The formation is lithologically equivalent with the upper non-marine part of the Venetia Formation in the Clarke River Basin, and the Piccadilly Formation in the Burdekin Basin.

HARRY CREEK FORMATION

Introduction

The formation was formally defined by Lang & others (1989b), although it was originally described by Lang (1985, 1986a) and first published by Withnall & others (1988b).

The unit is exposed in several synclinal cores in the Mount Brown Creek, Bullock Dray Creek, and Harry Creek areas. The Harry Creek Formation is the highest preserved part of the Bundock Creek Group and conformably overlies the Boroston Formation.

The base of the Harry Creek Formation is marked by the first incoming of thick red to reddish brown tuffaceous

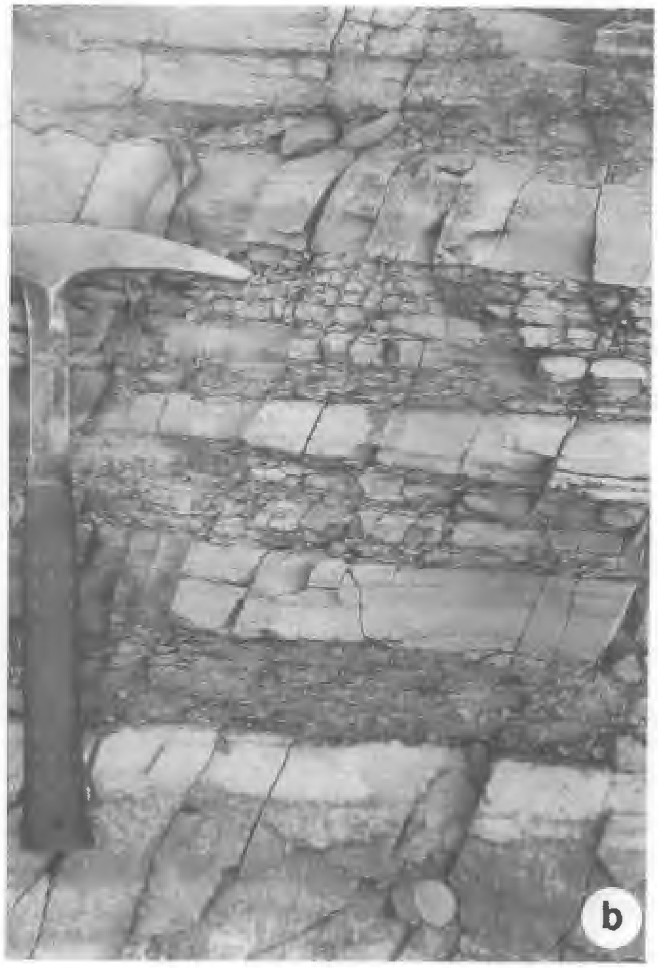


PLATE 33. Boroston Formation and Harry Creek Formation.

a. **Small to medium-scale trough cross-bedded, pebbly quartzose sandstone and conglomerate (Lithofacies St, Gt and Gm), interpreted as channel-fill deposits within a low-sinuosity stream. Boroston Formation, 7859-492467 in Mount Brown Creek.**

b. **Interbedded reddish, fine-grained volcaniclastic sandstone and mudstone, interpreted as reworked tuff. Harry Creek Formation, approximately 530 m in the type section (refer to Figure 64).**

siltstones and volcaniclastic sandstones. These are commonly interbedded with thin conglomerates with a matrix of coarse to very coarse-grained, poorly sorted sublabile sandstone, containing quartz, quartzite and occasional volcanic clasts. This usually overlies a ridge-forming sequence of pebbly and cobbly quartzose conglomerate and cross-bedded pebbly sandstone of the Boroston Formation. The boundary is transitional and to a certain extent arbitrary, as several quartzose sandstones and conglomerates occur throughout the lower part of the formation.

Type section

The base of the type section was placed by Lang & others (1989b) in an unnamed tributary of McKinnons Creek at 7859-372601. However, a more continuous section through the boundary and lower 50 m can be observed along strike at 355599 (Figure 54). The type section which follows the creek contains 560 m of volcaniclastic siltstones, sandstones and conglomerates. The top is at 365588 in the hinge of the Harry Creek Syncline.

Lithology and sequence

The Harry Creek Formation consists predominantly of fine to coarse-grained, poorly sorted reworked tuff, although quartzose sandstones and conglomerates are more common in the lower part of the unit (Figure 54). Trough cross-bedding, flat lamination, ripple cross-lamination, and graded bedding is common, although many of the beds are apparently structureless. The reworked tuffs range from fine-grained sandstone and siltstone (Plate 33b) to pebbly and cobbly conglomerates containing angular lithic fragments up to 3 cm in diameter, ranging in composition from flattened scoria to rhyolite and andesite. The colour ranges from a pale green to a deep reddish brown. In the upper half of the unit, several primary tuffs occur, being distinguished from the epiclastics by the lack of non-volcanic rock fragments, and the dominance of angular volcanic clasts, shattered feldspar, high temperature quartz, and some biotite.

Just above the base of the Harry Creek Formation near Teddy Mount (7859-426634) a probable andesite lava flow is interbedded with the tuffs. This andesite is the only known lava flow in the formation (and the Bundock Creek Group), although some of the apparently concordant rhyolite bodies mapped as part of the Montgomery Range Igneous Complex could be lavas rather than sills. The flow is about 3 m thick and is very vesicular near the top.

Environment of deposition

The formation is non-marine, and seems to represent a generally lower energy environment than the relatively high energy alluvial plain depositional environment of the underlying Boroston Formation. There are however, numerous coarse-grained quartzose or tuffaceous sandstones and conglomerates amongst the fine-grained sediments, indicating higher energy conditions in places, especially in the upper part of the sequence.

The finer-grained tuffaceous intervals, which are usually laminated, ripple cross-laminated, and in places burrowed and associated with plant fragments, probably represent tuffs which were either originally waterlain, or reworked from airfall deposits and ultimately accumulated in an alluvial plain (overbank) or shallow lacustrine setting. The cross-bedded sandstones and conglomerates probably represent fluvial channel deposits (sand sheets, dunes, and gravel bars). The poor sorting of angular volcanic clasts in the coarser-grained, tuffaceous intervals may indicate they accumulated close to their source.

The mean palaeocurrent azimuth in quartzose sandstones is to the east, although a few readings in the more tuffaceous units trend to the west (Figure 37 and 54). The source area appears to have initially been the Georgetown Province, but a rhyolitic to andesitic volcanic source became more dominant with time. It is uncertain whether the epiclastics are related to some of the pre-folding rhyolitic intrusions of the Montgomery Range Igneous Complex or the volcanic rocks of the Lyall Formation in the Clarke River Basin to the east.

Other volcanic sources include the more distant volcanics overlying the Georgetown Province 50 to 100 km to the west and northwest, for example, the Newcastle Range Volcanic Group, and volcanics (now mainly eroded) related to the Bagstowe and Lochaber Ring Dyke Complexes. The onset of this volcanism around 330 Ma (mid Carboniferous, L.P. Black, unpublished data) would be consistent with the age of the Harry Creek Formation.

Fossils and age

No fossils other than poorly preserved plant fragments and burrows are known. The Harry Creek Formation, because of its abundant volcanic component, may be Late Visean in age corresponding with the onset of extensive continental volcanism throughout northeast Queensland. On lithological grounds, it may correlate with the Lyall Formation the Clarke River Basin, for which palynological evidence indicates a Visean age (Playford, 1988).

MONTGOMERY RANGE IGNEOUS COMPLEX

Introduction

Intrusive rocks in the Bundock Basin were originally assigned by White (1962a) and Branch (1966) to a single unit, the Montgomery Range Rhyolite Porphyry, but because it contains a host of hypabyssal and plutonic rocks, it was renamed the Montgomery Range Igneous Complex by Withnall & others (1988b) and redefined by Lang & others (1989b).

The complex crops out as an irregular belt, approximately 18 km wide between 'Pandanus Creek' and 'Gregory Springs' homesteads. The belt includes the Montgomery Range which has rugged relief ranging from 50 to 250 m. The Montgomery Range Igneous Complex is a series of intrusions consisting of a variety of lithologies including granite, microgranite, granodiorite, rhyolite and dacite. They occur as stocks, sills and dykes, and intrude all of the units of the Bundock Creek Group.

Lithology

Granite and microgranite. The granitic rocks are the most abundant intrusives. The colour ranges from pale pink to a deep reddish orange. The rocks are fine to medium-grained and the texture ranges from granophyric to equigranular hypidiomorphic.

Two main types of granite were recognised in the Montgomery Range, based on their texture, composition and colour. The first type forms a large pluton just north of Mount Brown Creek. It is red in colour and has an equigranular texture. The main mafic mineral is biotite which has partly altered to chlorite. The feldspar is partly sericitised. The second type has a granophyric texture, contains less quartz, generally contains minor hornblende, and is also much paler in colour. A microgranite intrusion east of Teddy Mount is generally aphyric to sparsely porphyritic and its composition is very similar to the granite.

Granodiorite. The large stock east of Teddy Mount consists of pale grey medium-grained granodiorite containing 10-15 percent hornblende (partly altered to biotite and chlorite).

Rhyolite. The rhyolite in the Montgomery Range crops out as sills, dykes and massive intrusions showing a great variety of texture and colour. Some of the more common varieties are: (a) finely flow-banded rhyolite with small (1-2 mm), sparse pink feldspar crystals in a greenish matrix; (b) moderately to abundantly porphyritic rhyolite with phenocrysts of quartz and feldspar up to 10 mm, in an orange to pink microcrystalline groundmass; and (c) spherulitic rhyolite containing spherulites up to 10 mm with radiating and concentric structure, in a microcrystalline groundmass of quartz and feldspar. The feldspar in the rhyolite is consistently sericitised. Most of the rhyolites show chilled margins on both the upper and lower contacts.

Two main periods of rhyolite intrusion into the Bundock Basin can be recognised. The first, which occurred before the main folding event, and before the main granite emplacement, includes mainly the porphyritic and spherulitic rhyolite varieties. A younger group of dykes locally intrude some of the granite plutons near their margins. This group probably post-dated the folding, and includes dykes of aphyric, flow-banded rhyolite.

Dacite. Two large dacite sills occur to the south of Teddy Mount in the headwaters of Mount Brown Creek and Dingo Creek, but many other much smaller dacite sills intrude the Bundock Creek Group. The dacite is pale grey with very abundant hornblende prisms up to 3 mm throughout. Minor phenocrysts of feldspar are present locally. Sericitisation of the feldspars is common.

Alteration. Alteration of the igneous rocks in the northeast of the Bundock Basin is widespread. It includes sericitisation of the feldspars, chloritisation of the mafic minerals and epidotisation of some of the rhyolites.

Contact Metamorphism

Contact metamorphism around the larger plutons is locally very extensive. Induration is very intense up to 750 m from the edge of some of the granitic plutons suggesting that the contacts extend at a low angle below the surface.

Age and intrusive relationships

The presence of abundant tuffs in the Harry Creek Formation, indicates proximity to explosive rhyolite extrusion. Intrusions such as that at Teddy Mount were probably emplaced into the upper part of the Bundock Creek Group around this time. After major NE-SW folding, which probably occurred in the Early Carboniferous, granite plutons and more rhyolites were intruded along a NE-SW trend between Pandanus Creek and Gregory Springs homesteads. Minor rhyolite and dacite dykes and dyke swarms were intruded after emplacement of many of the granites.

DETAILED SEDIMENTOLOGY OF THE BULGERI FORMATION

(S.C. Lang)

This chapter describes the results of a detailed facies analysis of the Bulgeri Formation. A general description of the rock types and stratigraphic relationships is discussed in the previous chapter.

Since the Bulgeri Formation is dominantly a non-marine sequence, most of the lithofacies are identical to those described in the scheme developed by Miall (1977, 1978), and used with some modification by Rust (1978, 1979, 1984), Massari (1983), Rust & Gostin (1981), and Moore (1979). A similar scheme was applied to the description of the Bulgeri Formation by Lang (1985, 1986) and is adopted here. The scheme is summarised in Table 6 and the lithofacies shown therein will be referred to throughout the following text and on the logs of measured sections. Table 7 summarises the distribution of the lithofacies. Architectural elements recognised in the formation are summarised in Table 8. The various Lithological Associations referred to in the text were described in the previous chapter.

ROCKFIELDS MEMBER (UNITS A TO D)

The member forms a sinuous folded belt from about 7858-485335 near Pages Dam in the south to about 7859-585545 in the hinge of the Atherton Creek Anticlinorium.

The member crops out as a series of low strike ridges, sparsely vegetated with stunted silver leaf ironbark and quinine bush. Individual bands of white and brownish tones on the colour aerial photographs correspond with the volcaniclastic sandstones and siltstones (reworked tuffs) and fine-grained redbeds, respectively.

The unit is 795 m thick in the type section, thins progressively to the northeast, and wedges-out near the nose of the Atherton Creek Anticlinorium. Four subdivisions, Units A-D can be recognised within the member, and these are described and interpreted below. Lithological equivalents occur in the Six Mile Syncline area underlying unnamed conglomerate members of the Bulgeri Formation.

Unit A - sequence

Unit A forms the basal sequence of the Rockfields Member, and is laterally continuous for at least 40 km of strike length above the unconformity. The unconformity truncates the shales of the Mytton Formation at a low angle (Plate 24a), and in places is distinctly channelised (Lang, 1985, 1986a). The sequence is up to 60 m thick in the northeast (the hinge of the Rockfields Syncline), and gently thins to about 45 m in the Broken River area, wedging out towards the southwest (Figures 46 and 55). Broadly, the sequence fines upward from conglomerate and pebbly sandstone in the lower part, to mudstone and sandstone in the upper part. The Unit A sequence in GSQ Clarke River 2 in the northeast (Figure 40) contrasts with the sequence in the Broken River - Page Creek area in the southwest (Figures 47 and 55).

In GSQ Clarke River 2 (Figure 40) and in the surrounding outcrops in the hinge of the Rockfields Syncline, the sequence is marine influenced and consists entirely of Lithological Association 8. The unconformity with the underlying Mytton Formation is marked by a thin, polymictic conglomerate which fines-upward into fine-grained, calcareous sandstone and drab, burrowed mudstone (Lithofacies Ge, Gm, Sh, Se, Sm, Fb). Two such fining-upward sequences underlie a 6 m thick conglomerate and sandstone interval (Lithofacies Gm, Ge and Sh) very similar to the lower part of Unit A in the southwest. Overlying this is a sequence consisting of burrowed or laminated, drab, fine-grained intervals (Lithofacies Fb, Fl and minor Fm), intercalated with massive or laminated, drab, calcareous, fine-grained sandstone intervals (Lithofacies Sm, Sh, minor Se). The intervals range up to 7 m thick. Some sandstones are intensely burrowed and churned. Carbonaceous mudstone grading to coal (Lithofacies C) occur as thin bands within the thick sandy intervals. Disarticulated spiriferid brachiopods, thin shelled bivalves, and small gastropods occur as shell lags in both the fine-grained and sandy intervals, commonly overlying burrowed erosive surfaces (Plate 24g). Fine-grained redbeds occur 50 m above the base of the unconformity, interbedded with medium-grained sandstones mapped as Unit B.

In the Broken River - Page Creek area, the lower part of Unit A comprises mainly conglomerate and pebbly sandstone typical of Lithological Association 8. The unconformity is marked by a channelised base overlain by a fining-upward sequence of polymictic, pebbly or cobbly conglomerate (Lithofacies Gm, Gp, Gt) and pebbly sandstone (Lithofacies Sp, St) ranging between 2 and 12.5 m thick (Plate 24a). The channel-fill has a subtle lateral accretion architecture, containing trough and planar cross-beds mainly trending northeast, but several trend directly opposite (Figure 38 and 39). Marking the top of this sequence is a blanket up to 3 m of well sorted fine-grained sandstone (Lithofacies Sh, Sr and lesser small scale St and Sp). The upper part of Unit A differs markedly from the sequence in the northeast. The sequence comprises mainly fine-grained redbed intervals (Lithological Association 2) up to 1 to 10 m thick, and consisting dominantly of Lithofacies Fm, with lesser Fr, P minor Fl. The redbeds are laterally extensive (greater than 20 km) and are intercalated with medium to very fine-grained, drab sandstones up to 0.1-4 m thick (Lithofacies Se, Sp, St, Sh and Sr) and minor, thin, drab fine-grained intervals (Fl and Fm) of Lithofacies Association 8. The sandstones overlie sharp, erosional bases, and fine upward into the redbeds. They contain bidirectional cross-beds (Plate 24b) and ripple cross-lamination with a dominantly northeast and a lesser southwest trend (Figure 37), and some contain hummocky cross-stratification (Lithofacies Shx - Plate 24c). Unlike the northeastern area, no definitely marine fossil fragments have been observed in the sequence, although rare fish (non-marine?) fragments have been recovered from the redbeds.

Thin intraformational conglomerates (Ge) comprising red mudstone clasts, reworked calcrete glaebules and fish fragments occur in several places, either as the bases of sandstone intervals, as discreet intervals up to 1 m thick, or as part of heterolithic lateral accretion deposits. A heterolithic lateral accretion deposit in the Broken River section (Figure 38, 32.5-35 m - Plate 24d) begins with red, cross-bedded intraformational conglomerate (Ge and Gp). This is overlain by inclined foresets of Lithofacies Ge interbedded with fine-grained redbeds (Fm and P) containing desiccation and synaeresis cracks, raindrop impressions (Plate 24 e, f), ripple marks, tracks, trails, lycopod plant remains, vague burrows, rhizoliths and small calcrete glaebules. Current directions within the foresets are bidirectional (trending northeast-southwest), and lie almost at right angles to the trend of the inclined foresets, which dip gently to the south.

Table 6: Lithofacies Scheme - Bulgeri Formation

Lithofacies	Sedimentary Structures	Interpretation
Gravelly Lithofacies (G)		
Gm gravel, massive or crudely horizontally stratified	horizontal stratification, imbrication	longitudinal bars, lag and sieve deposits
Gt gravel, stratified	trough and low-angle cross-bedding	minor channel fills
Gp gravel, stratified	planar (tabular) cross-bedding	linguoid or transverse bars
Ge gravel, massive, scours, intraclasts	crude cross-bedding	scour fills
Sandy Lithofacies (S)		
Sh sand, very fine to very coarse, may be pebbly	horizontal lamination or stratification, parting or streaming lineation	planar bed flow (lower and upper flow regimes)
St sand, very fine to very coarse, may be pebbly	solitary or grouped trough cross-bedding	dunes (lower flow regime)
Sp sand, very fine to very coarse, may be pebbly	solitary or grouped planar (tabular) cross-bedding	linguoid, transverse bars, sandwaves (lower flow regime)
Sl sand, fine to medium	low-angle trough cross-bedding	scour fills, crevasse splays, antidunes
Ss sand, medium to very coarse, may be pebbly	broad, shallow scours	scour fills
Sr sand, very fine to coarse	ripple cross-bedding and ripple marks	ripples (lower flow regime)
Se sand, scours with intraclasts	crude cross-bedding	scour fills
Ssd sand, fine to medium	soft-sediment deformation	slumping, water-escape
Sm sand, fine to medium	marine shelly fossils	shallow marine sandbar, beach
Shx sand, fine to medium	hummocky cross-stratification or wavy to low-angle inclined lamination	shallow marine storm deposit, and washover deposits
Fine-grained Lithofacies (F)		
Fl fine to very fine sand, silt, and mud	fine lamination, ripple cross-lamination, ripple marks	overbank or waning flood deposits
Fm very fine sand, silt and mud	massive, desiccation cracks	overbank, channel fill or drape deposits
Fr fine to very fine sand, silt, and mud	vertical to subvertical rhizoliths	vegetated overbank deposits
Fb fine to very fine sand, silt, and mud	bioturbation, laminated or massive	backswamp or bay deposits
Fsd very fine sand, silt, and mud	soft-sediment deformation	slumping, water-escape
Fcm very fine sand, silt, and mud	shallow marine shelly fossils, may be bioturbated	shallow marine bay deposits
Other Lithofacies		
P carbonate	pedogenic nodules, subvertical tubes	pedogenic horizons
T tuff, tuffaceous fine sand and silt, gravelly in places	Tm - massive to laminated Ta - accretionary lapilli	airfall tuff and reworked tuff
C coal, carbonaceous siltstone	laminated or massive	peat swamp, backswamp

Table 7: Distribution of Lithofacies in the Bulgeri Formation.

Subunits	Gm	Gt	Gp	Ge	Sh	St	Sp	Sl	Ss	Sr	Se	Ssd	Sm	Shx	Fl	Fm	Fr	Fb	Fsd	Fcm	P	T	C
Northern area	C	R	C	C	C	A	A	C	A	C	C	R	R		C	A	C		R	R	A	R	
Southern area	C	R			C	A	A	C	A	R	R	C			R	R	R				R	R	
Subunit Q	C	R	R	C	C	A	C	C	A	C	C	R	R		C	C	C	R	R	C	R	C	
Subunit P	C		R	C	C	A	C	C	A	C	C	R			C	C	R				R		
Subunit O				C	C	A		C		C			R		C	C		C		C			
Subunit N	C			C	C	C	C	C	A	C	C	R			C	C	R		R		C	R	R
Subunit M	C	C	R	C	C	A	C	A	A	R	A	R			R	C			R		C		
Subunit L	R			C		A	R	C		C		C			C	A			C		A	R	
Subunit K		R			C	C	C		A		A				C	C					C		
Subunit J	A	A	R	C	R	A		C	A	R	C					C							
Subunit I	C	C	R	C	C	A	C	A	C		A					C	C	R			R		
Subunit H						A	C		C		C												
Subunit G	A	A	C	C		C			C														
Subunit F	R				C	A	C		C		A					R							
Subunit E	A	A	A			A		R	A		A	R			R	R							
Subunit D			R	R	C	A	C	A	C		A	R			C	A					C		
Subunit C					A	A	C	A	A	A	A	A			R	C		R	R			C	
Subunit B					C	C		C	C	C	C	R			R	C	R	R	R		C	C	
Subunit A	A	C		R	C	C		C		A	C	C	C	R	A	C	A	C	R	C	C		R

A = abundant; C = common; R = rare. Lithofacies scheme as shown in Table 6.

Table 8: Summary of architectural elements in the Bulgeri Formation

Architectural elements	Lithofacies assemblages	Description	Distribution
Gravelly channel-fill			
GCH Gravelly channels	Gm, Gt, Ge, Ss, St, Se, (also Sh, Sm & Fb in Unit A only)	Sheet-like or lenticular bodies 1-5 m thick and extending from 10 m to >100 m laterally. Composed of stacked Gm, Gt, and occasionally Ge, typically fining-upward into pebbly sandstone (Ss, St). Large scale Gt typically fills channel scours in sets up to 2 m thick. May contain several combinations of gravelly and sandy channel-fill elements. Basal surfaces typically erosional and concave to planar. Upper surfaces usually eroded and planar to concave. Bipolar cross-bedding occurs in basal Unit A.	Especially common in Unit A, E, J and M, and in the proximal parts of the undifferentiated Bulgeri Formation north of the Clarke River Fault.
GB Gravelly longitudinal bars	Gm, Sh, (minor Sp & Sr)	Sheet-like bodies 40 cm-1 m thick and extending from 10 m to >50 m laterally. Amalgamated bodies up to 5 m thick and extending >200 m laterally. Typically composed of imbricated Gm overlying planar basal surfaces and overlain by a drape of 1-30 cm thick sheets of Sh with minor Sr. Locally sets of Sp up to 40 cm thick overlie either the Gm or Sh. Top surfaces usually eroded.	Mainly occurs in Units G, I, J and M, some in Unit E.
GT Gravelly transverse bars	Gp, Gt, Gm, Ge, St, Se	Lenticular to sheet-like bodies 0.5-3 m thick, extending from 5 m to at least 20 m laterally. Composed of large master foresets of Gp up to 2 m thick, with smaller sets of Gt, Ge, Ss, Se and St on the lower parts of the master foresets. Typically the trend of the master foresets are at a high angle to the mean current direction for associated sandy channel elements. Basal surface erosional and planar to gently concave.	Particularly common in Unit E, less common in Units D, G, J and M.
GS Gravelly sieve deposits	Gm, Sh	Lenticular bodies 0.5-2 m thick, extending from 5 m to at least 10 m laterally. Composed of massive clast-supported gravel, with little sandy matrix. In places interbedded with thin beds of Sh. Clasts are mainly reworked, partially reddened limestone, derived from local uplifted fault blocks of Devonian limestones. The matrix consists of quartz sand and red silt.	Confined to unnamed calcirudite lenses in northeastern areas (Six Mile Syncline, Dip Creek Syncline, and vicinity of GSQ Clarke River 1).
Sandy channel fill			
CH Sandy channels	Ss, St, Sl, Se	Sheet-like bodies of Ss, St and rarer Sl and Se, ranging from 0.3-5 m thick, extending laterally for >50 m. Stacked bodies form extensive sheets >10 km laterally.	Units F, H & K.
LS Laminated sand sheets	Sh, Sl, (minor Sp, St & Sr)	Sheet-like or lenticular bodies 4-10 m thick and extending >1500 m laterally. Composed of Sh and Sl, with erosively planar to slightly concave basal surfaces. Upper surfaces generally eroded, being irregular, concave or planar; where not eroded they are planar to slightly convex. Minor Sp, St and Sr.	Common in most units.

Architectural elements	Lithofacies assemblages	Description	Distribution
DU Dune complexes	St, Sl, Sp, (minor Se, Sh & Sr)	Sheet-like bodies 1-10 m thick and extending >1500 m laterally. Composed of amalgamated St, Sl and Sp, with lesser Se, Sh and Sr. Form laterally extensive multistorey sandstone bodies with erosive, commonly channelised bases. Individual elements range from 0.5-5 m thick, 5 to 100 m long, and 5 to 100 m wide. Upper surfaces generally eroded, being irregular, concave or planar; where not eroded they are planar to slightly convex and gradational with overlying floodplain elements.	Common in Units B, C and D, less common in I, J & M.
LDA Lateral to downstream accretion macroforms	Sl, Sh, Sp	Sheet-like or tapered wedge-like bodies 0.5-2 m thick and extending >200 m in a lateral or downstream direction. Composed of Sl, Sh, and Sp, lying within gently dipping master foresets. Planar to slightly concave bases, in places stepping down-dip. Upper surfaces erosively irregular and planar or scalloped.	Confined to mainly Units B, C, D and N. Heterolithic sandy and muddy lateral accretion deposits in the upper part of Unit A.
LB Linguoid barforms	Sp (minor Se & Sh)	Sheet-like macroforms >1-3 m thick and >120 m long in the downstream direction. Composed of amalgamated Sp sets, 0.1-1.5 m thick . Minor Se and Sh may be present. Erosive, sharp, concave to gently convex basal surfaces. Upper surfaces erosively sharp.	Mainly in Unit C, but also occurs in Unit L and N.
SF Scour fills	Ss, Se, Ge	Either lenses 0.1-0.4 m thick and extending 1-4 m laterally, or sheet-like bodies 0.1-0.6 m thick and extending >20 m laterally. Composed dominantly intraformational lags of Ge or Se. Bases always erosive, and irregular to concave. Upper surface gradational, sharply erosive or concave.	Common in most units.
Floodplain complexes			
LE Levees	Fm, Fr, P, (lesser Sr, St & Sh)	Sheet-like bodies 1-4 m thick and mostly >1500 m laterally. Form part of fine-grained redbed intervals which can be traced for >4 km laterally. Contain gently inclined accretionary layers which are marked by sandier laminae, and can be traced >20 m down-dip into an OF element. Composed of reddened Fm with lesser Sr, St and Sh. Desiccation cracks and bioturbation due mainly to plant rooting are particularly common. Sharp, planar, apparently non-erosional bases. Upper surface usually truncated by erosive surfaces at the base of CS or channel-fill elements.	Common in Units B, C, D, top part of K, L and M. Calcic palaeosols (P) very common in Units D, K, and L.

Architectural elements	Lithofacies assemblages	Description	Distribution
CS Crevasse splays	Sh, Sl, St, Sp, Sr, (minor Se)	Proximal CS are lozenge-shaped or lenticular bodies 0.1-1.3 m thick and < 13 m wide, whereas distal CS are sheetlike 0.1-2 m thick, > 100 m long, and 10 to > 30 m wide. Composed of Sh, Sl, St, Sp and Sr, with lesser Se. Climbing ripple cross-laminations are common in the upper part of individual beds. Linguoid and straight-crested ripple marks are common, particularly on upper surfaces. Desiccation cracks also common. Sharp, irregularly concave bases and sharp to transitional tops in proximal CS. Sharp, planar erosive bases, with undulating to planar tops in distal CS. Proximal CS coarser-grained than distal CS.	Mainly in Unit B, C, and L.
OF Overbank fines	Fm, Fl, Fr, P, (minor Sh, Sl, Sr, Sp & St)	Sheet-like bodies 0.3-2 m thick and mostly > 1500 m laterally. Form part of fine-grained intervals, which can be traced for > 4 km laterally. Also thin discontinuous lenses 0.05-1 m thick and 1-20 m wide, generally within sandy channel-fill elements. Composed of grey to greyish red Fm and Fl, with minor Sh, Sl, Sr, Sp and St. Green reworked tuffs extend 1-15 km laterally. Colour ranges from bluish grey to greyish red, or mottled mixtures of these. Asymmetric wave ripple marks are common, as well as mudcracks, synaeresis cracks, burrows, plant fragments, rootlet casts and fish bones. Bases are planar or gently concavo-convex, or gradational. Tops are erosive and irregular.	Common in most Units except E, F, G and H with a few near the top of Unit K. Decreasing abundance in the proximal parts of the Bulgeri Formation near the Clarke River Fault.
Marginal marine TC Tidal channels	St, Sr, Sh, Sm, (minor Ge, Se, Sp, Fl & Fm)	Erosively based, lenticular to sheet-like bodies between 0.1-4 m thick and > 50 m laterally. Composed of very fine to coarse-grained drab sandstone. Bipolar cross-bedding with NE-trending palaeoflows are dominant. Upper parts may be gradational with mudstone or inclined heterolithic foresets containing desiccation cracks, rain drop impressions, trails and reworked calcrete.	Confined to Unit A
STF Supratidal flats	Fm, P, Ge, Sr & Fl	Laterally extensive (> 10 km), fine-grained redbed intervals 1-10 m thick, intercalated with TC elements. Calcrete glaebules, desiccation cracks, bioturbation and thin sandy intervals with ripple cross-lamination are common.	Confined to Unit A, possibly in Unit O and Q
USF Upper flow regime sand flats	Sh (with parting lineation), Sr, Sp and rare Shx	Laterally extensive (> 20 km), clean, well sorted, very fine to fine-grained sandstone, with low-angle cross-bedding merging into flat lamination.	Confined to Unit A

Architectural elements	Lithofacies assemblages	Description	Distribution
WS Washover fans	Shx, Sh, Sr, minor Sp Fm and Fl	Fine to medium-grained, pale grey sandstone up to 1 m thick, typically <0.4 m, and laterally extensive (>30 m). Sharp basal surfaces with flat or low-angle inclined laminations or undulating hummocky? cross-stratification. Ripple cross-lamination and convolute lamination are common. Interbedded with laminated mudstone (Fl) or red mudstone (Fm). Occurs in the middle of the Unit A sequence either within STF, or overlying TC elements.	Confined to Unit A
BBL Back-barrier lagoon	Fb, Fl, and Sm, minor Se	Range from light to dark grey, muddy sandstone with scattered quartz and feldspar granules and abundant shale rip-up clasts, to grey mudstone and sandy mudstone with lamination disturbed by bioturbation and including shelly layers of molluscs (*Leiopteria*).	Confined to Unit A (GSQ Clarke River 2 and surrounding area only)
BBM Back-barrier marsh	C and Fl	Thin (<5 cm), dark grey, carbonaceous mudstone, muddy sandstone and thin coal bands. Calcareous in part. Interbedded with calcareous sandstone containing marine fauna, or massive and laminated sandstone	Mainly confined to Unit A, but minor occurrences in Unit N in non-calcareous rocks. (Both GSQ Clarke River 2 and surrounding area only)
BC Barrier complex	Sm, Sh and minor Se	Thick interval (up to 15 m) of light to medium grey, fine-grained sandstone, calcareous in part, and typically massive or laminated. Rip-up clasts common, and scattered quartz and feldspar granules occur mainly at the bases overlying mud-cracked TC elements.	Confined to Unit A (GSQ Clarke River 2 and surrounding area only)
TIC Tidal inlet channel	Sm, Sh and Se, with basal Ge and Gm; minor Fb	Fining-upward successions of pebbly sandstone and minor conglomerate up to 3 m thick. Sharp erosive bases marked by quartz and feldspar granules to pebbles and rip-up clasts. Upper parts mainly fine-grained, laminated, calcareous sandstone grading to mudstone. Overlies the unconformity in GSQ Clarke River 2, and intercalated with the basal gravelly TC elements.	Confined to Unit A (GSQ Clarke River 2 and surrounding area only)
FTD Flood tidal delta	Sm, sh and Fb	Typically coarsening-upward successions up to 5 m thick of dark grey, pyritic mudstone and fine-grained sandstone grading to light grey, calcareous, medium to coarse-grained sandstone. Include rip-up clasts and shell hash (*Cyrtospirifer* and *Leiopteria*). Fine-grained lower parts typically burrowed with thin shelly sandstone layers. Sandwiched by BB elements.	Confined to Unit A (GSQ Clarke River 2 and surrounding area only)

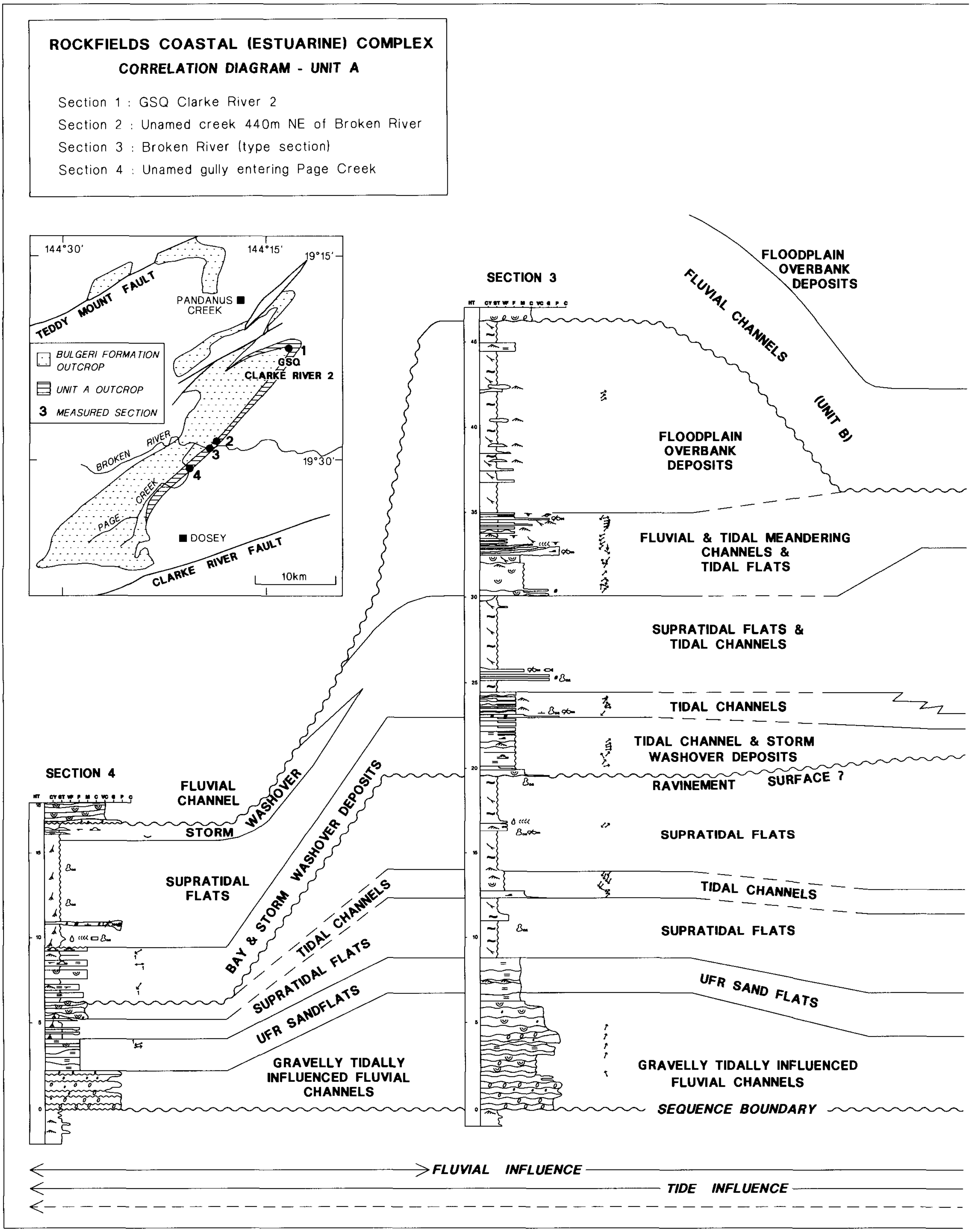
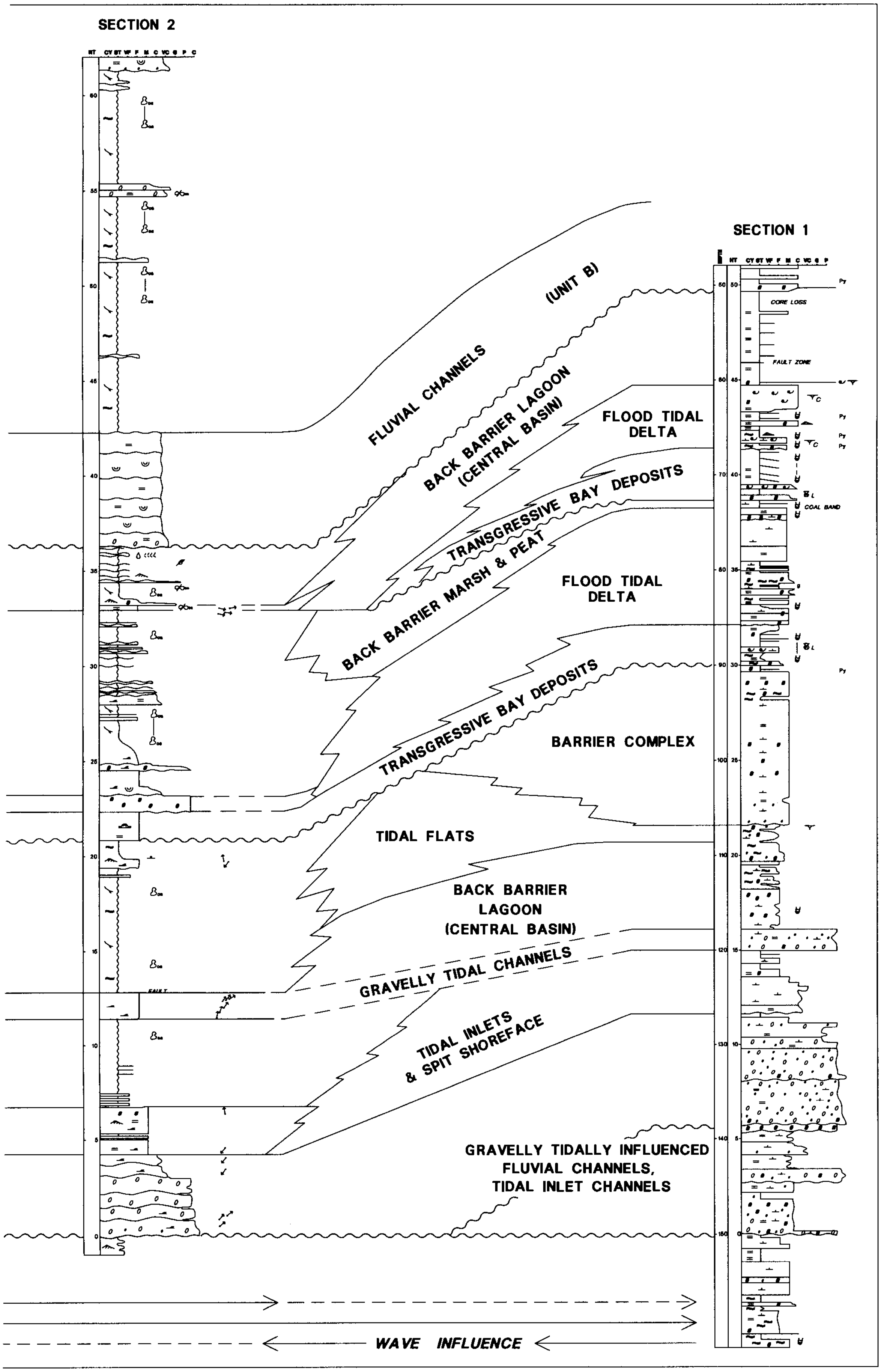


Figure 55. Correlation of sections through Unit A of the Rockfields Member from southwest to northeast showing the change from essentially alluvial and coastal plain (estuarine) facies to mainly shoreline facies.


SECTION 2
SECTION 1
(UNIT B)
FLUVIAL CHANNELS
BACK BARRIER LAGOON (CENTRAL BASIN)
FLOOD TIDAL DELTA
TRANSGRESSIVE BAY DEPOSITS
BACK BARRIER MARSH & PEAT
FLOOD TIDAL DELTA
TRANSGRESSIVE BAY DEPOSITS
BARRIER COMPLEX
TIDAL FLATS
BACK BARRIER LAGOON (CENTRAL BASIN)
GRAVELLY TIDAL CHANNELS
TIDAL INLETS & SPIT SHOREFACE
GRAVELLY TIDALLY INFLUENCED FLUVIAL CHANNELS, TIDAL INLET CHANNELS
CORE LOSS
FAULT ZONE
COAL BAND
WAVE INFLUENCE

Unit A - interpretation

The upper part of Unit A holds the key to the interpretation of the sequence, and will be interpreted first. In the northeast (Figure 40), the association of thick sandstone intervals containing carbonaceous or coaly bands, interbedded with burrowed fine-grained intervals, both containing shallow marine fossils, suggests a paralic depositional setting. This contrasts with the southwestern area, which contains no definitively marine facies. Instead it is dominated by laterally extensive, fine-grained redbeds showing abundant evidence of subaerial exposure (desiccation cracks, rhizoliths and calcrete), but also preservation of delicate structures (raindrop impressions, tracks and trails) which implies periods of relatively passive sedimentation. The occurrence of synaeresis cracks, which are formed by subaqueous salinity changes in shallow water such as tidal pools (Donovan & Foster, 1972), suggests these redbeds were deposited under supratidal conditions subject to inundation during high tides and storms followed by desiccation and pedogenesis. The sandstones containing bidirectional palaeocurrents, and also heterolithic lateral accretion deposits, indicate deposition under fluvial and tidal conditions, whereas the hummocky cross-stratified sandstones were deposited under storm conditions.

The redbeds are therefore interpreted as supratidal mudflat deposits (STF), and the sandstones and heterolithic lateral accretion deposits are interpreted as tidal channel or tidal creek deposits (TC). The hummocky cross-stratified sandstones may be interpreted as storm washover deposits (WS), laid down during storm inundation of the supratidal mudflats (Moslow, 1983). The upper part of Unit A in the southern area was therefore deposited on a fluvial, tidal and storm influenced, estuarine, coastal plain.

Palaeocurrents in Unit A indicate a northeasterly dipping palaeoslope, and this explains the lateral (down-palaeoslope) transition from coastal plain sediments in the southwest to paralic facies observed in the northeast. Supratidal mudflats indicate protection by a barrier complex (BC), and the elements of a barrier shoreline system can be recognised in GSQ Clarke River 2. The thick intervals of lithofacies Sm and Sh in the borehole indicate deposition under relatively high energy conditions, and may represent barrier shoreface deposits, and the interbedded intervals of Lithofacies Fb with lesser Sm may represent back-barrier lagoon deposits (BBL). The shell lags may have been deposited during storms as part of flood tidal delta prograding into the back-barrier lagoon. The thin bands of Lithofacies C interbedded with the barrier shoreface deposits can therefore be interpreted as back-barrier peat marsh deposits.

The basal gravelly and sandy fining-upward deposits at the base of Unit A have to be interpreted in the context of the overlying sequence. The coarse basal gravels and dominant northeasterly palaeocurrents suggest a system of incised fluvial channels (CH), the gravel being deposited as gravel bars and channel lags. The bidirectional current directions in the pebbly sandstones may indicate the action of powerful tidal currents in macrotidal estuarine distributary channels. The fining-upward intervals of Lithofacies Gm, Ge, Sh, Se, Sm, and Fb in the lower part of the sequence in the borehole are similar to tidal inlet channel deposits (TIC) (Moslow, 1983). Tidal inlets are to be expected along a barrier shoreline, and the gravel from the estuarine distributaries would accumulate on the channel floor, and be overlain by sands of the adjacent spit platform as the inlet migrated laterally along the coast (Moslow, 1983). The flat-laminated and massive sandstones (Lithofacies Sh, Sm) which overlie the gravelly Lithofacies in the northeast may therefore represent shoreface deposits of the spit platform (USF), but in the southwest, they could also be interpreted as sandflats deposited under upper flow regime conditions within the estuarine channels. Several distinct facies, or architectural elements, of both barrier shoreline and estuarine coastal plain depositional systems can therefore be recognised Unit A.

Unit A records a brief transgressional event, overlying incised fluvial tidal channels that mark the sequence boundary. This resulted in a wave and tide dominated sandy barrier shoreline complex, back-barrier lagoon and marsh complex being deposited over an estuarine distributary complex due to partial drowning of the coastal plain. However, with the exception of inundation during storms, direct marine influence was restricted to the northeast. The coastal plain was traversed by tidally-influenced gravelly and sandy rivers that drained northeast into an estuarine complex, dominated by supratidal mudflats.

A modern analogue for the lower part of Unit A may be the Pioneer River, which forms a tropical, macrotidal estuary on the tide and wave-dominated coast of Queensland (Hacker, 1988). The river carries large quantities of gravel and sand directly to the estuary during seasonal flooding associated with the monsoon and cyclones. North and south of this area are wide intertidal flats and swamps sheltered by wave-dominated beaches (Jones, 1987) and these are analogous to the supratidal mudflats, back-barrier marshes and barrier shoreface of Unit A.

Units B, C and D - sequence

Unit B directly overlies the basal unconformity around the nose of the Broken River Anticline in the south, and also along part of the southern limb of the Atherton Creek Anticlinorium in the northeast. Unit A was either eroded or never present in these areas, but in most places the boundary with Unit B is apparently conformable. Unit B is laterally continuous for at least 50 km of strike length above the unconformity, gradually thinning from over 250 m in the southwest, to 225 m in the Broken River type section, to 60 m northwest of GSQ Clarke River 1, wedging out near the nose of the Atherton Creek Anticlinorium. Unit C conformably overlies Unit B in the Broken River section, the boundary placed at the base of a thick sandstone interval which overlies a thick fine-grained redbed interval forming the upper part of Unit B. In the Broken River section, Unit C and D are 470 m and 55 m thick respectively, but they are gradually truncated to the northeast by Unit E, and Unit D is therefore not present in Diggers Creek (Figure 56). Unit B, C and D become coarser-grained to the southwest, and south of Pages Dam they cannot be readily distinguished, and pass laterally into undifferentiated Bulgeri Formation. In the Chinaman Creek area in the north, the lowermost part of the undifferentiated Bulgeri Formation has many similarities to Units B and C, and may be regarded as a lateral equivalent of the Rockfields Member.

Unit B, C and D are composed mainly of thick multistorey sandstone bodies intercalated with fine-grained intervals. The units can be distinguished in the field on the basis of grain-size and Lithofacies. The sandstones of Unit B and D are mainly coarse-grained (Lithological Association 1), whereas Unit C, and some Unit B sandstones, are fine to medium-grained, generally better sorted, and contain pervasive soft-sediment deformation (Lithological Association 3). The fine-grained intervals in Unit B and D are mainly fine-grained redbeds (Lithological Association 2), whereas in Unit C they are mainly drab siltstone or fine-grained sandstone (Lithological Association 5). Green reworked tuffs (Lithological Association 6) occur in both Units B and C.

Multistorey sandstone bodies in Units B, C and D range from 3-10 m thick, but some amalgamated bodies are up to 20 m thick in Unit B. The bodies are laterally extensive (1 500 m) and ridge-forming, and have a distinctly layered appearance on aerial photographs. Sandstone bodies of Lithological Association 1 in Units B and D are dominated by Lithofacies St, with lesser Sh, Sl, Sp, Se and Sr (Plates 25b and 27d). Sandstone bodies of Lithological Association 3 in Units B and C are dominated by Lithofacies Sh and Sl (associated with parting lineation), with lesser St, Se, Sp, and Sr. Some flat-laminated sandstones contain abundant placer magnetite (Unit B, Figure 38). Convolute lamination is pervasive (Plate 25c, d, e), with overturned cross-beds less common. Although most structures are small-scale and localised, some are large-scale (elutriation pipes up to 5 m in amplitude), and clearly deform erosive contacts between several beds for at least hundreds of metres laterally (Lang & Fielding, 1991). The bases of most sandstone bodies are erosive, and most are flat or distinctly concave. These erosive surfaces are commonly strewn with quartz granules and small pebbles. Some erosive surfaces are overlain by intraformational conglomerate or pebbly sandstone (Lithofacies Ge and Se), especially where they overlie fine-grained intervals. Some of these intraformational conglomerates are cross-bedded (Lithofacies Gp), but most are scour fills (Plate 27e). Rip-up-clasts are either red, drab or variegated. Some sandstones contain low-angle, inclined surfaces containing cross-beds or parting lineation indicating lateral or down-dip accretion. Lycopod stem or log casts occur near the bases of some sandstone bodies (Plate 25a), and fish bone fragments occur on foresets or strewn above erosion surfaces in pebbly lags.

Most fine-grained intervals are thick (1.0-10 m) and laterally extensive (1 500-4 000 m). Some fine-grained intervals occur as thin (0.05-1.0 m), laterally discontinuous units within multistorey sandstone bodies. The fine-grained redbeds of Lithological Association 2 in Units B and D commonly contain greenish grey reduction spots and mottles, especially immediately underneath sandstone bodies. Typical lithofacies are Fm, Fl, Sr and small scale St, though these are commonly destratified by bioturbation (mainly rhizoliths), and sporadic, small pedogenic calcrete glaebules occur in places (P). Current ripples, desiccation cracks, and sandstone dykes are common. In a few places, low-angle lateral accretion surfaces covered by desiccation cracks and rhizoliths occur. Plant fragments and fish remains occur sporadically.

The dominantly drab, fine-grained intervals of Lithological Association 5 in Units B and C comprise dominantly Lithofacies Fl and Sr, with lesser Fm, and rarely P. Plant and fish fragments, are common. Desiccation cracks and soft-sediment deformation are rare, but wave and current ripples are common (Plate 26a, b).

Most fine-grained intervals contain thin, sheet-like, lenticular, or lozenge-shaped sandstones (Plate 25d and 26c), which are dominated by Lithofacies Sh, Sl and topped by St, Sp and Sr (Lithological Association 3).

The fine-grained intervals contain numerous reworked tuff intervals (Lithological Association 6), and comprise Lithofacies Fl, Sh and Sr, with lesser St and Gm. These intervals are laterally extensive (15 km), up to 6 m thick, and composed mainly of fine to coarse silt-grade ash (mainly glass shards, volcanic quartz, and feldspar), and detrital muscovite. The shards are replaced by zoisite, clinozoisite, chalcedony, and lesser calcite.

The best known and thickest green tuff interval or bed (GRTB), lies in the upper part of the Rockfields Member (Figure 42). The lower part of the GRTB is marked by a dark green, structureless bed with angular rhyolite clasts (Lithofacies Tm), overlain by a normally graded bed containing accretionary lapilli up to 10 mm in diameter (Lithofacies Ta, Plate 27b). The upper part of the GRTB comprises interbedded conglomeratic and fine-grained tuffaceous intervals (Plate 27a), with lithic clasts ranging up to cobble-grade (70 mm in diameter). The clasts are mainly rhyolite lava, and fragments of green, fine-grained tuff similar to the matrix, although there are also large feldspar crystals and a few metamorphic rock clasts. The coarse clasts are randomly distributed in the fine-grained matrix, or confined to scour fills and thin, normal and reverse-graded beds. The volcanic clasts are commonly subrounded, but many are angular, especially the fine-grained tuff clasts.

The upper part of the GRTB is variably structureless, laminated or thin bedded, and ripple cross-lamination and wave-formed micro-ripples occur in places. Scour-surfaces are common, and usually occur at the base of graded beds. Plant fragments and rhizoliths occur at the southwestern margin of the GRTB. Palaeoflows were to the east or northeast, consistent with the enveloping fluvial channel sandstones (Figure 37). These sandstones contain rip-up-clasts of green tuff, diluted by the overwhelming supply of non-volcanic detritus. In the southwest, rhizoliths and plant fragments occur in the thickest interval.

A striking feature of the Rockfields Member is the pervasive soft-sediment deformation, and in the GRTB this includes convolute laminations, water escape structures, flame structures, clastic dykes and sills, ball and pillow structures, slumping, brecciation, and microfaults (Plate 27c).

After corrections for folding have been made, palaeocurrents from Units B, C and D (Figure 37) have mean azimuths ranging from northeast to north, indicating a southerly source area.

Units B, C and D - interpretation

No marine fossils have been observed in this sequence. This, together with and the common occurrence of plant fragments, rhizoliths and desiccation cracks in the fine-grained intervals, and the abundance of laterally extensive cross-bedded and flat laminated sandstone channel bodies, indicates a non-marine, alluvial plain depositional system. Bidirectional cross-bedding typical of Unit A is lacking, suggesting that tidal processes were probably absent.

The occurrence of weakly developed pedogenic calcrete glaebules in the laterally extensive fine-grained redbed intervals of Units B and D indicates calcic soil development on alluvial floodplains where sedimentation rates were faster than the rate of pedogenesis (Leeder, 1975). For calcrete to have formed at all, the climate would have been warm and seasonal (Goudie, 1973, 1983), and this is consistent with the equatorial palaeolatitudes inferred for northeastern Australia in the Late Devonian (Li & others, 1991). This climate explains the variable degree of oxidation within the fine-grained intervals, which reflects in part the variable degrees of oxidation and reduction during inundation and subsequent desiccation of floodplain areas. The occurrence of wave ripples, and the laterally extensive reworked tuffs in the floodplain deposits indicates the presence of standing water, probably as semi-permanent floodplain lakes (Lang & Fielding, 1991). The low-angle lateral accretion surfaces within some of the fine-grained intervals are interpreted as levee deposits. The thin, sheet-like, lenticular, or lozenge-shaped sandstone bodies within the fine-grained intervals contain evidence of initially rapid deposition (Lithofacies Sh, Sl) followed by waning flow (Lithofacies St, Sp, and Sr), and

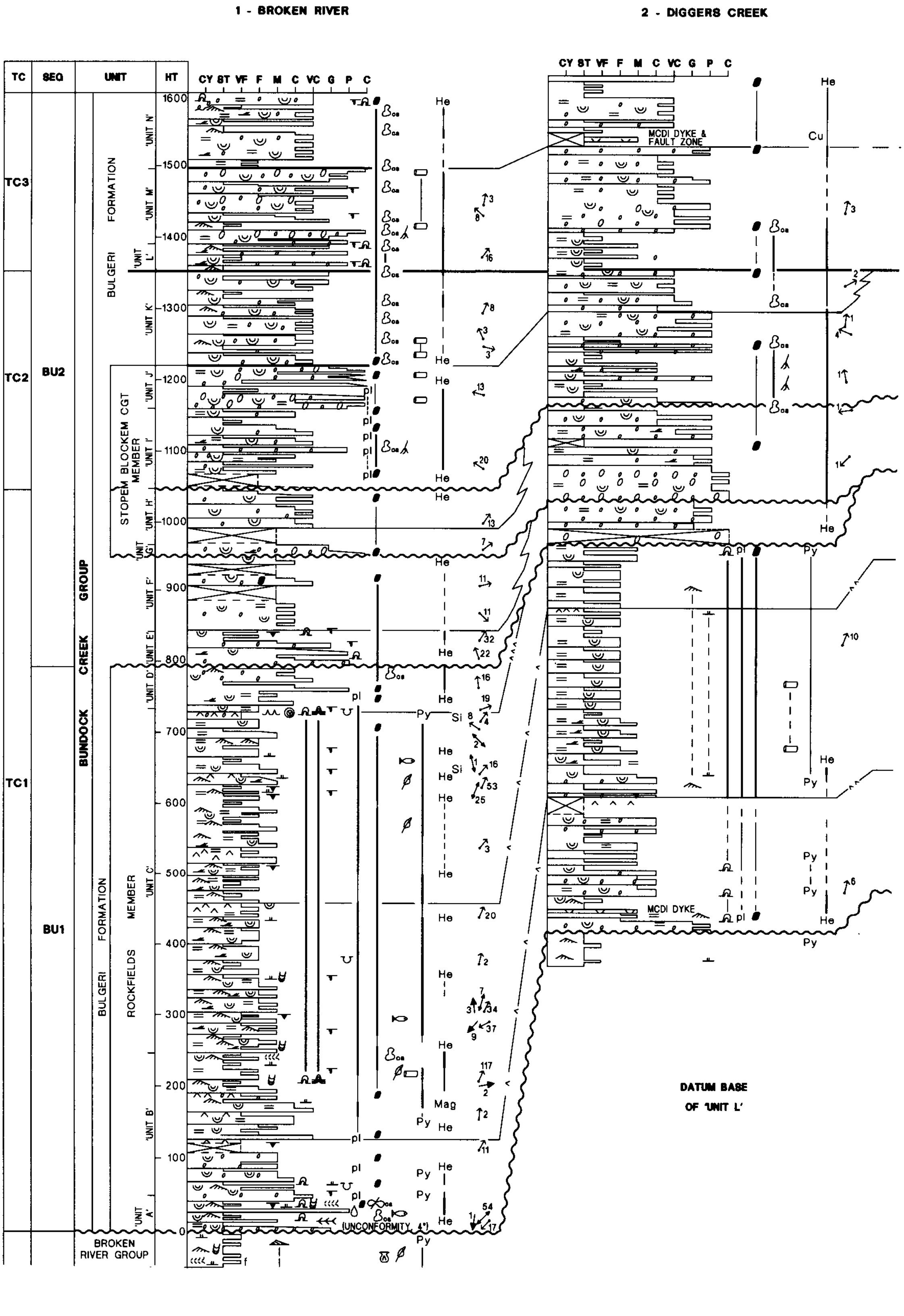
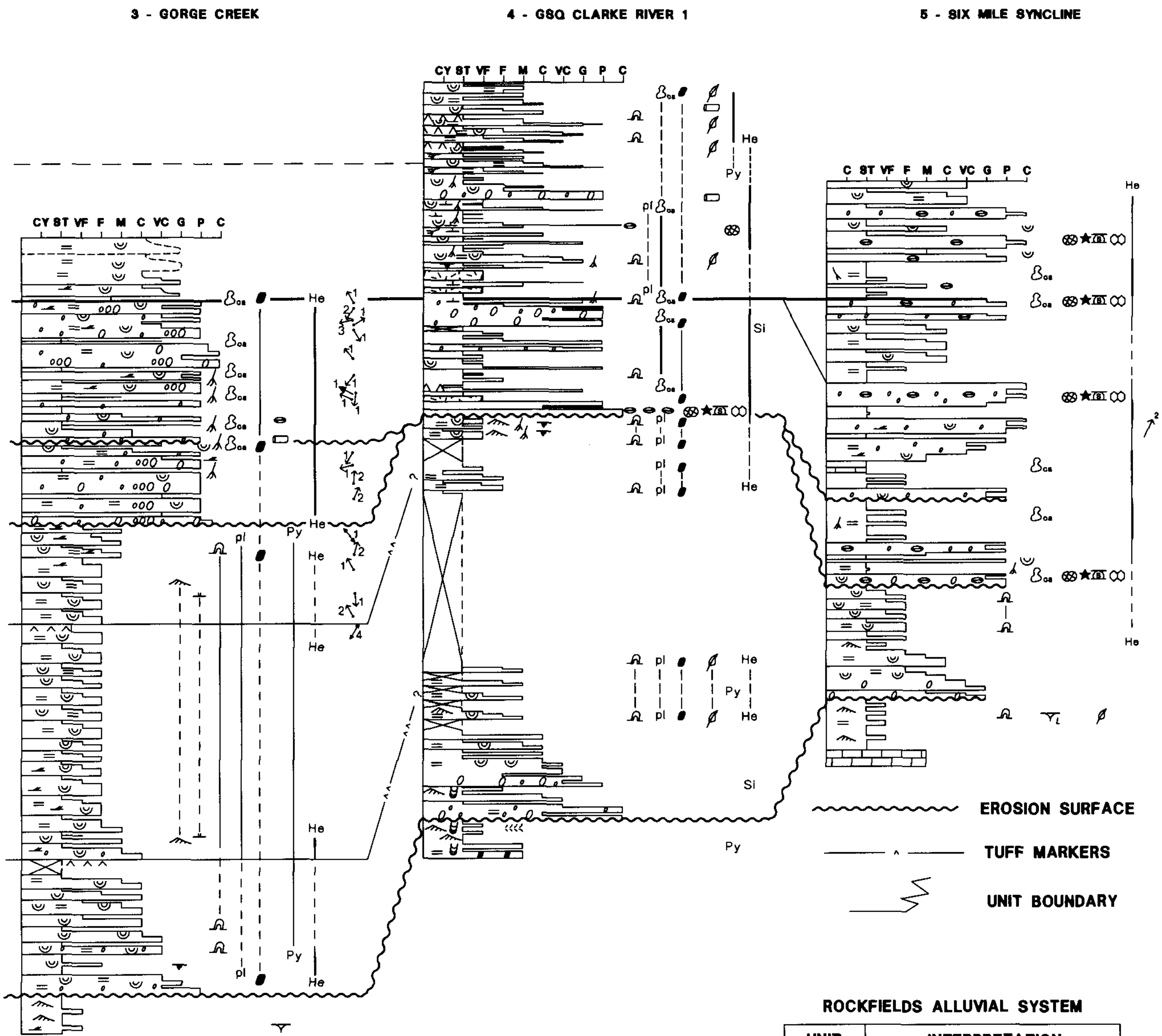


Figure 56. Correlation of sections through the lower part of the Bulgeri Formation from southwest to northeast showing facies changes and erosion surfaces.



ROCKFIELDS ALLUVIAL SYSTEM

UNIT	INTERPRETATION
UNIT D	COARSE SANDY LOW-SINUOSITY STREAMS & FLOODPLAINS WITH RED PALAEOSOLS
UNIT C	SEASONAL SANDY LOW-SINUOSITY STREAMS & FLOODPLAINS WITH SEMI-PERMANENT FLOODPLAIN LAKES, & TUFF & REWORKED TUFF
UNIT B	COARSE SANDY LOW-SINUOSITY STREAMS & FLOODPLAINS
UNIT A	COASTAL PLAIN (ESTUARINE CHANNELS TIDAL MUDFLATS)

STOPEM BLOCKEM ALLUVIAL SYSTEM

UNIT	INTERPRETATION
UNIT L	RED CALCIC PALEOSOLS WITH LITHIC & QUARTZOSE SANDY CHANNELS
UNITS G, I, J & M	RED LITHIC GRAVELLY & SANDY BRAIDED STREAMS & FLOODPLAIN CALCIC PALAEOSOLS WITH LOCALLY DERIVED LIMESTONE CLAST-DOMINATED SHORT HEADED FANS

BULGERI ALLUVIAL SYSTEM

UNIT	INTERPRETATION
UNIT K & N	QUARTZOSE COARSE SANDY BRAIDED STREAMS & FLOODPLAINS WITH PALAEOSOLS
UNIT H	QUARTZOSE COARSE SANDY BRAIDED STREAMS
UNITS E & F	QUARTZOSE COARSE SANDY & GRAVELLY BRAIDED STREAMS & ALLUVIAL PLAINS

Figure 57. Detailed lateral profile showing typical architectural elements of the Rockfields Member and pervasive soft-sediment deformation.

these are interpreted as crevasse splay deposits (Plates 25d and 26c). The rest of the fine-grained deposits represent undifferentiated overbank fines.

Lang & Fielding (1991) interpreted the multistorey sandstones of Units B and C as sandy flood deposits of broad, low-sinuosity streams, and this could also be extended to cover Unit D. Most multistorey sandstone bodies contain extensive flat lamination and were deposited as laminated sand sheets during rapid flows (1 m/s). The flat-lamination with parting lineation in fine to medium-grained sand indicates upper-flow regime plane bed conditions, whereas the cross-bedded parts were deposited as dune complexes or linguoid bars under lower-flow regime conditions (Harms & Fahnestock, 1965; Harms & others, 1975), and probably in deeper parts of active channels (Miall, 1985). The intraformational conglomerates represent scour fills. The presence of both red and drab mudclasts indicates that some fine-grained deposits were already oxidised and reddened before they were eroded (eg. desiccated overbank deposits or alluvial plain palaeosols), whereas others were relatively unoxidised when they were eroded (eg. abandoned channel-fills, and unoxidised overbank deposits). The low-angle lateral to down-dip accretion deposits are similar to the lateral or downstream accretion macroforms described by Miall (1985), which probably formed bank-attached or mid-channel bars.

Similar sequences have been described from flood deposits of low sinuosity and ephemeral streams by McKee & others, 1967; Smith, 1970, 1971; Picard & High, 1973; Cant & Walker, 1978; Miall, 1970, 1977, 1978, 1981; Rust, 1978; Steel & Aasheim, 1978; Parkash & others, 1983; and Tunbridge, 1984. However, the closest comparison can be drawn with bars, bar-complexes and sandstone sheets of the Brownstones of the Welsh Borderland (Allen, 1983), and the sheet sandstones of the Tertiary of Spain (Atkinson, 1983; Friend & others, 1986; and Marzo & others, 1988).

The large scale soft-sediment deformation that deforms several erosive contacts was interpreted by Lang & Fielding (1991) as mass dewatering due to earthquakes of magnitude 5 with possible epicentres along the Clarke River Fault Zone 20 km to the south. The coarser grain-size of the Unit B and D sandstones may indicate minor uplift events.

In summary, Units B, C and D of the Rockfields Member were probably deposited on a broad, sandy braidplain, which contained low sinuosity channels and extensive, partially oxidised floodplains ('Rockfields' alluvial system). Several architectural elements have been recognised by Lang & Fielding (1991) including laminated sand sheets, dune complexes, linguoid bars, scour fills, and lateral-downstream accretion macroforms in the channels, and levees, crevasse splays and overbank fines on the floodplain.

Lang & Fielding (1989, 1991) suggested that a modern analogue is the seasonally inundated low-sinuosity channel system of the alluvial plains and fans surrounding the Gulf of Carpentaria, north Queensland. Sedimentation rates were high, probably in response to periodic uplift of the Lolworth Ravenswood Province south of the active Clarke River Fault Zone. During the deposition of Units B and D, the sedimentation rate probably exceeded subsidence on account of the increased grain-size. The occurrence of semi-permanent floodplain lakes in Unit C suggests subsidence rates may have exceeded the sedimentation rate at times. Alternatively, it is possible that the relatively-high sea-level postulated for the Frasnian (Veevers, 1984) was responsible for the high base level which would have promoted lacustrine conditions.

UNDIVIDED BULGERI FORMATION (UNITS E AND F)

Units E & F - sequence

Units E and F form a wedge-like sequence 158 m thick in the Broken River (Figure 38). A major erosion surface occurs at the base of Unit E, truncating hundreds of metres of the underlying sequence towards the northeast (Figure 56). Unit F is truncated between the Broken River and Diggers Creek to the northeast by a major erosion surface at the base of Unit G (Figure 56), which also truncates all of Unit E between the north and south branches of Gorge Creek.

Unit E and F comprise a thick, fining-upward sequence of quartz-dominated conglomerate and sandstone typical of Lithological Association 1, with minor intervals of fine-grained redbeds typical of Lithological Association 2. Unit E forms a distinct ridge-forming unit of sheet-like or lenticular bodies of white to slightly reddened pebbly to cobbly conglomerate (Lithofacies Gt, with lesser Gm and Gp) and pebbly medium to very coarse-grained sandstone (Lithofacies St, Ss, and Se, with lesser Sh, Sl, and Sr). Rare, mudcracked, slightly reddened muddy sandstone grading into fine-grained redbeds (Lithofacies Fm, Fl) occurs in the upper part of Unit E. Numerous internal erosion surfaces occur within the sandstone bodies, including deep channel-fills (Plate 30a, b). Unit F comprises thick, sheet-like multistorey cross-bedded sandstone bodies. They are typically white, coarse to very coarse-grained sandstone and dominated by St, Ss and Se with lesser Sh and Sp. Minor conglomerate Gm and red Fm occurs in places.

Palaeocurrent trends from Units E and F are spread from northwest to east, with mean azimuths of north and northeast respectively (Figure 37). This is consistent with trends in the underlying Rockfields Member. Unit E marks the first major input of red jasper into the sequence, in addition to abundant quartz and quartzite and lesser mica schist and dark grey or green chert.

Units E & F - interpretation

The association of abundant Lithofacies St, Ss, and Se with lesser Sh, Sl, Sp and Sr in multistorey sandstone bodies in both Units E and F is typical of the sandy bedforms described by Miall (1985). They are composed mainly of dune complexes (Lithofacies St, Sl, and minor Sp, Sh and Sr) and scour fills (Lithofacies Ss and Se). These are stacked vertically and laterally to form sheet-like channel-fill complexes. The association of Lithofacies Gt with lesser Gm and Gp in Unit E is typical of the gravelly bars and bedforms described by Miall (1985). These include gravelly channel-fills, lag deposits, longitudinal bars, and linguoid bars. Lithofacies Fm and Fl represent minor overbank deposits, probably abandoned channel-fill. The preservation potential of fine-grained deposits in this sequence was low, and this is reflected in the common occurrence of both red and drab mudclasts in most of the sandstones (Lithofacies Se). These deposits are typical of low-sinuosity (braided) gravel-bed streams, which form major trunk rivers or lie within the lower reaches of large alluvial fans (Williams & Rust, 1969; Rust, 1978; Miall, 1977, 1985).

The major erosion surface at the base of Unit E suggests a major down-cutting episode in response to uplift. The surface was filled by the first major input of quartzose gravels and sands derived largely from a metamorphic source to the south. The red jasper was probably derived from the erosion of the red jaspers similar to the Ordovician Wairuna or Judea Formation. Uplift of the Lolworth-Ravenswood Province along the Clarke River Fault Zone to the south resulted in the development of an alluvial system, comprising gravelly low-sinuosity rivers (Unit E) and sandy low-sinuosity rivers (Unit F). Flood plain sediments were rarely preserved due to lateral erosion by river channels on the alluvial plain.

In summary, Units E and F were deposited in gravelly and later sandy low-sinuosity rivers of an alluvial system, hereafter called the 'Bulgeri' alluvial system, which was stimulated by uplift of the Lolworth- Ravenswood Province to the south. The fan system filled a major palaeovalley scoured into the underlying Rockfields Member.

STOPEM BLOCKEM CONGLOMERATE MEMBER (UNITS G TO J) AND RELATED ROCKS OF UNDIFFERENTIATED BULGERI FORMATION (UNITS K TO M)

The Stopem Blockem Conglomerate Member (SBCM) is confined to the Rockfields Syncline and forms a distinctive range of hills known locally as the Red Range. Good exposures occur in a series of gorges, the largest being the Red Range Gorge on the Broken River. It has a distinctive, dark brown tone on the airphotos, which clearly delineates a lenticular outline. The Member is 239 m thick in the type section (Figure 41), thickening to 300 m between Gorge Creek and the Pandanus Creek - Jessie Springs track (Figure 44). The Member wedges out at 7858-508402, (8 km southwest of Red Range Gorge). On the northern limb of the Rockfields Syncline, the member thins considerably until it wedges out at the nose of the Atherton Creek Anticlinorium (7859-587545).

The SBCM can be subdivided into four sequences (Units G to J) based on grain-size and composition. Units G, I and J are characterised by red conglomerates and sandstones containing abundant red jasper and arenite clasts (Lithological Association 4), interbedded with fine-grained redbeds (Lithological Association 2). In the northeast, the conglomerates contain limestone clasts which may locally dominate, forming calcirudite lenses (Lithological Association 7). Unit H comprises drab coarse to very coarse-grained sandstones (Lithological Association 1).

Similar rocks to those of the SBCM are developed in the immediately overlying sequence of undifferentiated Bulgeri Formation (Units K to M) in the main outcrop belt between Pages Dam, the Broken River and Gorge Creek. In general terms, Unit K is similar to Unit H, whereas Units L and M are similar to I and J respectively. Near Pages Dam in the southwest, Unit M forms a distinctive lens of conglomerate like the SBCM, and is shown on the map as an unnamed conglomerate member of the Bulgeri Formation - Du_c. This interval, from Unit G to M, approximately relates to the 'RR 2' unit of Guillebert & others (1979).

Similar rocks to those in the Unit G to M interval occur in the Six Mile Syncline area in the north. Red conglomerate lenses similar to the SBCM are shown on the map as unnamed conglomerate members of the Bulgeri Formation (Du_c). Similar rocks also occur in the Craigie area in the southeast (McLennan, 1986), and in the outlier near Maitland Creek (Plate 31c and d) to the north of the Teddy Mount Fault (Withnall, 1989b, and later in this report). Unnamed calcirudite lenses (Du_a) are interbedded with the SBCM in the hinge area of the Rockfields Syncline, and they may be the only equivalents of the SBCM in the Dip Creek Syncline. Calcirudite lenses are interbedded with the unnamed conglomerate members in the Six Mile Syncline, and also occur sporadically in the fault block north of Teddy Mount. In these areas, however, the local sequences are different to the main outcrop belt, and are therefore not subdivided.

Units G to M - sequence

Unit G is the lower conglomeratic subdivision of the SBCM, and forms a sheet-like unit beginning 2 km southwest of the Red Range Gorge, thickening to 12 m in the Broken River, and to 100 m in the Gorge Creek area 13 km to the northeast (Figure 41, 43 and 44). The sequence thins to 45 m in GSQ Clarke River 1 (Figure 47), and continues to thin until it wedges out near the nose of the Atherton Creek Anticlinorium. Unit G lies on a major erosion surface which truncates 300 m of the underlying section (Units F, E, D, and the upper part of Unit C) in the Gorge Creek area (Figures 44 and 56). The erosion surface eventually truncates all of the Rockfields Member around the nose of the Atherton Creek Anticlinorium. Unit G is coarsest in the Gorge Creek area, where large cobbles and rare boulders occur (Figure 44, Plate 28a). Elsewhere, the conglomerates are pebbly, and grade into pebbly sandstone.

Unit G is characterised by reddened Lithofacies Gt, Gm, Ge, Gp, with lesser St and Ss and minor Sp and Sh. A typical vertical profile may begin with an erosion surface strewn with Lithofacies Ge, but more commonly is overlain by Lithofacies Gm, Gt or Gp, then followed by Lithofacies Sh, St, Ss or Sp (Plate 28e). Lithofacies Fm is rare. Tracing erosion surfaces reveals that the conglomerate-sandstone bodies are complexes of amalgamated flat or concave-based tabular or lenticular bodies tens of metres wide, up to several metres thick, and many tens of metres (possibly hundreds of metres) long in the down-current direction. Lithofacies Gt (usually large low-angle trough cross-beds) commonly cuts deeply into Lithofacies Gm. Some bodies are entirely composed of Lithofacies Gp up to a metre thick (Plate 28c). In GSQ Clarke River 1, calcirudite up to 15 m thick locally underlies Unit G. Palaeocurrents trend from north to southwest (Figure 37).

Unit H is a wedge beginning approximately 3 km to the northeast of the Broken River, thickening to 40 m in the Broken River (Figure 41) and increasing in thickness to the southwest. Where the underlying Unit G wedges out southwest of the Broken River, Unit H cannot readily be differentiated from Unit F, and eventually it passes into undifferentiated Bulgeri Formation.

Unit H is a typical example of Lithological Association 1. The dominant Lithofacies are drab Lithofacies St and Ss with minor Se, organised into multistorey, tabular, cross-bedded sandstone bodies similar to Unit F. They commonly start with an erosion surface filled by Lithofacies Ss or Se, and then are overlain by cosets of St. Palaeocurrents trend from north to east (Figure 37).

Unit I is 123 m thick in the Broken River (Figure 41), but it wedges out completely about 8 km southwest of the river. To the northeast, Unit I gradually thins to 105 m in Diggers Creek (Figure 43), then 95 m in Gorge Creek in the northeast (Figure 44). Faulting and facies changes in the vicinity of GSQ Clarke River 1 make it difficult to be certain whether Unit I is present or not, but it appears not to be present in Atherton Creek on the northern limb of the Rockfields Syncline.

Unit I consists of Lithological Association 2 and 4. It comprises lenticular pebbly sandstone bodies ranging from 0.2-2 m thick, 2-15 m wide, and several to tens of metres long in the down-current direction. Sheet-like, multistorey pebbly sandstone and conglomerate bodies are up to 10 m thick, hundreds of metres wide, and at least tens of metres long in the down-current direction. Both bodies have sharp, planar or concave, erosive bases, commonly strewn with red rip-up-clasts (Se and Ge). The sandstones consist dominantly of Lithofacies St (Plate 29d), Sl, Ss, and Sh (with parting lineation), with lesser Sp, commonly in the upper part of beds. The conglomerates comprise mainly Lithofacies Gm, Gt, and are commonly overlain by cross-bedded pebbly sandstones (Lithofacies St, St, Ss and Sp). In the Gorge Creek area, these conglomerates contain increasing amounts of limestone clasts (Figure 44). These bodies fine upward and are overlain either gradually or abruptly by fine-grained redbeds intervals (Lithofacies Fm) from 0.05 to 10 m thick, and up to hundreds of metres along strike. Sporadic calcite-filled rhizoliths (Lithofacies Fr), and minor concentrations of small calcrete glaebules occur in places (Lithofacies Fr & P). Palaeocurrent readings are mainly from Lithofacies Sp, and are spread from southwest to north (Figure 37).

Unit J is 58 m thick in the Broken River (Figure 41), and wedges-out approximately 7 km to the southwest. The unit thins slightly to the northeast, being 40 m in Diggers Creek. However, near the south branch of Gorge Creek, Unit J abruptly thickens up to 95 m (Figure 43) due to the vertical stacking of a higher conglomerate sequence (Unit J^1). Unit J and J^1 appear to wedge-out in the hinge area of the Rockfields Syncline.

Unit J is dominantly a gravelly unit, mainly comprising Lithological Association 4. The unit is mainly pebble conglomerate, but cobble conglomerate occurs in the north branch of Gorge Creek to the northeast. Like Unit G, tracing erosion surfaces reveals that the conglomerate bodies are complexes of amalgamated flat or concave-based tabular or lenticular bodies, tens or in the case of tabular bodies, hundreds of metres wide. Both types of bodies are up to several metres thick, and many tens of metres (possibly hundreds of metres) long in the down-current direction. Lithofacies Ge and Se commonly overlie erosive surfaces, and are overlain by Lithofacies Gt (usually large low-angle trough cross-beds), which mainly fill scours cut into Lithofacies Gm. Tabular bodies up to several metres thick of single sets of Lithofacies Gp occur in places. Imbrication of clasts is common, particularly in Lithofacies Gm, but also in Gt. Fining-upward cycles are common, with sheet-like conglomerate bodies passing from gravelly Lithofacies to St, Sh, and Sr. Minor lenticular or sheet-like bodies of Lithofacies St, Ss, Sl, and lesser Sh, Sp, Sr are intercalated with the conglomerate bodies. Thin units (m thick) of red Lithofacies Fm occur in places. Thin, lenticular, horizontally stratified sandstones (Lithofacies Sh) occur within Lithofacies Fm. *Leptophloeum australe* stems occur in places (Plate 28b). Palaeocurrent trends range from northeast to southwest (Figure 37).

Units I and J form an overall coarsening-upward sequence up to 190 m thick in the Gorge Creek area. Due to faulting and facies changes, it is uncertain if either Unit I or J is present in GSQ Clarke River 1, but they do not appear to be recognisable along the northern side of the Rockfields Syncline.

Unit K forms a thick wedge above the SBCM. In the Broken River, the unit is 135 m thick (Figure 41), but it thins to 60 m in Diggers Creek (Figure 43) and it appears to almost wedge out completely near the south branch of Gorge Creek. The unit is only a few metres thick in the north branch of Gorge Creek (Figure 44), and is not recognisable in GSQ Clarke River 1.

Unit K is composed dominantly of drab, coarse to very coarse-grained sandstone and conglomerate (Lithofacies Se, Ss and St, with lesser Gm) and minor interbedded fine-grained redbeds (Lithofacies Fm and P). The sequence is very similar to Unit H but has thicker redbed intervals, which in places contain well-developed calcrete glaebules (Plate 29a). Unit K forms a coarsening-upward sequence in the Broken River section. Palaeocurrents are dominantly to the north and northeast (Figure 37).

Unit L forms a distinctive sequence up to 45 m thick, dominated by fine grained-redbeds. The unit can be traced for over 30 km along strike, from west of Pages Dam to the south branch of Gorge Creek, where the sequence appears to pass laterally into the upper part of Unit J^1. The unit reappears in GSQ Clarke River 1, where it may be up to 130 m thick, apparently replacing Units I, J and K. It then passes southwest along strike to the nose of Atherton Creek Anticlinorium.

The fine-grained redbeds are up to 10 m thick, and composed of Lithofacies Fm, Fl and P. They are interbedded with coarser-grained intervals from 0.05-6 m thick, which form the base of fining-upward cycles ranging from 0.05 to 20 m thick. The coarser intervals comprise mainly red conglomerates and red or drab pebbly sandstones grading into red, fine to coarse-grained sandstones and calcirudites (Lithofacies Ge, Gm, Se, St, Sh, Sl, and Sp). The most striking feature about Unit L is the advanced development of calcrete glaebules in the fine-grained redbeds. Although most glaebules are less than 1 cm in diameter, several intervals occur where the glaebules are closely spaced and up to 3 cm in diameter (Lithofacies P in Fm; Plate 29b). In places the calcrete forms carbonate masses or laminar sheets (eg. between 433 and 515 m in GSQ Clarke River 1; Lang, 1986b). Some intraformational conglomerates contain reworked calcrete glaebules up to 1 cm in diameter. In the borehole, several microdiorite dykes or sills intrude the redbeds, and skarn-like hornfels is developed where the intrusives are in contact with calcrete.

Unit M is a conglomeratic wedge similar to the Stopem Blockem Conglomerate Member, and is mapped as an unnamed conglomerate member (Du_s) on the Broken River Special map. The unit thins towards the northeast from 105 m in the Broken River, to approximately 20 m in GSQ Clarke River 1.

Unit M consists mainly of a mixture of drab, red and variegated pebbly sandstone and pebbly to cobbly conglomerate (Lithofacies St, Sl, Ss, Se, Gm, Ge, Gt) with lesser, laterally discontinuous fine-grained redbed intervals (Lithofacies Fm and P). Calcrete glaebules are commonly developed in the fine-grained redbeds, though not to the extent seen in Unit L. The conglomerate and sandstone bodies are essentially the same as those in Unit J, but vuggy, pedogenic carbonate cement is common. Unit M forms a distinctive coarsening-upward sequence in the southwestern areas, with palaeocurrents trending north to southwest. Carbonised log casts are common at the bases of some conglomeratic beds.

As previously mentioned, the Chinaman Creek area, and other areas to the southeast and northwest, contain rocks comparable to the sequence between Units G and M in the Rockfields Syncline. These rocks have not been studied in the same level of detail, but all the facies are represented, as well as bodies of calcirudite, many of which are very poorly sorted and very coarse-grained. As discussed previously, these calcirudites appear to be locally derived, and obviously became interleaved with the other rock types typical of Units G to M. The distribution of these rocks was mapped by Jell (1967). The red conglomerates and sandstones are cross-bedded, and palaeocurrents trend mainly to the north (Figure 37).

Units G to M - interpretation

The lithofacies associations and their geometries within this interval show some similarities to those previously described and interpreted from Unit E and F. The rocks can be interpreted in terms of channel-fill and overbank complexes deposited on the broad proximal reaches of an alluvial plain.

The thick, pebbly to cobbly conglomerate and pebbly sandstone bodies of Units G, J and M represent large channel-fill complexes, composed mainly of scour fills

(Lithofacies Ge, Gm, Se, and Ss) gravelly bars and bedforms (Lithofacies Gm, and Gt) with lesser dune complexes (St, Sl, Sp), transverse or linguoid bars (Gp), and laminated sand sheets (Sh). This combination is typical of low-sinuosity gravelly rivers in the upper parts of alluvial fan systems (Miall, 1977, 1978). Judging by the geometries of these bodies, and the thickness of individual cross-bed sets, the river channels were tens to possibly hundreds of metres wide, and up to a few metres deep. The grain-size distribution within the generally smaller, pebbly conglomerate and pebbly sandstone bodies of Units I and L contain the same elements as above, but represent relatively smaller channel-fill complexes either more distal on the alluvial plain, or as minor channel fills on the surrounding floodplains.

The floodplains of Units I and L, represented by the thick fine-grained redbed intervals of Lithofacies Fm, Fl, Fr and P, were laterally extensive (hundreds of metres to many kilometres wide), and their preservation potential was a function of the proximity to the major alluvial channels. The minor fine-grained intervals interbedded with the conglomeratic bodies of Units G, J and M represent minor overbank deposits, probably abandoned channel-fill. The preservation potential of these fine-grained deposits was low, and this is reflected in the common occurrence of red rip-up-clasts (Plate 29e) in most of the bodies (Lithofacies Ge and Se). The presence of reworked calcrete glaebules in thin conglomerates of Unit L indicates the erosion of moderately developed red calcic palaeosols (Stage II and III of Gile & others, 1966). Gile & others suggested, on the basis of Quaternary calcrete studies, that calcic palaeosols may take up to several thousand years to develop, indicating that parts of the floodplains formed major inter-fluvial areas for thousands of years. Wright (1990) reviewed the question of the rates of calcrete formation, and indicated that Stage III calcretes may take hundreds of thousands of years to form. In areas of very high Ca^{++} supply, mature calcretes may take as little as three thousand years to form. The development of laminar sheets (Stage IV calcrete), normally considered to take very long periods of time (hundreds of thousands of years or 1 Ma), could represent calcification of root-mats that may also have formed rapidly.

The association of abundant Lithofacies St, Ss, and Se with lesser Sh, Sl, Sp and Sr in the drab, multistorey sandstone bodies in both Units H and K is typical of the sandy bedforms described by Miall (1985). They are composed mainly of dune complexes (Lithofacies St, Sl, and minor Sp, Sh and Sr) and scour fills (Lithofacies Ss and Se). These are stacked vertically and laterally to form sheet-like channel-fill complexes. These deposits are typical of low-sinuosity (braided) gravel-bed streams, which occur as either major trunk rivers or on the lower reaches of large alluvial fans (Williams & Rust, 1969; Rust, 1978; Miall, 1977, 1985).

The major erosion surface at the base of Unit G suggests a major down-cutting episode, greater than that marked by the base of Unit E, and probably in response to uplift in the south or southeast. The palaeovalley was first filled by a major input of gravels and sands derived largely from a metamorphic source to the south. The abundant red jasper and quartzose arenite clasts were probably derived from the erosion of jaspers and quartzose arenites, which are the characteristic rock types of the Ordovician Wairuna and Judea Formations.

Uplift of the Lolworth-Ravenswood Province along the Clarke River Fault Zone to the south resulted in the development of a proximal alluvial plain, traversed by gravelly low-sinuosity rivers (Units G, J and M). This will be called the 'Stopem Blockem alluvial system'. These rivers coalesced with the mainly sandy low-sinuosity trunk streams of Units H and K, which like Units E and F, formed part of the 'Bulgeri alluvial system'. Units G to J may represent the fill of a major incised palaeovalley. The deepest part of this palaeovalley, and probably the axis of the system, was in the Diggers- Gorge Creek area, where the sequence comprising Units G to J is thickest, and where the maximum clast sizes occur (up to boulder-grade, Plate 28a). This is consistent with palaeocurrents from the southeast, and with the dominance of clasts that were likely to have been derived from an uplifted Camel Creek Subprovince. The presence of calcirudite lenses closely associated with the 'Stopem Blockem type' conglomerates indicates that a very local source of uplifted Devonian limestone was also contributing sediments to the alluvial systems. The distribution of the these lenses, and the general thinning of units over the Atherton Creek Anticlinorium, was considered by Lang (1985, 1986a) to point to an intra-basinal fault block, which enabled the Chinaman Creek-Dip Creek-Lockup Well-Jessie Springs limestones to supply large limestone clasts almost directly into the 'Stopem Blockem' fan system. Given that the 'Stopem Blockem' system indicates dispersal from the south-southwest in the Chinaman Creek area (Figure 37p), it is likely that the gravelly rivers must have swept around the uplifted limestone fault block from the southeast, receiving debris flows from short-headed fans draining the karsted area.

The significant degree of reddening and palaeosol development in the conglomeratic and fine-grained bodies of Units G, I, J, L and M suggests that these deposits were subject to oxidation over several thousands years, and this would have been possible if deposition on interfluvial areas of the alluvial system was episodic. This could happen if no major channel avulsion occurred on the interfluves between the 'Stopem Blockem' alluvial system in the southeast and the 'Bulgeri' fan system in the southwest. A similar situation is occurs on the interfluves of the modern alluvial systems around the Gulf of Carpentaria (Grimes & Doutch, 1978).

BULGERI FORMATION (UNITS N, O AND P)

Units N, O & P - sequence

Unit N (1 495 to 2 400 m), Unit O (2 400 to 2 550 m) and Unit P (2 550 to 2 990 m) are relatively poorly known, but most of Units N and P is similar to Unit K, whereas Unit O is similar to parts of the middle of Unit Q.

Unit N is a very thick sequence of fining-upward successions, each beginning with a drab, pebbly sandstone (Lithological Association 1) that grades upwards into finer sandstones (Lithological Association 3) and then into either drab and/or variegated fine-grained intervals (Lithological Associations 5 or 2) and in places green reworked tuffs (Lithological Association 6). Red jasper and arenite clasts typical of Units E to M become much less common in the sandstones of Unit N, and they are not commonly found above the middle of the unit. Unit N was intersected in the upper 150 m of GSQ Clarke River 1, and typical fining-upward sequences range from 2 to 10 m thick. The sandstones are typically erosively based, the contact strewn with quartz pebbles and red or drab rip-up-clasts (Lithofacies Se), and overlain by flat lamination, and small to large-scale trough (Plate 30c), low-angle trough, and planar tabular cross-beds (Lithofacies Sh, St, Sl, and Sp). Convolute lamination is common in the lower half of Unit N. Most sandstone bodies range from 1 to 6 m thick, tens or hundreds of metres wide, and at least tens of metres long in the down-flow direction. The thinner and commonly finer grained sandstone bodies (up to 1 m thick, and tens of metres wide) are commonly lenticular (Plate 29f) or lozenge-shaped, and dominated by Lithofacies Sh (with parting lineation), and lesser Sr and St.

Fine-grained intervals in Unit N either sharply or gradationally overlie the sandstones. The redbeds are typically destratified by pedogenic structures such as calcrete glaebules (Plate 29c) or rhizoliths (Lithofacies Fm and Fr), but in places laminations and ripple cross-lamination can be observed (Lithofacies Fl). Calcrete is however, largely confined to the lower 500 m of Unit N, and coincides with the most reddened part of the sequence. The drab fine-grained intervals are poorly exposed in outcrop, but in the core they are laminated or massive, and commonly carbonaceous or even coaly (Lithofacies Fl, Fm and C). Dichotomous plant fragments and lycopod spores have been recovered from these samples (Lang, 1986b). Several green, reworked tuff intervals occur throughout the fine-grained parts of the sequence (mainly Lithofacies Fl), and these are best seen in GSQ Clarke River 1, where they form cherty or greasy green fine-grained intervals up to 5 m thick (eg. 26-31 m).

The palaeocurrent readings from Unit N (Figure 37) range from southwest to east, and although probably too few to be meaningful, suggest a southerly to southeasterly source.

Unit O is very poorly exposed, largely represented by a topographically low gullied area. It is approximately 160 m thick in the type section. The sandstones are more labile than those in Unit N and P, but are otherwise similar in the lower 50 m of the sequence (Lithological Association 3, and Lithofacies St, Sh, and Sr). The upper part contains the second marine influenced interval in the Bulgeri Formation. In a gully crossing at 7859-469387, poorly preserved gastropods, bivalves, and crinoid ossicles occur in a poorly sorted, burrowed, muddy, very fine to fine-grained micaceous sandstone grading to mudstone (Lithological Association 8, and Lithofacies Fl, Fcm, and Sm). In the type section, no fossils have been recognised except plant fragments, but burrows and calcareous concretions occur in places (Lithological Association 5).

Unit P is a 345 m thick, coarsening-upward sequence dominated by drab, medium to very coarse-grained sandstone and granule, pebble and cobble conglomerate (Lithological Association 1), with lesser interbeds of drab to variegated fine-grained intervals (Lithological Association 5 and 2). The sandstones are typically 1 to 10 m thick, and many are amalgamated to form thick multistorey sandstone bodies up to 70 m thick, and extending for hundreds of metres at least. Most of the sandstones contain medium to large scale cross-beds (Lithofacies St, Sl and Sp - Plate 30d), but some of the thinner sandstones are dominated by flat lamination and ripple cross-lamination (Lithofacies Sh and Sr). The conglomerates are horizontally stratified, massive or vaguely cross-bedded (Lithofacies Gm, and Gt). The uppermost cobbly conglomerate crops-out poorly, but it is apparently massive. Low-angle lateral accretion foresets occur in places. Fish bones and log casts are common at or near the base of many sandstones. The fine-grained intervals are typically laminated or massive, and contain vague burrows, rhizoliths, and plant fragments (Lithofacies Fm, Fr and Fl). Palaeocurrents from the sequence mainly come from the upper part, and indicate a westerly source area (Figure 37).

Units N, O & P - interpretation

The relatively coarse grainsize of the sandstones in the lower 500 m of Unit N suggests that it may have been deposited on part of the 'Bulgeri alluvial system.' The degree of reddening and the common development of calcrete glaebules in the fine-grained intervals indicates that these intervals were subject to oxidation, possibly as part of the development of calcic palaeosols on extensive interfluve areas in the lower part of an alluvial system. The sandstones are interpreted as low-sinuosity (braided) river channel-fill deposits, whereas the fine-grained intervals are overbank or channel abandonment deposits, some of which remained unoxidised, but most of which were subject to variable degrees of oxidation and pedogenesis. The upper half of Unit N, where redbeds are less common, and calcrete is rare to absent, may represent the alluvial plain deposits, more subject to inundation and therefore less oxidised.

Unit O has characteristics of both marine and non-marine facies, and is therefore interpreted as a coastal plain to muddy nearshore succession, deposited during a brief transgressional event in the Late Devonian. Although the poorly preserved fauna cannot be dated, the relative stratigraphic position of the sequence well below the Famennian-Tournaisian boundary (Lang, 1985, 1986a), and below the marine sequence of the Jamieson Member, suggests that Unit O could be either late Frasnian or early Famennian. If so, this represents a newly recognised transgression in the region.

The coarsening-upward trend of Unit P, and the nature of the Lithofacies, suggest that it was deposited firstly on an alluvial plain, and then on an upper alluvial plain. The palaeocurrent directions indicate an uplift in the west, resulting in the shedding of relatively coarse (cobbles) sediments presumably derived from metamorphics of the Georgetown Province to the west and north. The sandstones and conglomerates represent channel-fill deposits, and the fine-grained intervals represent overbank deposits. The proximal part of the alluvial system may be represented by the cobbly conglomerate that forms the top of Unit P. This unit might be a lateral equivalent of the conglomeratic rocks high in the undifferentiated Bulgeri Formation between Pages Creek and the Gregory River.

JAMIESON MEMBER (UNIT Q)

The member forms a sinuous folded belt from about 7859-627595 in the faulted core of the Dip Creek Syncline, to about 7858-354303 south of the Stopem Blockem Range. It may extend farther south towards the Clarke River Fault Zone, but it becomes difficult to distinguish from the rest of the Bulgeri Formation, and therefore it has not been differentiated there.

The lower part of the unit overlies a distinct ridge, formed by the underlying conglomerate at the top of Unit P. The unit forms a series of low strike ridges, sparsely vegetated with eucalypts. Quinine bush occurs over the fine-grained redbed intervals, especially in the upper part of the member. The unit is 670 m thick in the type section, and thins progressively to the northeast until it wedges-out in the Dip Creek Syncline. The unit is overlain apparently disconformably by the Turrets Formation (Lang, 1985, 1986a).

Unit Q - sequence

The lower third of this sequence comprises a fining-upward sequence of grey to brown, fine to very coarse-grained, labile feldspathic sandstone or pebbly conglomerate (Lithological Association 1 and some 3) topped by greyish red to brown, fine-grained sandstone and siltstone (Lithological Association 2). The sandstones and conglomerates contain an increasing amount of volcanic detritus towards the top of the sequence (Plate 31a). Greenish grey mudstone containing marine fossils occurs in the middle of the sequence, interbedded with thin granule conglomerates (Lithological Association 8). Olive green, silicified, volcaniclastic siltstones and fine-grained sandstones (reworked tuffs) occur mainly in the upper half of the sequence (Lithological Association 6).

The fining-upward sequences in the lower 215 m of the formation in the type section (2 990-3 205 m) typically begin with an erosive surface strewn with quartz or volcanic pebbles and red or drab rip-up-clasts (Lithofacies Gm, Se). This is overlain by flat lamination, small to medium scale trough and planar tabular cross-bedding, and ripple cross-lamination and convolute lamination, (Lithofacies Sh, St, Sp and Sr), grading upward into variegated very fine-grained sandstone, siltstone or mudstone containing ripple cross-lamination, rhizoliths and plant fragments, and rare desiccation cracks (Fl, Fm, and Fr). The lowermost 90 m of the sequence generally has coarser-grained sandstones and thinner fine-grained redbed intervals than the overlying 125 m, which has finer-grained sandstones and thicker redbed intervals.

The middle of the sequence in the type section (3 205-3 285 m) is dominated by massive, burrowed, greenish grey mudstones up to several metres thick containing brachiopods, bivalves, ostracodes and plant detritus (Lithofacies Fcm). They are interbedded with thin, polymictic granule conglomerates (Lithofacies Gm). At approximately the same stratigraphic level, but in the Dip Creek Syncline (7859-597572), this marine-influenced part of Unit Q contains calcareous, poorly sorted, medium to very coarse-grained cross-bedded sandstone containing disarticulated brachiopods and crinoid ossicles (Lithofacies Sp, Sm), interbedded with grey mudstones and poorly sorted granule conglomerates (Lithofacies Fcm and Gm).

The upper 375 m of the sequence in the type section (3 285-3 660 m) is generally similar to the lower part of the sequence (Lithofacies St, Sh, Sl and Sr, with variegated Fm and Fl), although the outcrop is poorer, and the sandstones contain noticeably more volcanic detritus. Burrows occur in the sandstones, including a large mud-filled burrow similar to *Beaconites antarcticus* (cf. Allen & Williams, 1981) at 7858-620544. Thin green reworked tuffs occur in places, and these commonly contain pink zeolites lining the joints. A conglomeratic sandstone 55 m from the top of the sequence is overlain by the highest known fine-grained redbeds of the Bulgeri Formation, which are in turn overlain by a dark grey, silicified, volcaniclastic silty mudstone interval. Accretionary lapilli occur within this interval immediately under the base of the Turrets Formation.

Most of the palaeocurrent directions from the Jamieson Member come from the basal third of the unit. The overall trend is bimodal, from the northeast and the southwest (Figure 37).

Unit Q - interpretation

The unit contains features typical of non-marine conditions in the lower and upper parts, with a marine-influenced middle part. The sandy fining-upward successions topped by variegated, fine-grained redbeds are interpreted as channel-fill and floodplain deposits respectively. The coarser grain size and the relatively lesser amounts of fine-grained deposits in the lower 90 m of Unit Q are probably indicative of an upper alluvial plain depositional setting. The overlying 125 m, however, contains a greater amount of fine-grained deposits compared to sandstone deposits, and it grades into marine facies, suggesting that it was probably deposited on a lower alluvial plain. The bimodal palaeocurrent trend (Figure 37) could be due to tidal influences, but was more likely to be a product of higher stream sinuosities, with the dominant direction (northeast) representing the palaeoslope direction. The fine-grained fossiliferous mudstones in the middle of the sequence represent transgressive, muddy nearshore deposits, and the granule conglomerates and fossiliferous sandstones may represent storm lag deposits. The upper part of the sequence marks a return to lower alluvial plain deposits, although the uppermost, grey to green volcaniclastic fine-grained beds probably represent lacustrine deposits.

In summary, the Jamieson Member was deposited in alluvial plain, coastal plain and muddy nearshore environments due to transgression in the mid-Famennian. During subsequent regression in the mid to late Famennian, deposition took place on an alluvial plain, and in minor floodplain lakes.

UNDIFFERENTIATED BULGERI FORMATION IN THE SOUTH

Description

The Bulgeri Formation south of the Pages Dam area to the Gregory and Clarke Rivers is almost entirely composed of drab, coarse-grained pebbly sandstones and pebble to boulder conglomerate (Plate 31b; Lithological Association 1, only minor 4). The proportion of fine-grained intervals (Lithological Associations 2, 5 and 6) becomes steadily less to the south, and most of them are intensely reddened, although in the Craigie area they are variegated red to green despite the presence of the most advanced stages of calcrete development in the basin (McLennan, 1986). The sandstones are dominated by broad scour fills and medium to large scale trough and low-angle trough cross-bedding (Lithofacies Ss, St and Sl), with lesser horizontal stratification (Lithofacies Sh -without parting lineation). Rip-up-clasts become rarer to the south. Conglomerates are massive, or crudely bedded, in places cross-stratified (Lithofacies Gm, and Gt). Red jasper clasts are rare to absent in the Gregory River area, and occur only in minor amounts in a conglomerate close to the basal unconformity east of Dosey, and in red conglomerates similar to Unit G in the Craigie area (McLennan, 1986). Fine-grained intervals are mainly red Lithofacies Fm and P, or rare drab Fl and Fm. A few thin green reworked tuffs occur near the Clarke River - Gregory River confluence. Palaeocurrents trend mainly to the north, but are spread from southeast to west (Figure 37).

Interpretation

In the south, the dominance of coarse-grained lithofacies, the dominance of channel-fill structures, the absence or rarity of fine-grained deposits, and the palaeocurrent data, all indicate a major alluvial system, the 'Bulgeri alluvial system' flowing northward from the Clarke River Fault Zone along the present basin margin. Presumably, part of the system may have originally accumulated on the Lolworth-Ravenswood Province as valley fill, but was never preserved except perhaps for a small area near 'Yering' homestead. The composition of the rocks indicates an overwhelming supply of sediments eroded from the metamorphic and plutonic rocks of from the Lolworth-Ravenswood and/or Georgetown Provinces. The 'Bulgeri' alluvial system, was probably a major trunk river system draining to the north and northeast (Units E, F, H, K, part of L and M, N, O, P and Q). The only significant evidence of 'Stopem Blockem' type clast compositions is in the Craigie area (McLennan, 1986), and this is in accord with the southeasterly provenance. In summary, two major fan systems existed during the deposition of the Bulgeri Formation. The larger, and probably the more constantly active was the 'Bulgeri' alluvial system emanating from the south or southwest, whereas the other, the 'Stopem Blockem' alluvial system, emanated from the southeast (east of Craigie).

STRUCTURE OF THE GRAVEYARD CREEK SUBPROVINCE

(I.W. Withnall)

The first detailed structural studies of the area were by Arnold (1975), Arnold & Henderson (1976) and Arnold & Rubenach (1976). These were confined to the area adjacent to the Camel Creek Subprovince in the eastern part of the subprovince where the structure appears to be somewhat more complex. However, their studies did not extend to any of the units above the Graveyard Creek Group. Geologists from Minatome (Australia) Pty Ltd and Urangesellschaft (Australia) Pty Ltd (Guillebert & others, 1979) interpreted an angular unconformity in the middle of the Bundock Creek Group, but our work has found no evidence for this. The structure of the Graveyard Creek Subprovince is overall much less complex than the Camel Creek Subprovince, and we have shown the timing of deformation events are significantly different. Low-angle thrusting and pervasive development of melange appears to be largely confined to the basal Judea Formation, the remaining units being deformed mainly by large-scale northeast-trending folds. The only angular unconformities are at the base of the Graveyard Creek Group and a slight angular unconformity between the Broken River and Bundock Creek Groups.

DEFORMATION OF THE JUDEA FORMATION

An important feature of the Judea Formation is early deformation characterised by abundant boudinage, local mesoscopic isoclinal folds, bedding-parallel faulting and cleavage, and commonly a thorough disruption of strata to produce melange. The melange consists of clasts of arenite (ranging from a few millimetres to several metres) in a mudstone matrix, and grades into boudinaged arenite. As in the Camel Creek Subprovince, Arnold (1975) and Arnold & Henderson (1976) interpreted this deformation as pre-D_1, and referred to it as D_s. This type of deformation is widespread in the Camel Creek Subprovince, even in rocks of probable Early Devonian age. However, in the Graveyard Creek Subprovince it is restricted to the Judea Formation. It is not evident in the overlying Graveyard Creek Group and is evidence for an unconformity between the units. Other evidence for an unconformity above the Judea Formation is discussed in the previous chapter.

The area north and west of the Gray Creek Complex in the Greenvale area is the most intensely deformed part of the Judea Formation and is probably of higher metamorphic grade than in the Broken River area. Primary structures are largely obliterated, and the mudstone has a phyllitic appearance. Bedding is generally discontinuous and transposed parallel to a strong cleavage. Rootless isoclinal fold hinges are common. The deformation is interpreted to be the same as that causing the boudinage and melange elsewhere. The original bedding fissility may have been enhanced by intense thrust-related(?) deformation and higher metamorphic grade. Arnold (1975) reported that biotite, in addition to muscovite and chlorite, defined the cleavage. The bedding-parallel cleavage is locally overprinted by a crenulation cleavage (S_2), which in places is axial plane to moderately tight, mesoscopic folds. The predominant trend is north-northeast (Figure 58). Later, open, kink-like folds are also present. The crenulation cleavage probably formed at the same time as the S_1 cleavage in the Graveyard Creek Group in the same area. The latter cleavage probably pre-dates the main deformation of the Poley Cow and Jack Formations in the Broken River area, and is probably absent from the Judea Formation there also.

The least disrupted part of the Judea Formation known is in the type section on the western limb of the Broken River Anticline along the Broken River, where apart from minor boudinage and later mesoscopic folds, the sequence is relatively coherent. However, some melange occurs on the other limb of the anticline (Plate 6d).

In the Broken River and Horse Creek areas, a pervasive slaty cleavage, S_1, overprints the effects of the earlier deformation, and is associated with mesoscopic folds. It trends northeast (Figure 58) and is parallel to the axial planes of the regional folds which also affect the younger Silurian to Carboniferous rocks. S_1 in the mudstone occurs as a fine, pervasive crenulation of the bedding fissility (which is defined by detrital micas and fine diagenetic chlorite and muscovite) or as dark anastomosing lines of opaques. F_10 fold axes and L_10 intersection lineations are commonly more steeply plunging than in the overlying units (Figure 58) suggesting that some folding (at least on a small scale) predated the main event, and provides further evidence for an unconformity. The earlier folding accounts for the greater spread of poles to S_0 than in the Poley Cow Formation (Figure 59), but a girdle through the maxima plunges about 25° southwest similar to the plunge of major folds in the overlying units (Figures 59 and 64).

Apart from the internal disruption, bedding in the Judea Formation is generally roughly concordant with that in the overlying Graveyard Creek Group (compare Figures 58 and 59), although locally it is strongly discordant (Plate 8c). In addition, a gross stratigraphic sequence of basal Donaldsons Well Volcanic Member, overlain by quartz-rich flysch, in turn overlain by Graveyard Creek Group, without any major angular discordance, is maintained through most of the outcrop area from Greenvale to the Broken River. A more complicated outcrop pattern should have resulted if a major folding event pre-dated the Graveyard Creek Group. Therefore the early deformation in the Judea Formation may be related to recumbent folds, thrusts, or slides, probably restricted mainly to the sedimentary rocks. The contact between the Judea Formation and the Halls Reward Metamorphics is a major mylonite zone, and may be a thrust or a reversed listric fault or detachment zone. The internal deformation within the Judea Formation could be related to thrusting along this contact.

FOLDING OF THE SILURIAN-CARBONIFEROUS ROCKS

Graveyard Creek Group

In much of the outcrop area, the Graveyard Creek Group has been deformed by one main deformation which produced folds with northeast-trending axial planes. This folding is of the same generation as that which folded the Broken River Group and Bundock Creek Group (see below), because no **major** angular unconformities have been recognised anywhere from the Graveyard Creek Group through to the top of the Bundock Creek Group. A **slight** angular unconformity does occur at the base of the Bundock Creek Group. The similar orientation of the fold axial planes in the three Groups (Figures 59, 61 and 62) provides further support for the conclusion.

In the southern outcrop area (Poley Cow and Jack Formations), the folds have relatively shallow plunges (up to 30°) both northeast and southwest, producing an elongate dome-and-basin pattern, somewhat disrupted by a set of north-trending faults. This is reflected in the plots

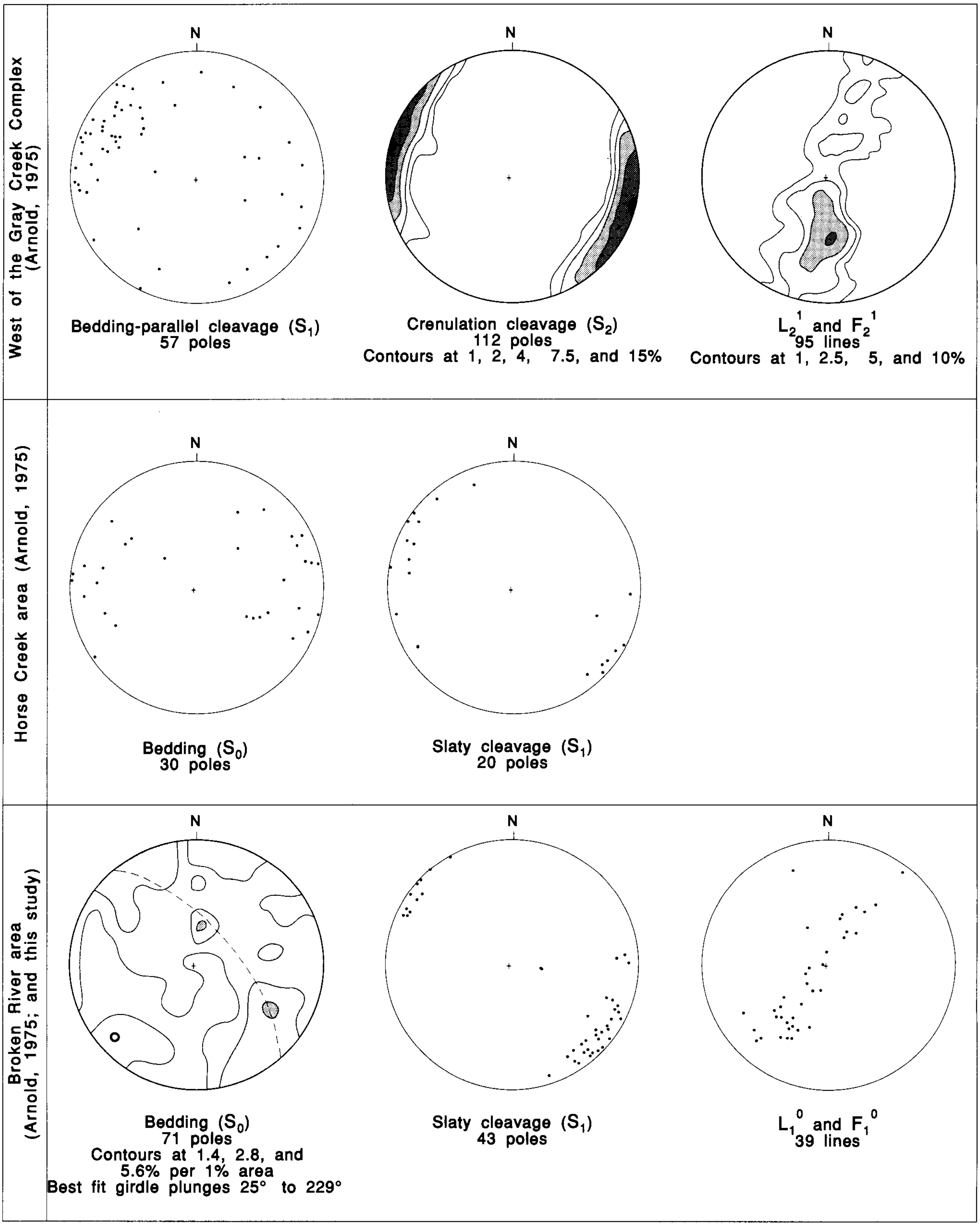


Figure 58. Structural data from the Judea Formation.

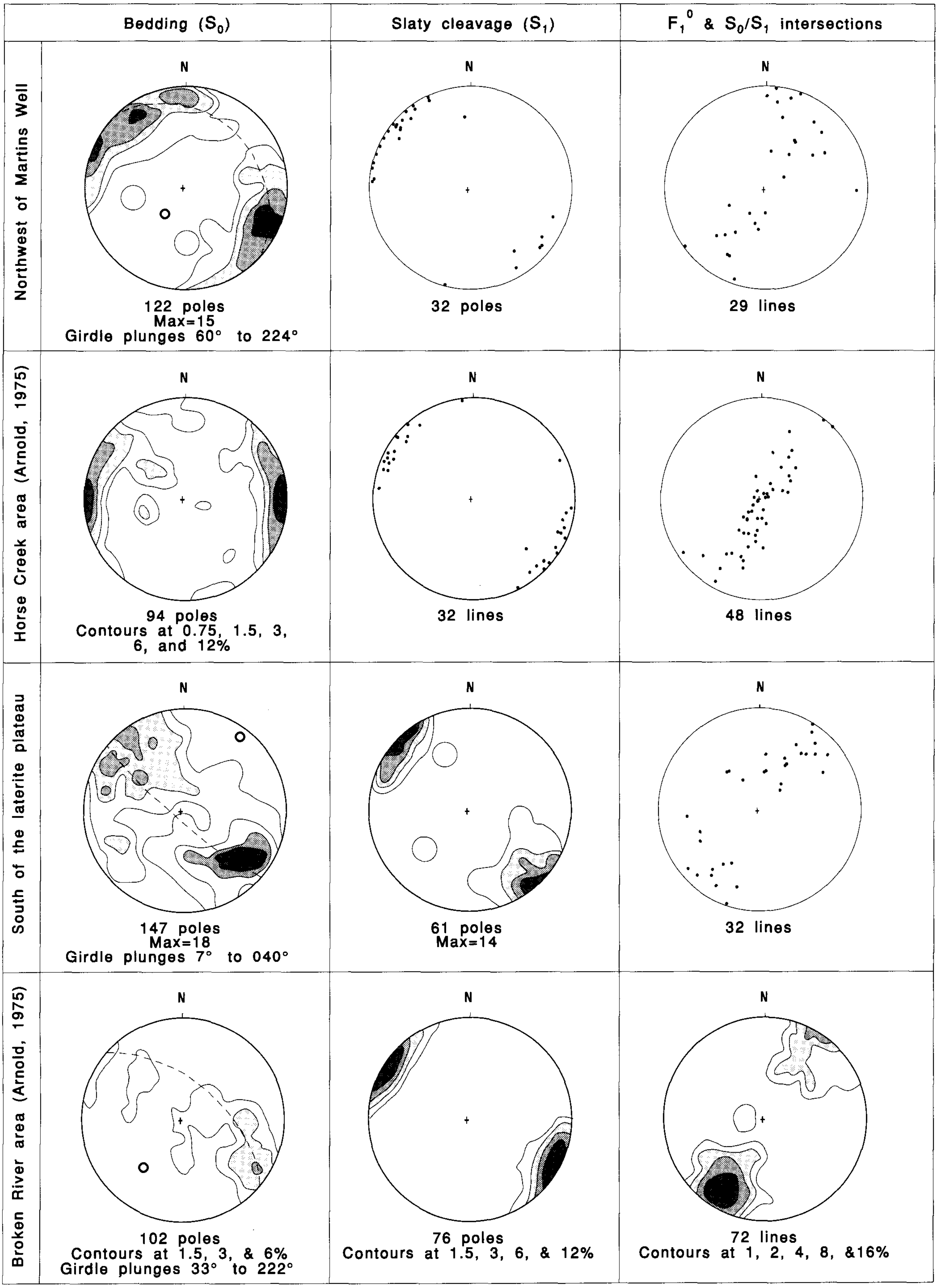


Figure 59. Structural data from the Graveyard Creek Group. Contours at 1, 2, 4, 8, and 12 points per 1% area unless otherwise specified.

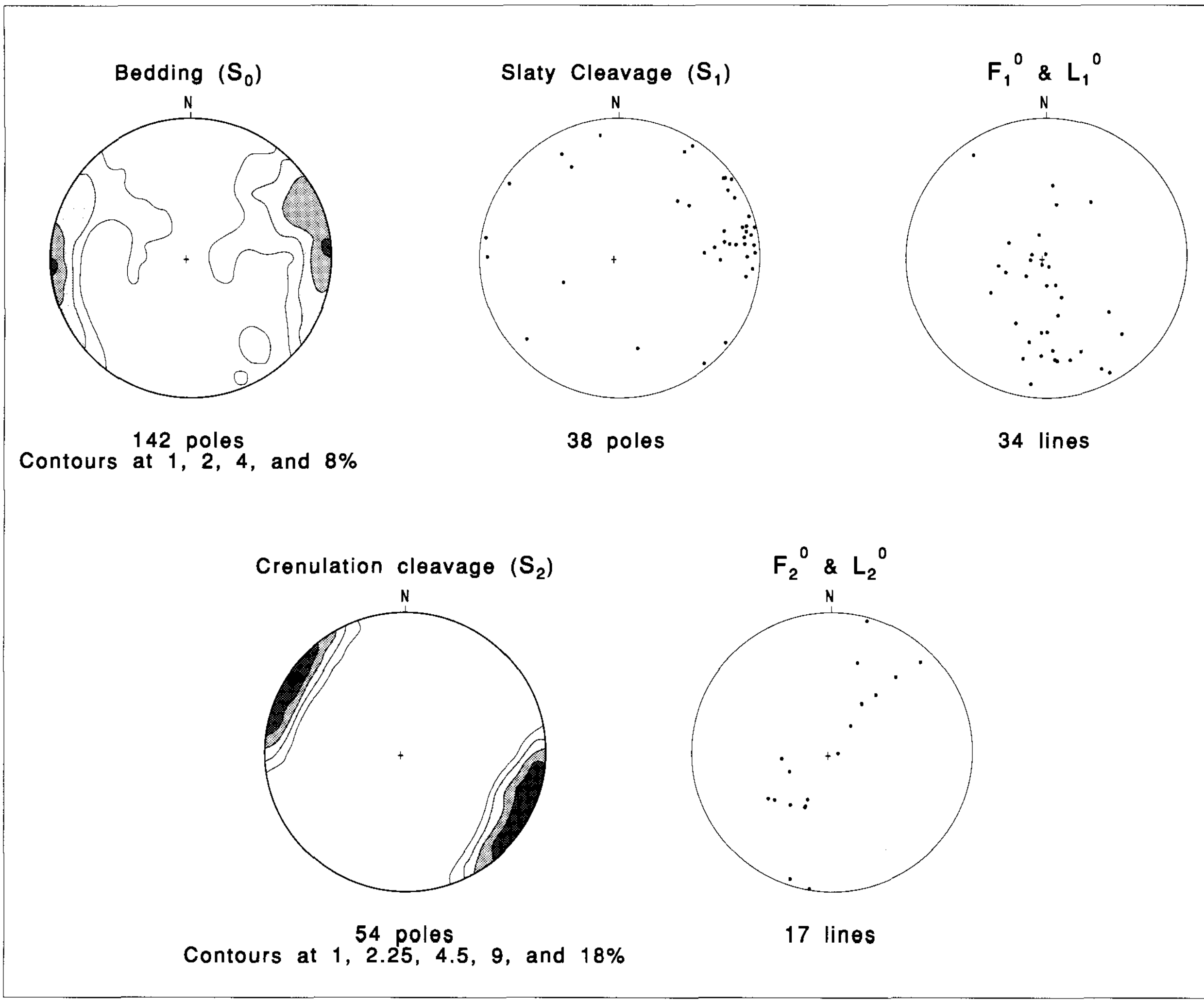


Figure 60. Structural data from the Graveyard Creek Group west of the Gray Creek Complex and in the headwaters of Horse Creek (from Arnold, 1975).

of poles to S_0 and fold axes and S_0/S_1 intersection lineations (Figure 59). Along and adjacent to the Broken River itself, the overall plunge indicated by the plot of fold axes and lineations is about 20° southwest (Arnold & Henderson, 1976).

S_1 in the Poley Cow Formation ranges from a fracture cleavage to a weak slaty cleavage defined by sparse, very fine-grained muscovite and chlorite. Pencil slates formed by the intersection of this cleavage with the bedding fissility occur locally. In addition, weathering in some mudstones produces aligned ellipsoids which appear to be parallel to the regional fold axes.

In the Black Wattle Anticline, which folds the Graveyard Creek Group in the north near 'Pandanus Creek', most outcrops show no slaty cleavage, and at best it is extremely weak. The anticline trends northeast and is probably related to the main deformation. The very elongate, parallel-sided core of Crooked Creek Conglomerate in this anticline indicates a horizontal axis and an absence of previous or subsequent folding, both of which should have resulted in a more complex fold pattern. Plots of data from the area northwest of Martins Well demonstrate the overall northeast trend of the folds (Figure 59), but suggest an overall plunge of about 60° towards 224°. This plunge probably relates to the Six Mile Syncline, about which most of the data was collected. The reason for the dramatic change in plunge between the Black Wattle Anticline and Six Mile Syncline is not known.

However, an earlier deformation was recognised by Arnold (1975) and Arnold & Rubenach (1976) farther to the east on the western side of the Gray Creek Complex along Dinner Creek and the headwaters of Horse Creek; it is also evident along Gray Creek near Top Hut yards (Arnold & Henderson, 1976). A weak slaty cleavage, S_1, with an approximate northerly orientation, is overprinted by a weak crenulation cleavage, S_2, which trends northeast (Figure 60). Farther west S_1 becomes vanishingly weak, and S_2 is a slaty cleavage instead of a crenulation cleavage. Because of its northeastern orientation, S_2 in these areas is probably equivalent to S_1 farther west and in the south. The earlier cleavage is probably related to folds mapped in the Top Hut area, which have anomalous, approximately north-trending rather than northeast-trending axial planes. The angular difference between these folds in the Graveyard Creek Group in the Top Hut area, and the northeast trends in the younger units, was the main evidence used by Green (1958) and White (1965) for an unconformity at the top of the "Graveyard Creek Formation". The folds presumably die out rapidly southwards as well as to the west, because no angular discordance can be demonstrated there between the Graveyard Creek Group and the overlying Shield Creek Formation and Broken River Group.

Arnold (1975) and Arnold & Henderson (1976) recognised only one cleavage in the Graveyard Creek Group (Quinton Formation) in the area along and adjacent to the lower reaches of Horse Creek, but they suggested that the decreased regularity of S_0 there was due to the incipient development of an earlier deformation. This would also explain the angular unconformity there between an outlier of Clarke River Group and the Graveyard Creek Group. If only one deformation affected this area as elsewhere, a concordant (although disconformable) relationship might be expected. The folding is probably more than incipient, because the Horse Creek Syncline is truncated by the unconformity at the base of the outlier. This syncline which trends north-northeast thus probably formed during the earlier deformation. Also the plot $F_1$0 fold axes from the Horse Creek area (Figure 59) shows that they are much steeper than in the southern areas, suggesting that the folds were superimposed on earlier folds.

Later folding also locally affected the Graveyard Creek Group. For example, near Turtle Creek, some open, easterly-trending folds, as well as rare slaty cleavage with a similar trend, are present at outcrop scale; larger-scale folds with a similar orientation are outlined by the Martins Well Limestone Member on the limbs of the major folds. Folds with similar trends deform the Broken River and Bundock Creek Groups (see below). In addition, at the Broken River crossing, a crenulation cleavage trending about 020° overprints the shallowly dipping slaty cleavage. This may be related to the large syncline which has its axial trace trending north-northeast across the Broken River near the crossing and other north-trending folds farther downstream. Anomalously strong, north-trending folding, which overturned some of the Clarke River Group adjacent to this area, may be related to this later event.

Broken River Group

In general, folds in the Broken River Group plunge between 10° and 30° to the southwest or northeast (Figure 61). In the Atherton Anticlinorium and Dip Creek and Rockfields Synclines, the overall plunge is about 20° southwest. Farther south between Gorge Creek and the Broken River, the overall plunge is shallower and is about 10° southwest. South of the Broken River in the Broken River Anticlinorium the folds are doubly-plunging, generally up to 20° northeast or southwest but the overall plunge is still about 10° southwest. Folds in the Broken River Group are noticeably tighter, and of smaller wavelength, than those in the overlying Bundock Creek Group, and are commonly overturned. The slight difference in the plunge of fold axes may reflect the slight angular unconformity between the Broken River Group and the Bundock Creek Group, since inclined surfaces when folded will produce inclined fold axes. However regional variations in plunge (as noted here within the Broken River Group) could partly account for the differences.

Axial-plane cleavage is moderately to poorly developed in the Broken River Group, and is commonly associated with a pencil cleavage.

Bundock Creek Group

The Bundock Creek Group, in the southern half of its outcrop area, is folded into open to tight, gently plunging, dome-and-basin folds, which are mainly upright, although in the Dip Creek Syncline they are overturned towards the northwest. The overall plunge is shallow (about 5°) to the southwest (225°) (Figure 62), although around the hinge of the Broken River Anticlinorium, the plunge is much steeper (about 35°).

Cleavage is generally only weakly developed in the Bundock Creek Group. The strongest axial-plane cleavage in the Bundock Creek Group is confined to the southeastern limb of the Rockfields Syncline, in a narrow band trending northeast, and is clearly seen in the north branch of Gorge Creek. High angle, slaty cleavage is a prominent feature in the drill core from GSQ Clarke River 1 and 2 (Lang, 1986b). However, it is likely that cleavage development is subject to lithological control, because it is only noticeable in thin-bedded sandstone and mudstone, or massive mudstone sequences.

A weak northeast-trending fracture cleavage has been observed in the Turrets Formation, and Teddy Mount Formation as high as the Dyraaba Member. There is no evidence to suggest that this is not related to the same fold event in spite of the suggestion by Wyatt & Jell (1980) that the 'upper' Bundock Creek Formation was folded into a different style than the 'lower' Bundock Creek Formation. In the Dip Creek Syncline and Boroston Syncline, the 'upper' units have a similar deformation style as the 'lower' units and therefore were probably deformed in the same folding episode.

To the north and west, among the intrusions of Montgomery Range Igneous Complex, the 'upper' units are folded in more open, roughly triangular, dome-and-basin structures. This more open pattern is reflected in the plot of poles to S_0 (Figure 62), and may be due to two factors. Firstly, the 'upper' units of the Bundock Creek Group, deposited north of the 'Pandanus Creek-Gregory Springs ridge' may have been protected by the ridge, which reduced the effect of folding. Secondly, those sediments deposited in the deep 'trough', now folded into the Rockfields and Boroston Synclines, may have undergone more deformation when the compressive component of the folding event pushed them against the ridge. The ridge may have been controlled by a deep structural feature, possibly the buried southwestern extension of the Halls Reward Fault.

The folding mechanism was probably flexural slip, giving rise to essentially parallel folds, but with slight attenuation of the limbs suggesting a weak component of simple shear. Flexural slip folding is considered to have taken place, because slip parallel to bedding has been observed. Such slip is evidenced by en-echelon microfaulting of quartz veins parallel to bedding. Interestingly, the folds change to similar folds towards the northeast, where the tightest folds occur. However, towards the southwest, these folds open-out, and die into the Boroston Syncline, possibly as monoclines (for example, the Rockfields Syncline and its unnamed anticlinal neighbour to the north).

The northeast-trending folds in the Dip Creek, Rockfields and Boroston Synclines have been deformed by a later north-south oriented compression, resulting in *en echelon*, east-trending dome-and-basin folds. This probably postdated the main northeast-trending faulting episode (see below), because many of those faults are also slightly bent. The east-west folding had more effect in the northern part of the Bundock Creek Group where D_1 was weaker. The north-northeasterly orientation of the girdle through the poles to S_0 from this area reflects the superimposition of open northeasterly and easterly-trending folds.

Age of folding

The main deformation in the Graveyard Creek Group affects all of the units up to the top of the Bundock Creek Group, and is thus probably Visean or younger. The granitoids of the Montgomery Range Igneous Complex (but not the rhyolite sills) clearly truncate the northeast-trending folds, but their age is presently uncertain.

The age of the earlier event in the Graveyard Creek Group is more of a problem. Although it folds the Graveyard Creek Group, the fact that it does not deform any of the Devonian rocks need not be significant, because of its localised extent even within the Graveyard Creek Group.

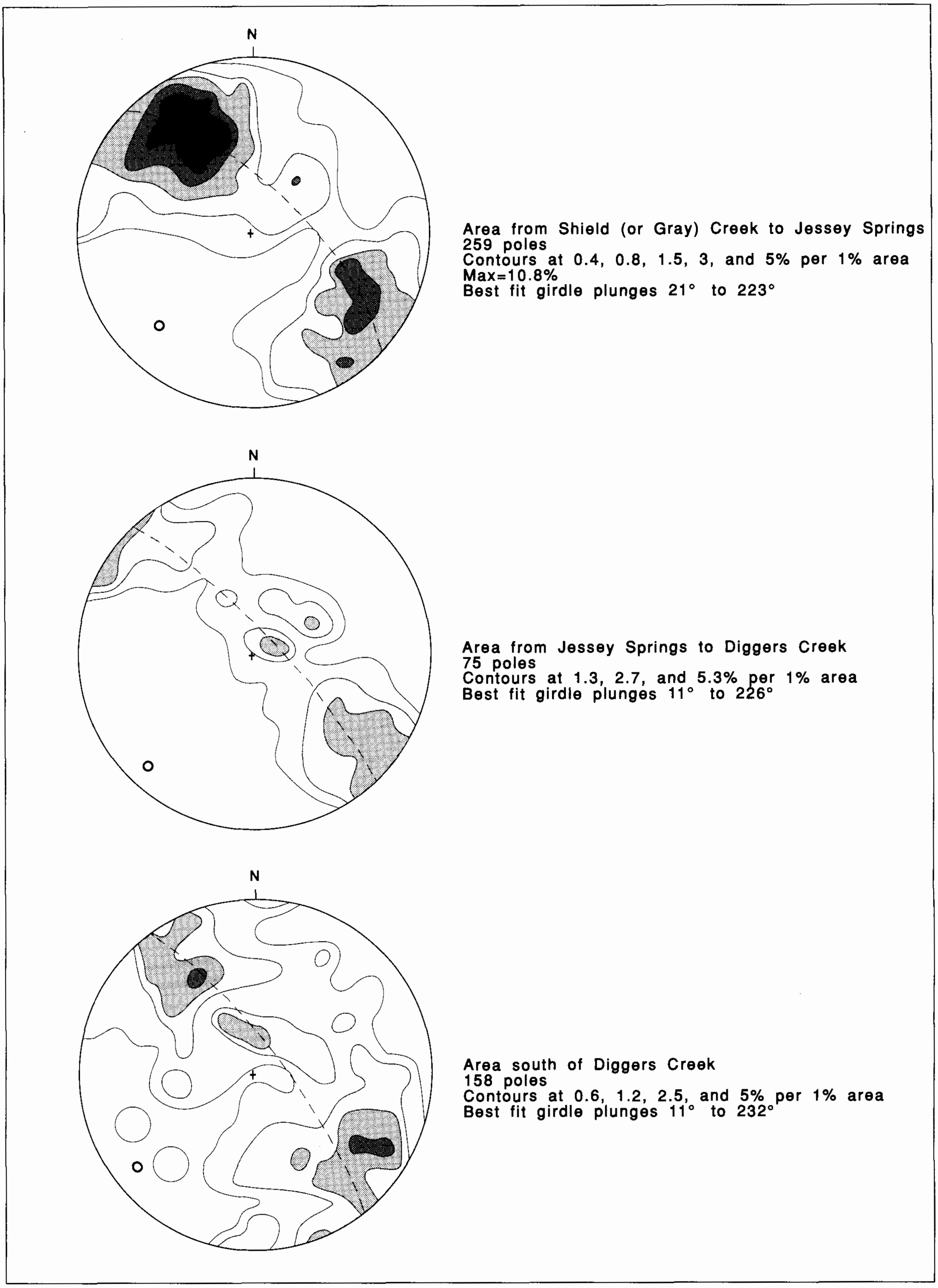


Figure 61. Plots of bedding from the Broken River Group.

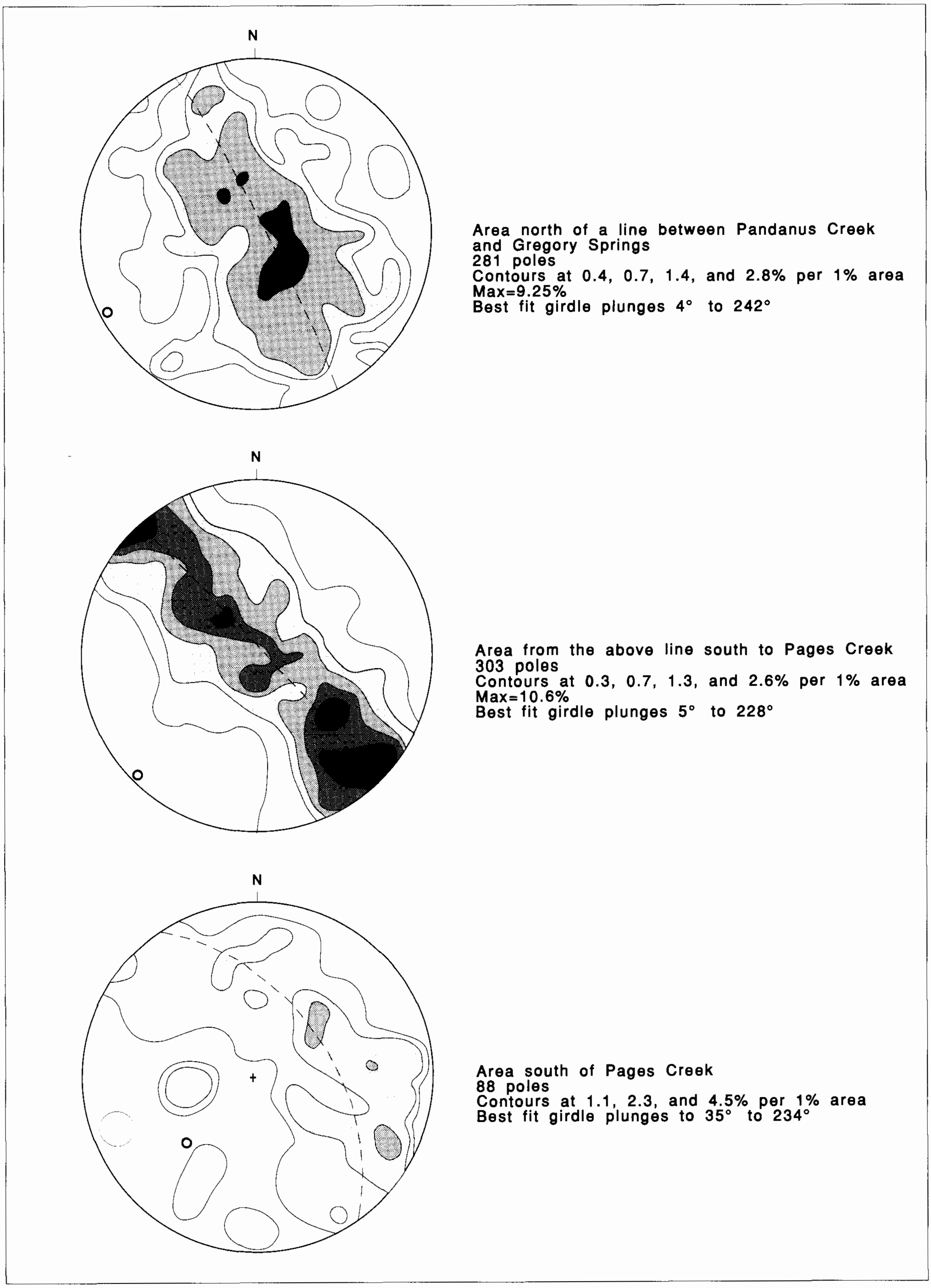


Figure 62. Plots of bedding from the Bundock Creek Group.

Nevertheless, it is may correlate with the apparent hiatus between the Graveyard Creek Group and Shield Creek Formation in the Lochkovian based on conodonts from the limestones (Figure 86). The Lochkovian break roughly corresponds with the radiometric age of approximately 400 Ma which is commonly obtained from older rocks in the Georgetown Inlier (Black, 1973; Black & others, 1979), and which has been suggested as the age of D_4 there (Black & others, 1979; Withnall & others, 1980a; Withnall, 1984), and the age of D_1 in the adjacent Camel Creek Subprovince (see above). The proximity of these earlier folds to the Gray Creek Fault suggests that they could be related to movement on that fault, and therefore to the thrusting and folding in the Camel Creek Subprovince.

The east-west folding may be related to a continent-wide north-south compressional event, postulated for the Mid-Carboniferous by Powell & others (1985), and resulting in the Alice Springs Orogeny and megakinking in the Lachlan Fold Belt. Folds with this orientation also occur in the Georgetown Province (Withnall, 1984, 1989b), and in the Hodgkinson Province (Hammond, 1986).

FAULTS

Apart from the major bounding faults, which are described in a separate chapter, faults mainly lie along four trends, northeast, northwest, east, and north. The dominant trend of faults is northeast, parallel to the main fold axes. They commonly truncate limbs of the major folds.

The subparallel Shield Creek and Tank Creek Faults lie along the northwestern limb of the Dip Creek Syncline. A narrow slice of Bulgeri Formation, 200 to 500 m wide lies between the faults. At the northeastern end of the Shield Creek Fault, the Dip Creek Limestone is truncated and juxtaposed against a the slice of Bulgeri Formation. However, along most of its length, the fault separates Teddy Mount Formation from the Bulgeri Formation. The Tank Creek Fault separates the slice of Bulgeri Formation from the Quinton Formation. The faults are possibly high-angle thrusts, related to the northwest-dipping overturned folds (Black Wattle Anticline and Dip Creek Syncline) in that area. Some strike-slip movement may also have occurred to account for the juxtaposition of the Bulgeri Formation against the Dip Creek Limestone.

This overturned fold/high-angle thrust fault couplet style occurs throughout the area, but is most commonly observed on a small scale in the Broken River Group to the south. However, the vergence of the folds and thrusts is opposite to that in the Tank Creek/Shield Creek area.

The most significant fault within the Graveyard Creek Subprovince is the Jessey Springs Fault which can be traced southwest for about 22 km from near Jessey Springs. To the northeast, under the western end of the laterite plateau, it probably connects with the Lockup Well Fault which can be traced for about 12 km. At the southwestern end of the Jessey Springs Fault, the lower part of the Broken River Group is juxtaposed against the Mytton Formation. The fault is exposed as a shear or melange zone up to 100 m wide. The melange consists of quartz in a matrix of sericite and minor chlorite (Humphries, 1990); late-stage epidote and haematite overprint the shear fabric, suggesting that the structure acted as a conduit for low-temperature, hydrothermal fluids. Dolerite dykes were also emplaced along the fault in places. A study of the fault by Humphries (1990) indicated a three-stage history involving early sinistral, followed by dextral and late-stage normal (west-block-up) movements. Humphries (1990) suggested that the fault was a primary Reidel shear related to movement on the Clarke River Fault.

The Phar Lap Fault diverges at a low angle to the east-northeast from the southwestern end of the Jessey Springs Fault. The fault dips steeply north-northwest. On the southern side of the fault, a series of anticlines with cores of Jack Formation form an *en echelon* arrangement. According to Humphries (1990), this suggests that the fault was a syn-deformational accommodation structure undergoing dextral strike-slip motion. Slickensides and drag-folds indicate that late-stage, normal, dip-slip movement also occurred.

The Lockup Well Fault has not be studied in detail. It lies partly along the northeastward projection of the Rockfields Syncline. It truncates the Dip Creek Limestone on the southeastern limb of the Atherton Creek Anticlinorium, juxtaposing it against the Mytton Formation. Farther along strike to the northeast, the Shield Creek Formation is juxtaposed against the Lockup Well Limestone. Significant apparent sinistral displacement is suggested by the outcrop pattern, but the structure is poorly known in this area, and vertical movement could account for much of the dislocation.

As suggested earlier in this report, the Shield Creek/Tank Creek Fault system and the Jessey Springs/Lockup Well Fault system may have be long-lived structures and have had an influence on sedimentation, particularly during the deposition of the Graveyard Creek Group. The Shield Creek/Tank Creek Fault system coincides with a marked decrease in the thickness of the Quinton Formation from west to east, and may thus have be the southeastern edge of a major depocentre. The Jessey Springs/Lockup Well Fault system may have controlled the northwestern edge of a postulated palaeo-high on which the Poley Cow Formation thinned out (locally completely).

The northwest-trending faults appear to be minor normal faults, and may be related to an orthogonal fracture pattern along which dolerite dykes, and some thick quartz veins have intruded. Those trending east have a slight strike-slip component (possibly sinistral), but are dominantly normal faults. They seem to form the tails to or splays from many of the northeast-trending faults, and may be related to them.

Movement on a set of north-trending faults in the southeast corner of the Subprovince appears to be mainly west-block-up, but it is not known whether they are normal or reverse faults. However, they are associated with the localised younger north to north-northeast-trending folds described above in this area, and could be high-angle thrust faults on the limbs of these.

CLARKE RIVER BASIN AND ASSOCIATED ROCKS

(J.J. Draper, M. Scott & I.W. Withnall)

The Clarke River Basin is centred 180 km west of Townsville and lies in the eastern portion of BURGES, the southern portion of CLARKE RIVER and the north western and central portion of EWAN (Figure 63). The Clarke River Basin overlies the Camel Creek Subprovince with almost all outcrop occurring east of the Gray Creek Fault. The main body of outcrop lies in the southern part of the Subprovince as far east as Blue Range, but with outliers to the north adjacent to and east of the Gray Creek Fault. The original extent of the basin is unclear.

The basin was first recognised during 1:250 000 mapping by joint Bureau of Mineral Resources and Geological Survey of Queensland field parties in the late 1950s (White, 1959, 1961, 1962a, 1965; Wyatt & White, 1960), and the rocks in the basin were all included in the Clarke River Formation (White, 1965). During the 1970s, the basin was prospected for uranium by AFMECO Pty Ltd (Fouques, 1975; Coles, 1976; Marlow, 1977; Dalgarno, 1977; Mouthier & Rippert, 1980) who informally subdivided the formation. Wyatt & Jell (1980) and Jell & Playford (1985) reviewed the geology of the basin using the data obtained by AFMECO Pty Ltd.

As a result of remapping of the Broken River Province by the Geological Survey of Queensland in the mid 1980's, the Clarke River Formation was upgraded to Group status with two defined formations (Scott, 1985; Scott & Withnall, 1987). The field mapping was supplemented with two fully cored stratigraphic bores, GSQ Clarke River 3-4R and 5 (Scott, 1986, 1988a).The lowermost unit is the Venetia Formation of latest Devonian to Early Carboniferous age (Tournaisian) whilst the uppermost unit is the Lyall Formation of Visean age. Two members have been defined in the Lyall Formation, the Furry Hoop Member and the Meath Rhyolite Member. Subsequent mapping in the Blue Range area has resulted in the definition herein of a third formation, the Ruxton Formation which was included by Scott & Withnall (1987) in the Venetia Formation, and which overlies a thin 'unnamed unit' which is now excluded from the Clarke River Group.

The Clarke River Group is intruded by rhyolites associated with the Meath Rhyolite Member, and by a granodiorite in the Blue Range area. The Oweenee Rhyolite and Malmesbury Microgranite (Scott, 1988b) are of a similar age to the Meath Rhyolite Member and probably form part of the same igneous suite. In the main outcrop area north of the Clarke River, the Clarke River Group is unconformably overlain by the Late Carboniferous to Early Permian Wade beds which are described herein.

'UNNAMED UNIT' UNDERLYING THE CLARKE RIVER GROUP

In the Blue Range area, the Clarke River Group unconformably overlies the Kangaroo Hills Formation although in places there is an unnamed, thin, sedimentary unit interposed between the Kangaroo Hills Formation and the Ruxton Formation. This thin unit crops out at a number of localities in the Blue Range area. The unit is variable in grainsize but has two major distinguishing characteristics. Firstly, it is composed entirely of reworked Kangaroo Hills Formation rock types, and, secondly, has a red to red purple colour. It is not shown on maps because of its limited exposure; it is usually exposed in erosion gullies on the flank of hills.

One of the better sections of the 'unnamed unit' is immediately beneath the type section of the Ruxton Formation where the unit is 10 m thick. The base of the section is a thick-bedded, pebble to cobble, massive, grain-supported conglomerate with sub-angular to sub-rounded clasts derived from the underlying Kangaroo Hills Formation. This basal conglomerate fines up at the top. The basal conglomerate is overlain by an overall upward fining sequence of conglomerate, sandstone, and mudstone. The conglomerates are similar to the basal conglomerate except finer (pebble sized) and thinner bedded (medium-bedded). The sandstone is labile, thin to medium-bedded, medium to very coarse-grained and massive. Mudstone at the top of the section is thick to very thick-bedded and is massive. The section is capped by thick-bedded conglomerate similar to the conglomerates lower in the section, and is overlain by quartzose sandstone of the Ruxton Formation.

Elsewhere the 'unnamed unit' comprises breccia, conglomerate and sandstone similar to those described above. At a small hill (8059-464962) just north of Blue Range, a gradation can be seen between bedded Kangaroo Hills Formation and breccia indicating that *in situ* brecciation occurred. This exposure is 10 m thick and it is only in the upper part that any evidence of rounding is present.

The rocks in the 'unnamed unit' are near to flat lying (<5°) and unconformably overlie the steeply dipping, tightly folded Kangaroo Hills Formation. In places, there is a slight angular discordance between the unit and the overlying Ruxton Formation. Furthermore, there is a sharp change from lithic labile sediments to quartzose sandstone. Edwards (1977) included the 'unnamed unit' in the Clarke River Formation.

The unit lacks fossils, and can only be dated by superposition. It predates the latest Devonian to Early Carboniferous Ruxton Formation, and postdates the major deformation of the Kangaroo Hills Formation. Withnall & Lang (1990) suggest a Frasnian age for the major deformation in the Camel Creek Subprovince including the Kangaroo Hills Formation. Therefore the unnamed unit is of Frasnian to Famennian age.

The unnamed unit contains no indication of marine deposition. The nature of the sediment and its relationship to underlying rocks suggest a valley fill origin.

CLARKE RIVER GROUP

The Clarke River Group (Scott & Withnall, 1987) is named after a major tributary of the Burdekin River and is synonymous with the Clarke River Formation of White (1959). The group includes all sedimentary and volcanic rocks deposited in the Clarke River Basin and in this report comprises three formations, the laterally equivalent Venetia and Ruxton Formations and the younger Lyall Formation which contains the Furry Hoop and Meath Rhyolite Members.

VENETIA FORMATION

Introduction

The Venetia Formation (Scott & Withnall, 1987) crops out in high ridges along the northern side of the Clarke River. Farther north outcrop is restricted to windows and embayments in the extensive Tertiary plateau basalts and laterites. There are small areas of outcrop to the south east of Niall Station, north of the Gill Creek area, east of Gray

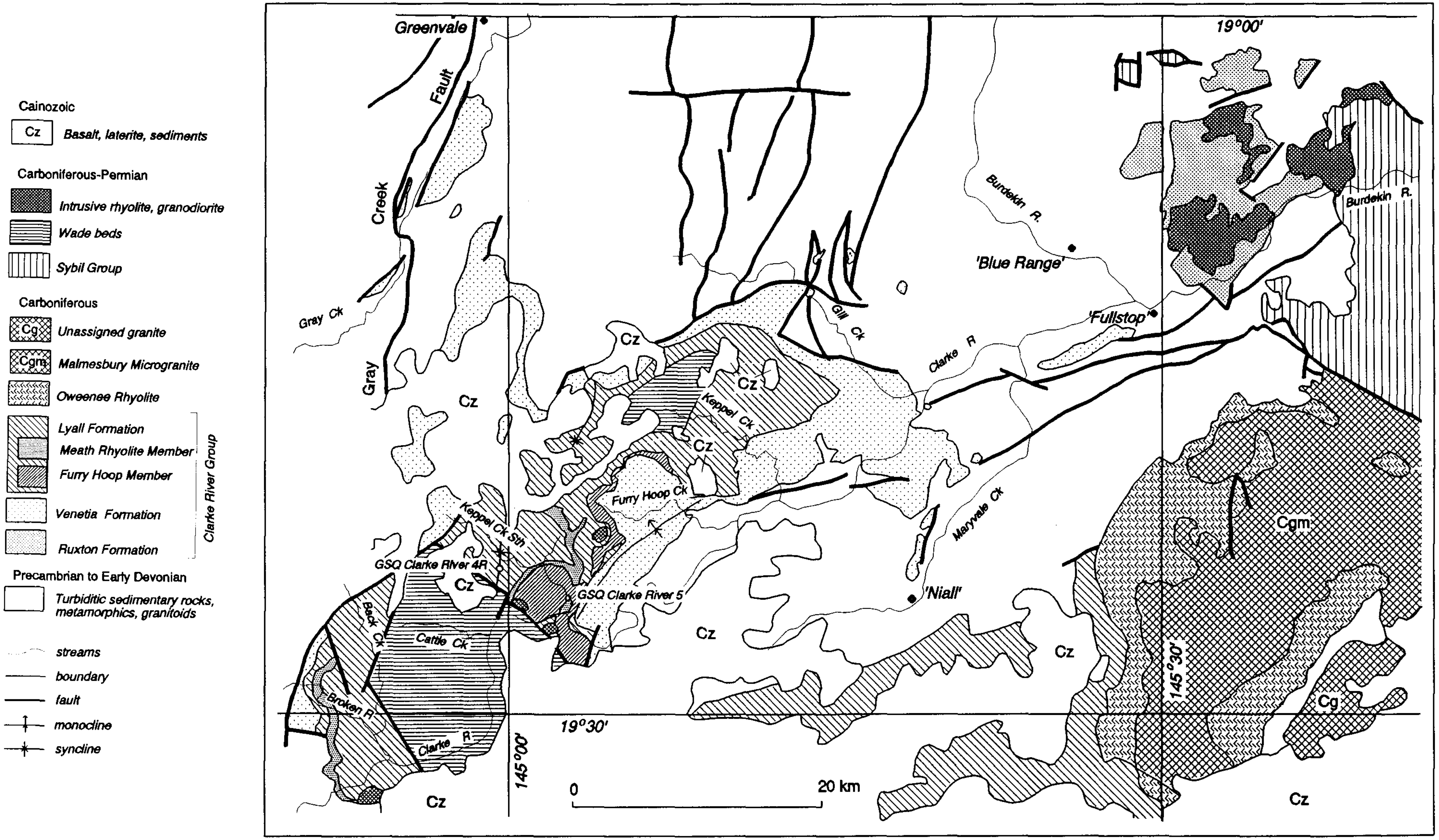


Figure 63. Simplified geological map of the Clarke River Basin.

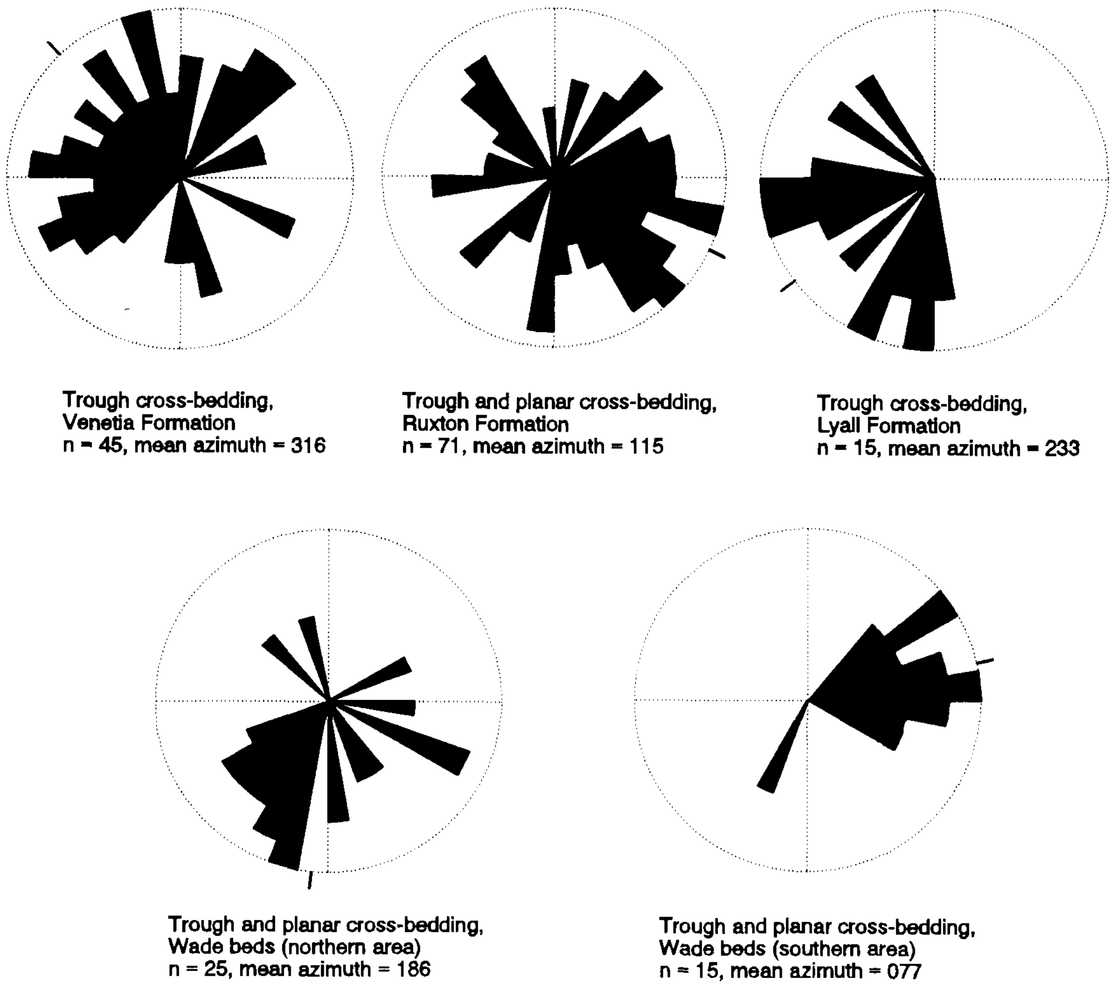


Figure 64. Palaeocurrent distribution for the Clarke River Group (plotting by 10^{0} intervals - area of segment proportional to number of readings).

Creek near Lucky Springs homestead, along the divide between Gray and Porphyry Creeks, and near the junction of Horse and Gray Creeks. A narrow belt along the northern edge of Gowrie Hills for about 10 km southwest of Fullstop homestead has also been included in this formation. Small isolated outcrops occur in the northern Camel Creek Subprovince overlying Perry Creek Formation.

Type section

The holostratotype was nominated by Scott & Withnall (1987) in the ridges north of the Clarke River from 7959-997528 (base) to 972534 (top). The 500 m section contains coarse to very coarse, lithofeldspathic sandstone which fines up through the sequence into fine to medium-grained micaceous feldspathic sandstone with minor tuff and siltstone. No marine rocks are present in the type section.

Reference sections were nominated at three localities:

(i) A 237 m section along the Clarke River from 981477 (base) to 969477 (top); the top is faulted against the Lyall Formation.

(ii) Along Gill Creek from 225685 (base) to 203682 and thence up an unnamed tributary to 157678 (top); this section contains marine sediments between 213679 and 195681.

(iii) The interval between 1 008.57 m (TD) and 533.45 m in GSQ Clarke River 5 (Scott, 1986, 1988a) which was fully cored; this bore did not intersect the base of the unit.

Lithology and sequence

The dominant lithology in the Venetia Formation is white, buff or grey, coarse to very coarse, micaceous lithofeldspathic sandstone and minor pebbly sandstone and conglomerate. These are interbedded with less abundant beds of siltstone and tuff.

The base of the unit consists of polymictic, pebble to boulder conglomerates and breccias derived from the underlying Camel Creek Subprovince rocks. Clasts include jasper, phyllite, quartzite, chert, quartzose arenite and schist. The basal conglomerates pass upwards into finer grained conglomerates and sandstones, and in some areas into marine sediments.

The marine rocks present immediately above the base of the unit are sporadically distributed and comprise calcareous siltstone and flaggy, fine-medium-grained sandstone with local impure limestones and skeletal grainstones, and fossiliferous conglomerates. In both Gill and Furry Hoop Creeks a white laminated tuff or tuffaceous siltstone is present within the fossiliferous interval. Fossils are present in the limestone and sandstone and include crinoids, brachiopods (chonetids, strophomenids, and productids), bivalves, gastropods, bryozoans, nautiloids, oncolites, plant fragments, sponge spicules, and conodonts. Sedimentary structures in the sandstones include planar lamination, burrows, low-angle trough and planar cross-stratification, convolute lamination and hummocky cross-stratification. Calcareous concretions to 30 cm are present in Gill Creek. Palaeocurrents, based mainly on low-angle trough cross-stratification, are predominantly

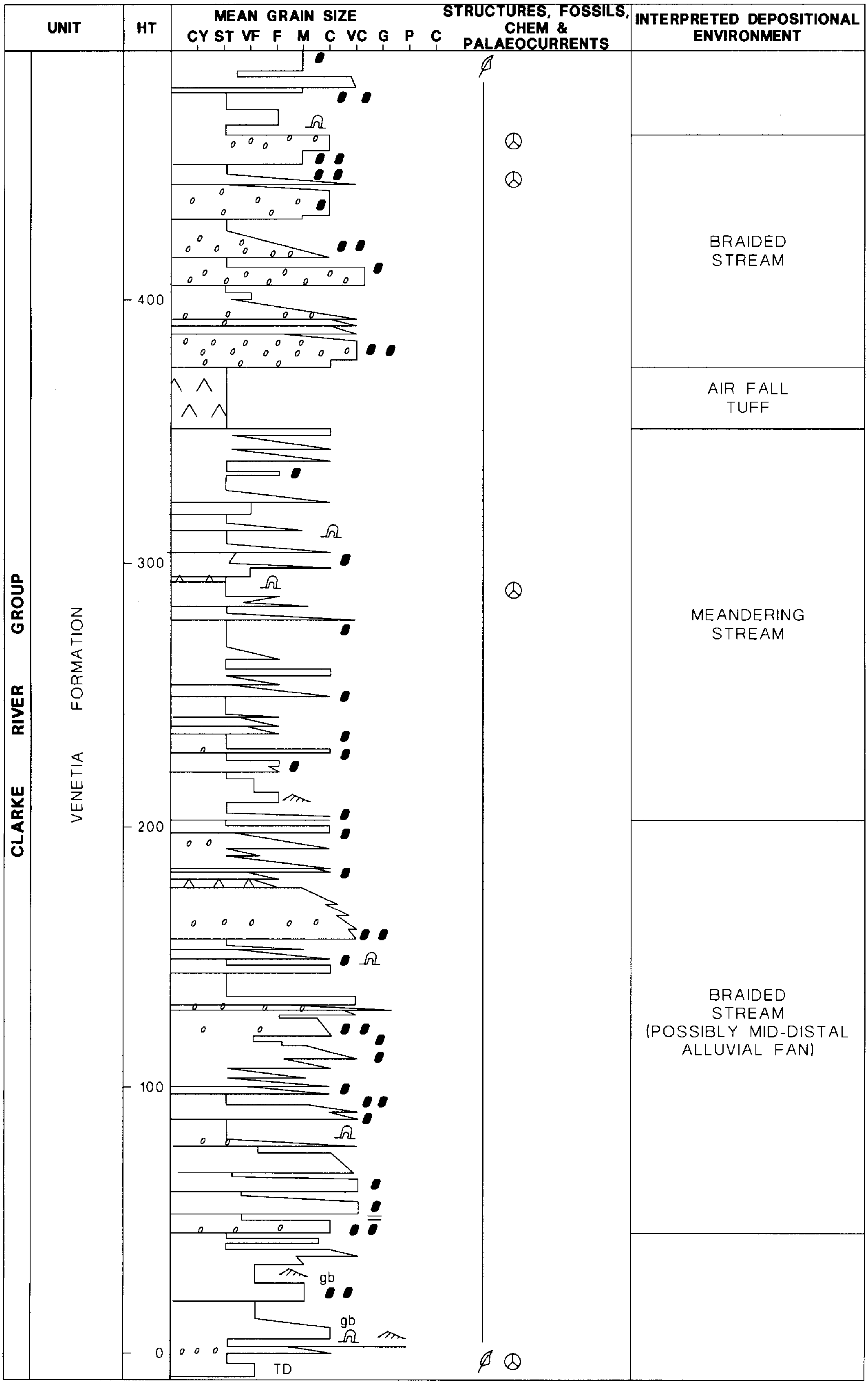


Figure 65. Generalised section through the Venetia Formation in GSQ Clarke River 5. See Figure 14 for reference.

towards the north west (Figure 64). The thickness of the marine beds is difficult to estimate but is unlikely to exceed 20 m.

The main part of the Venetia Formation conformably overlies the marine interval. The lithological sequence is shown in Figure 65, which is a log of the sequence intersected in GSQ Clarke River 5. Neither basement nor marine sediments were intersected so the total thickness of the unit is not plotted. Comparison of this log with the type section of Scott & Withnall (1987) indicate that the two section are similar in their gross characteristics.

Five subdivisions of the Venetia Formation are recognisable in GSQ Clarke River 5. From 954 m to 1 008.57 m (TD) the sequence comprises medium to coarse-grained, feldspatholithic, labile sandstone interbedded with siltstone and thinner bedded finer grained sandstone. Mud clasts are present in some sandstone. Soft sediment deformation and ripple cross-lamination are present in the finer grained rocks. Plant fragments and carbonaceous laminae are common.

The interval from 802 m to 954 m contains sandstones that are overall coarser grained than the underlying unit though compositionally similar; the sandstones are thicker and contain significantly fewer siltstone and thin sandstone interbeds. Occasional pebbles are present (quartzite and siltstone) and mud clasts very common. The sandstone beds generally fine upwards. Soft sediment deformation is present in the siltstones. Plant fragments occur throughout. A 2.5 m thick tuffaceous bed is present near the top of this unit. From 653 m to 802 m, there is a much greater proportion of finer grained sediments and a reduction in thickness of the sandstone beds which are finer but otherwise similar to those of the underlying unit. The sandstones fine upwards and contain numerous mud clasts.

At 653 m the sedimentary sequence is disrupted by a 23 m thick light green rhyolitic tuff. The overlying sediment (533.45 m to 630 m) comprises pebbly and very coarse sandstone in very thick often upward fining beds, siltstone and finer sandstone interbeds. Pebbles include quartzite, metamorphic rock types, and volcanics, and mud clasts are common. Plant fragments are present.

The rocks cropping out in the main basin area are very similar to those in GSQ Clarke River 5 and show sedimentary structures which are difficult to observe in core. Conglomerates are crudely stratified, massive or cross-stratified (medium-large-scale trough), range in grainsize to boulder and are both matrix and grain supported. Sandstones are massive, horizontally stratified and cross-stratified; types of cross-lamination include trough cross-lamination ranging from small to large-scale with the latter being more common, and large and medium-scale low-angle trough and planar cross-lamination.

The outliers to the east of the Gray Creek Fault overlie rocks of the Camel Creek Subprovince and contain similar rock types to the main area. Another outlier intersects the Gregory Development Road near the turnoff to Fullstop homestead. Conglomerate is the main lithology and it unconformably overlies Perry Creek Formation. The conglomerates are very thickly bedded, range in size from pebble to boulder and comprise quartz arenite, quartzite, red jasper, micaceous arenite. Conglomerates are both matrix and clast supported and are poorly horizontally stratified with possible trough cross-stratification in the finer beds. Minor sandstone is very coarse-grained to pebbly and contains medium-large-scale trough cross-stratification in thick to very thick beds. Purple brown mudstone with possible root mottles forms a very minor component. Palaeocurrent data are sparse (5 readings) and indicate an arc from 345° to 110°.

Discussion

The distribution of the sediment types, the broad palaeocurrent pattern, and the diffuse nature of the basin margins indicate that the Venetia Formation was deposited over a much larger area than preserved. Lateral equivalence exists with the Teddy Mount Formation and the Ruxton Formation (see below) and the three units were probably connected.

The basal conglomerate represents alluvial fan to braided stream deposits generated when the basin was initiated by uplift to the south east possibly along the Clarke River Fault. The palaeocurrent data indicates transport away from the Lolworth Ravenswood Block which provides a likely source for micas within the sediments. However, throughout the sequence, clasts derived from the Camel Creek Subprovince are present, indicating that such rocks were exposed to the south and south east.

Although the marine rocks crop out only sporadically, the widespread distribution of the known occurrences suggests that the marine facies were deposited over a large area; the marine rocks are probable correlatives of similar rocks in the Teddy Mount Formation and the Ruxton Formation. It is likely, therefore, that the marine rocks were deposited during a widespread marine transgression (recorded also in the Burdekin Basin (Lang & others, 1990)). The fauna found within the Venetia Formation is unlikely to represent marginal marine conditions. The presence of hummocky cross-stratification suggests a shelf like environment with the low-angle planar cross-stratification indicating shoaling or a beach. The sporadic distribution and thickness variations may reflect deposition over an irregular surface such as advancing fans and that the marine sediments were deposited partly as a distal fan delta deposit. The fact that the palaeocurrent data mirrors that in the underlying and overlying sediments supports this scenario. Deposition ceased when the alluvial plain prograded over the marine sequence thus re-establishing a totally non-marine basin.

The sequence in GSQ Clarke River 5 is representative of the remainder of the unit. The lowermost unit represents deposition under meandering stream conditions possibly on a coastal plain adjacent to the sea. The next highest unit has a very high sandstone to siltstone ratio and represents braided stream deposition perhaps from mid to distal alluvial fan streams. The braided facies passes upwards into a facies with much more fine-grained overbank sediment which is interpreted as having been deposited in a meandering stream system. The thick tuff between 630 m and 653 m marks a significant change in depositional style as it is overlain by pebbly sandstones and conglomerates; these are interpreted as having been deposited in a reactivated alluvial fan system.

Age

Age control in the Venetia Formation is based on limited data but several studies in the last few years have provided some control. Playford (1988) examined poorly preserved, sparse microfloras from GSQ Clarke River 5. A Tournaisian age is indicated for the unit and a sample at 713 m contains an assemblage with an implied late Tournaisian age. The evidence from this bore shows that the hiatus near the top of the Venetia Formation proposed by Scott & Withnall (1987) does not exist and that the sample which provided the Visean age (Jell & Playford, 1985) on which the hiatus was based was in fact from the Lyall Formation rather than the Venetia Formation (Playford, 1988). Since GSQ Clarke River 5 did not intersect the base of the unit, the age range of the unit could not be determined from palynology.

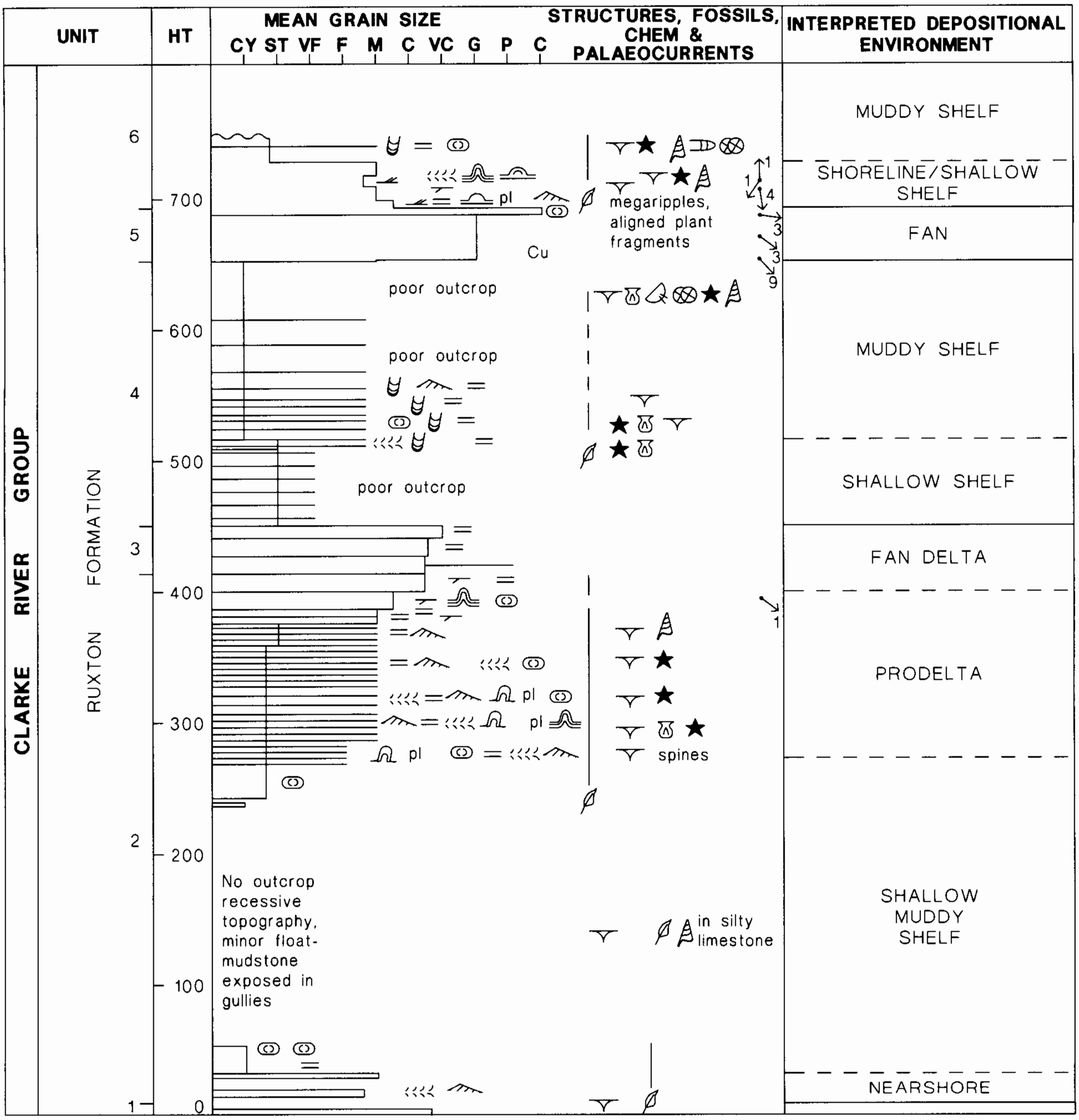


Figure 66. Type section for the Ruxton Formation in the Blue Range area between 8059-523588 and 530486. See Figure 14 for reference.

The marine unit near the base of the formation contains a good fauna but it has never been described. The faunas at Gill Creek and Gray Creek were initially assigned to the Tournaisian and "Devonian or Lower Carboniferous" respectively (Hill *in* White, 1965). Henderson (*in* Arnold,1975) identified a fauna from the Gray Creek area which was of Tournaisian age. Edwards (1977) studied the faunas at Blue Range (now referred to the Ruxton Formation) and assigned a small collection from the main area of the Clarke River Basin to the Tournaisian.

Conodonts have been recovered from the Gray Creek area (Mawson, personal communication). *Bipathodus aculeatus plumulus* and *Pseudopolygnathus primus* were recovered; the former has a very restricted range from latest Famennian to earliest Tournaisian. *Leptophloeum australe* is locally common, particularly towards the base of the formation. It is generally regarded as Late Devonian or Tournaisian.

The data available indicate an age from latest Famennian to late Tournaisian for the Venetia Formation.

RUXTON FORMATION

Introduction

The Ruxton Formation is herein defined for the first time and is named after Ruxton Waterhole on Expedition Creek, Blue Range (492866, EWAN sheet area). The name Ruxton has also been used for a tin mine in the Blue Range area. The unit is exposed over 286 km^2 in the Blue Range area where it forms the bulk of Blue Range in the north west corner of EWAN (8059). A fault-bounded block 30 km north-north east of Blue Range in KANGAROO HILLS (de Keyser & others, 1965) may represent an outlier of the Ruxton Formation.

Type section

The type section (unit-stratotype) is from 8059-523588 (base) at the headwaters of a tributary of 'Eastern Creek' to 530486 in 'Eastern Creek' (Figure 66). This section was first described by Edwards (1977) who recognised six subunits. The base of the unit unconformably overlies a purplish coloured conglomerate, sandstone and mudstone unit composed of fragments of Kangaroo Hills Formation (see above). The lowermost sub-unit comprises 7 m of white quartzose sandstone and pebbly sandstone which is coarse to very coarse, moderate to poorly sorted and medium to thick-bedded. Rare brachiopods are present.

The second sub-unit is 406 m thick and, overall, is poorly exposed with large intervals of no outcrop, particularly in the lower part. In the poorly outcropping areas, fine to medium-grained, medium-bedded, micaceous sandstone is dominant with lesser mudstone and siltstone. Carbonate concretions are common. Marine fossils include brachiopods, solitary rugose corals and gastropods. Plant fragments including *Leptophloeum* are common. Some 160 m of continuous section is exposed at the top of the unit in gullies and washouts. Interbedded sandstone and mudstone comprise the bulk of this sequence. The sandstone is very fine to medium-grained, thin to medium-bedded, labile and micaceous. Sandstones are laminated. Sedimentary structures include parting lineation, flute marks, current lineation (sole marks), convolute lamination, and ripple cross-lamination. Meandering horizontal feeding trails are preserved as sole marks. Fossils include plant fragments including *Leptophloeum*, brachiopods, crinoids, pelecypods, *Cladochonous* (tabulate coral), and gastropods. Mudstones are micaceous, laminated and thin to very thickly bedded. The mudstones contain plant fragments including *Leptophloeum*, and small brachiopods. Calcareous concretions are common. The sub-unit becomes sandier towards the top. Grainsize becomes coarser upwards with very coarse and pebbly sand at the top. Bedding ranges from medium to thick, but no pattern is obvious. The sandstone is laminated and has low-angle cross-stratification with laminae and cross-laminae defined by grain size variation. Minor plant fragments are present.

The third sub-unit, which forms a prominent ridge, is 37 m thick. Sandstone, pebbly sandstone and conglomerate are the rock types present. Bedding is thick to very thick. Composition ranges from quartzose to labile with muscovite present throughout. The pebbles are quartz. Some of the beds have poorly preserved trough cross-bedding.

The fourth sub-unit crops out poorly. At the base of the sequence, the fine-grained rocks pass laterally into the sandstones of the third sub-unit. The sub-unit becomes finer grained upwards, becoming mainly mudstone in the upper part. Sandstones which are restricted to the lower part of the unit are, fine to medium-grained, thin to medium-bedded and extensively bioturbated. As well as plant fragments, including *Leptophloeum*, crinoids, pelecypods and brachiopods are present. Mudstones are bioturbated and in places contain a fauna, in which all fossils are of very small size. Fossils include brachiopods, pelecypods, ostracodes and *Cladochonous*. The sub-unit is 200 m thick.

Sharply overlying the mudstone is the 40 m thick fifth sub-unit which comprises sandstone, pebbly sandstone and conglomerate. All are lithic labile and the conglomerate clasts include quartz, black chert, red chert, sandstone, phyllitic mudstone and mica schist. Bedding is thick to very thick. Grainsize varies from coarse sand to boulder. Internally the beds are massive or horizontally stratified with some beds fining upwards. Medium-scale trough cross-bedding is present; palaeocurrents from these indicate currents from the north west. Minor plant fragments are present.

The uppermost sub-unit gradationally overlies the fifth sub-unit. This sub-unit fines up from pebbly sandstone at the base to mudstone in the upper part. The sub-unit is truncated by erosion; about 60 m is preserved. Sandstones are mainly medium-grained with some coarse beds; pebbles occur in patches or as lags. Pebbles are similar to those in sub-unit 5 with pegmatite clasts also present. Bedding is medium to thick with beds massive or horizontally stratified. Sedimentary structures include parting lineation, linguoid ripple marks, streaming lineation, megaripples, ripple cross-lamination, medium-scale trough cross-bedding, water escape structures, possible hummocky cross-stratification near the top, and low-angle trough and planar cross beds. Plant fragments are present and often aligned. Marine fossils are present in the upper sandstones and include brachiopods, crinoids and gastropods. Horizontal feeding traces are preserved on some bedding planes. The overlying mudstone is weathered. Bioturbation occurs throughout. Fossils include brachiopods, crinoids, solitary rugose corals, large gastropods, straight nautiloids and pelecypods. Large calcareous concretions (to 1 m in diameter) containing fossils are present.

Lithology

No attempt was made during this project to map the sub-units in detail, but Edwards (1977) mapped the sub-units over much of the outcrop area.

Sub-unit 1 crops out throughout the area of the formation and is generally a quartzose sandstone similar to that in the type section. Some of the sandstone is sub-labile. Impressions of *Leptophloeum* are preserved. In some localities the sandstone is pebbly with mainly quartz pebbles.

Sub-unit 2 crops out about the faulted anticline in the central eastern area of outcrop and in the outlier in the north east of Blue Range. It also occurs adjacent to the fault in the south west. It appears to be absent in Blue Range proper where sub-unit 3 sits on sub-unit 1. The outcrop is similar to that in the type section. Fossils additional to those from the type section are *Lingula*, nautiloids and trilobites. Several thin tuffs are present.

The most widespread sub-unit is sub-unit 3 which forms the bulk of the Blue Range and extends south to the Burdekin River. It is gradational with sub-unit 2 or overlies sub-unit 1 as in the bulk of Blue Range. Unlike the type section, where pebbles are rare, conglomerates are common as are pebbly sandstones. Bedding is thick to very thick. The pebbles are dominantly quartz with variable amounts of red chert (jasper), black chert, orange chert, green chert, white chert, quartzite,metamorphic, and arenite; some of the clasts are quartz veined. Cross-bedding is common with a variety of types: large and medium-scale trough and large and medium-scale planar. This sub-unit appears to be conformable with sub-unit 1 where it overlies it. Sub-unit 4 has a restricted areal distribution being restricted to the area adjacent to the type section and the area just north of the Ruxton mine. It interfingers with sub-unit 3, the nature of the interfingering being best observed around the type section. The type section is representative of the lithologies observed. Tuffs are present.

The type section area and small areas around the Ruxton mine represent the extent of sub-unit 5, with sub-unit 6 being similarly restricted.

Discussion

Edwards (1977) interpreted the Ruxton Formation as having been deposited in a deltaic setting 'in which swiftly flowing, predominantly braided streams transporting coarse mature sediments prograded rapidly but intermittently out into a shallow, gradually transgressing sea'. He proposed two provenances; one to the north west and one to the south. The current study has provided support, in general, for his interpretation, although some of the detail needs to be modified.

Unit 1 in this study does not include the labile sediments which have been described above as 'unnamed unit'. The dominantly quartzose sandstone over much of the area was deposited in a braided fluvial environment as shown by trough cross-stratification and *Leptophloeum* remains. A marine influence is apparent in the south east where rare brachiopods are present. Palaeocurrent data are sparse but suggest major flow from the northwest but with some tidal influence (bipolar directions). Where unit 2 overlies unit 1, the basal sandstone represents a fluvial to transgressive shoreline sequence. The presence of *Skolithos*-like burrows at one locality indicates littoral conditions.

Unit 2 has many characteristics of muddy shelf deposits with the many sandstone beds with their upper flow regime character reminiscent of storm deposits. Several aspects, however, suggest a near shore environment. Plant material and marine faunas are intermixed even on individual bedding planes. Although *Leptophloeum* obviously floated well, the large quantity of plant litter suggests proximity to source. The presence of *Lingula* points to at least some deposition in intertidal to lagoonal environments. The common and diverse marine fauna indicates access to normal marine conditions. On the other hand, the fauna is dominated by small forms which indicated a stressful environment. The overall setting would appear to be nearshore to estuarine with the thin to medium-bedded sandstones representing flood events which carried both sand and plant remains. Sparse palaeocurrent data suggest the sediment was derived from the west to north west. In the type section area these conditions were stable for a long time with 100 m or so of interbedded mudstone and sandstone.

In the upper part of unit 2 the sequence coarsens and thickens upwards. The sandstones have low-angle cross-stratification and contain pebble bands. Marine faunas are lacking with only plant fragments present. Unit 3 consists of quartzose sandstone and conglomerate. Low-angle trough cross-stratification is present. An easterly direction of transport is indicated. The lack of fine sediment and lack of marine fossils indicate a braided stream environment.

A possible explanation for the deposition of units 2 and 3 is the presence of a large braidplain to the north west discharging into a shallow sea in the south east. The braidplain was very stable for a long time as shown by the high maturity of the sediments. Regular flooding swept fine sediment and plant debris into the shallow sea, such regular flooding causing distress to the marine fauna. Unit 3 was deposited when the braidplain advanced towards the south east becoming a braid plain delta (Nemec & Steel, 1988; McPherson & others, 1988) influenced by tidal movements.

The sharp break in the type section between units 3 and 4 is suggestive of delta abandonment and the onset of a major transgression. Laterally fluvial processes were continuing. The extent of the transgression represented by unit 4 is unknown due to the nature of the outcrop. Unit 4 has many characteristics in common with unit 2 and has an even more dwarfed fauna indicating unfavourable conditions. A muddy nearshore environment is likewise indicated. Unit 5 has a sharp contact with unit 4, the contact probably representing a disconformity. The very coarse grain size (up to boulder) and lack of marine indicators suggests an alluvial fan or braid fan resulting from renewed uplift to the north west.

Unit 6 fines upwards from boulder conglomerate to mudstone. As well as the grainsize variation there is a distinctive vertical change in sedimentary structures. Towards the base, the sandstones have parting and streaming lineation and current aligned plant fragments. Low-angle cross-lamination and water escape structures occur next. Megaripples, hummocky cross-stratification and feeding traces occur next with pebbles no longer present. Marine fossils appear at this level. The sequence becomes progressively muddier with a diverse, unstressed fauna and bioturbation. This sequence represents a transgression over the alluvial fan and the formation of a muddy shelf. The transgressive sequence has many indicators of wave reworking. The transgressive profile presented here is very similar to one described by Maejima (1988) in the Cretaceous of Japan.

Age

The Ruxton Formation has a diverse marine fauna which has not been studied in detail. Woods (1960,unpublished) identified a fauna from the Francis Creek area and suggested a Tournaisian age. Edwards (1977) described the marine fauna in an unpublished thesis; this thesis was the basis for the Tournaisian age for the unit given by Wyatt & Jell (1980). Edwards (1977) identified two faunas for which he proposed a range of earliest to late middle Tournaisian based on the scheme of Roberts (1975). Conodonts have been recovered from near the base of the unit in the south western area of outcrop. A latest Devonian to earliest Carboniferous age is indicated for the conodont fauna (B. Fordham, personal communication). The Ruxton Formation has a probable age range of latest Famennian to late Tournaisian.

Correlation - Ruxton and Venetia Formations

The Ruxton and Venetia Formations have a very similar age range and are obviously lateral equivalents although different depositional systems are represented. However, a broad correlation can be made. Both units have a basal conglomerate and sandstone unit although the Ruxton has a more mature basal unit. Marine units above the basal unit in both formations contain conodonts which indicate a latest Famennian to early Tournaisian age. Although marine deposition then ceased in the Venetia Formation, the overall sequences can be compared. One possible sequence boundary is present in the upper part of each formation. In the Venetia Formation, the coarse braided stream deposits immediately overlie air fall tuffs suggesting a tectonic event. In the Ruxton Formation, the conglomeratic unit 5 immediately overlies muddy shelf deposits, suggesting a tectonically influenced fan advance. No tuffs are observed, but the outcrop is poor and tuffs may have been reworked in the marine environment.

Between the conodont level and the possible sequence boundary, each formation has a three fold sub-division which is basically a coarse unit separating finer units. The coarser units may be either tectonically or eustatically controlled and are suggested as broad correlatives.

LYALL FORMATION

Introduction

The Lyall Formation (Scott & Withnall, 1987) contains two members, the Furry Hoop Member and the Meath Member. The Lyall Formation crops out in the central and western parts of the Clarke River Basin. It is obscured by Tertiary laterite to the north and by Cainozoic basalt to the south east. Significant outliers occur east and south of Niall homestead. The Furry Hoop Member crops out poorly and is covered by a veneer of alluvium over much of the area. It is best exposed in the centre of the Clarke River Basin in a domal structure in the area of Keppel Creek South and extending northeast for about 12 km. The Meath Rhyolite Member forms distinct ridges in the middle of the Lyall Formation. It crops out in the Keppel Creek South area and in windows in the laterite to the north. Ignimbrite and tuff

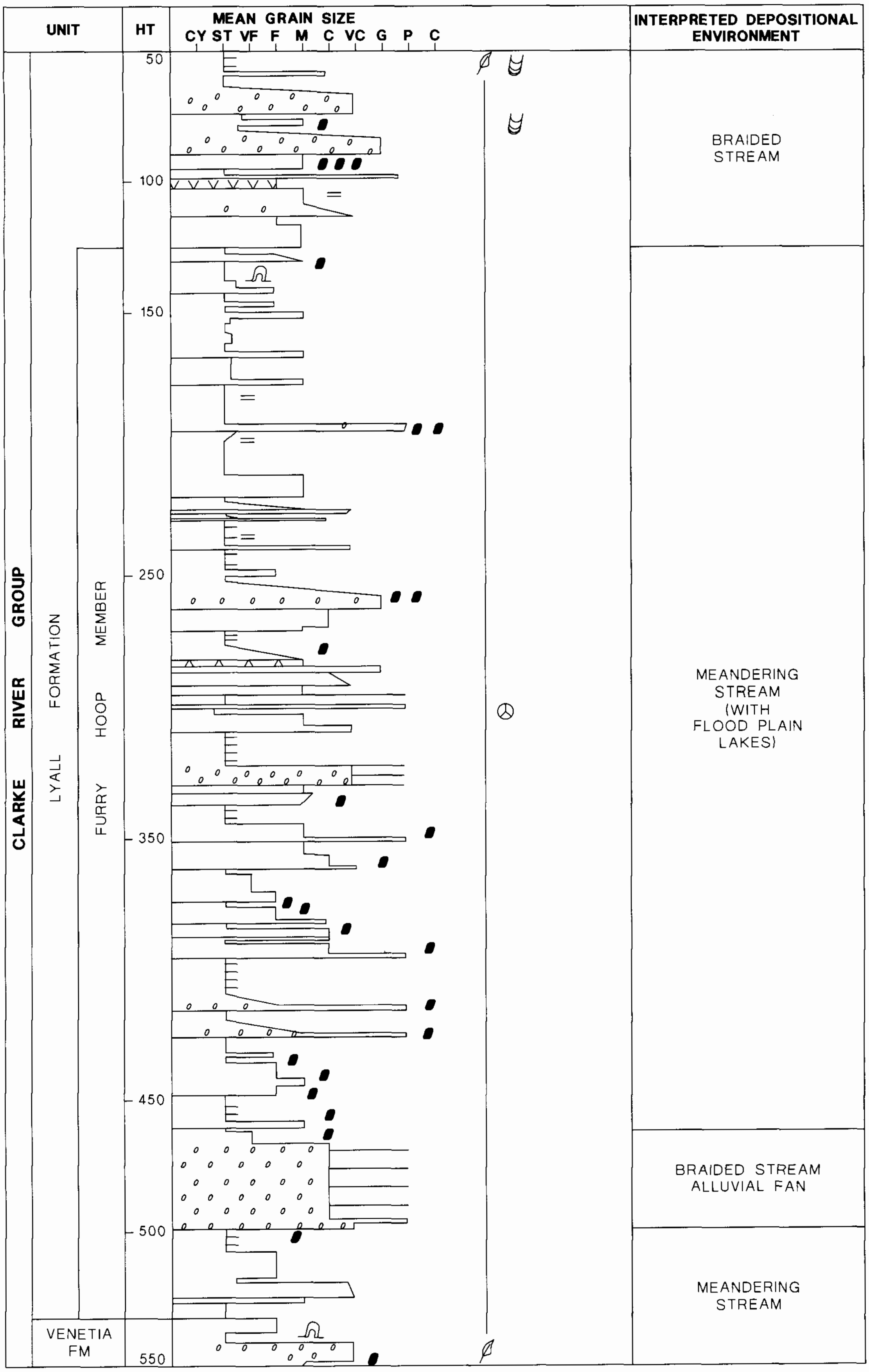


Figure 67. Generalised section through the Furry Hoop Member of the Lyall Formation in GSQ Clarke River 5. See Figure 14 for reference.

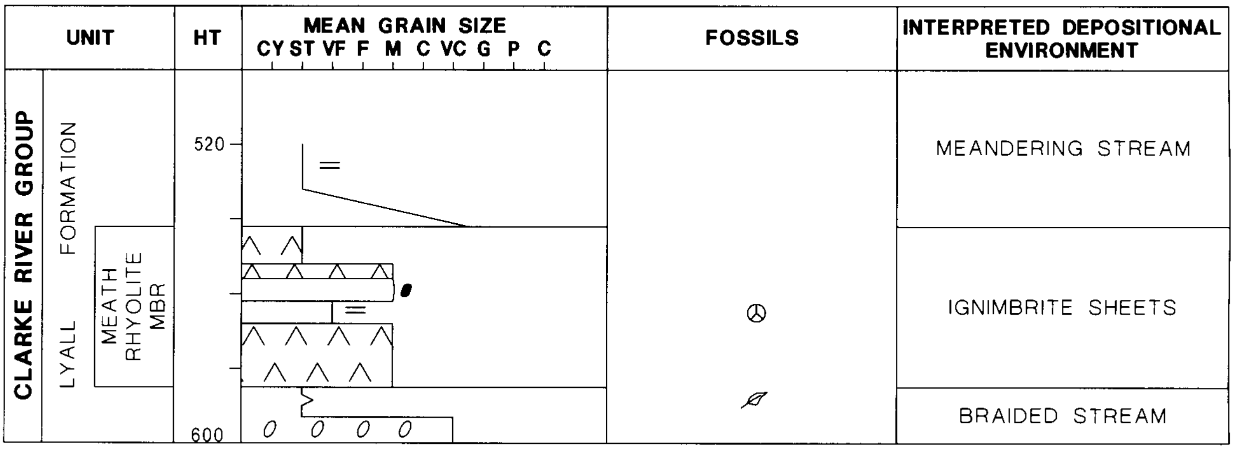


Figure 68. Generalised section through the Meath Rhyolite Member of the Lyall Formation in GSQ Clarke River 3/4R. See Figure 14 for reference.

in the west of the basin near the Broken River are also assigned to this member.

Type section

A composite type section was erected for the Lyall Formation (Scott & Withnall, 1987). The 'lower' Lyall Formation is represented in the section from 7959-961517 (top of Venetia Formation) to 949515 (base of Meath Rhyolite Member); the type section of the Furry Hoop Member is part of this section from 960516 (base) to 946505 (top). The Meath Rhyolite Member type section occurs along the Clarke River from 948504 (base) to 946505 (top). The 'upper' Lyall Formation section is in a tributary of Keppel Creek South and extends from 944568 (top of Meath Rhyolite Member) to 930550 (synclinal hinge).

Reference sections for the Lyall Formation have been erected in GSQ Clarke River 3/4R and 5. The 'lower' Lyall Formation was intersected in GSQ Clarke River 5 between 0 and 533.45 m with the Furry Hoop Member intersected between 125 m and 533.45 m. GSQ Clarke River 3/4R intersected 'upper' Lyall Formation from surface to 542.07 m and the Meath Rhyolite Member from 542.07 m to 584.75 m. From 584.75 m to 649.48 m (TD), the top of the 'lower' Lyall Formation was intersected.

Lithology and sequence

The 'lower' Lyall Formation consists largely of volcanolithic sandstone (sporadically pebbly), pebble to boulder conglomerate, red-green siltstone, fine-grained sandstone and tuff.

The vertical sequence of lithologies is best displayed in the stratigraphic bores. In GSQ Clarke River 5, the **Furry Hoop Member** (Figure 67) is probably in faulted contact with the Venetia Formation. The interval 499.46 m to 533.45 m contains fine and very coarse sandstone interbedded with siltstone and silty sandstone. From 466.87 m to 499.46 m, interbedded pebbly sandstone and conglomerate with maximum grain size of cobbles are present. The conglomerate is mainly grain supported with clasts of quartzite and metamorphics.

Overlying the conglomerate interval is a 341.87 m (125 m to 466.87 m) sequence which forms the bulk of the Furry Hoop Member. This interval contains volcaniclastic sandstone, and pebbly sandstone interbedded with siltstone and silty sandstone. The sandstones occur as thick to very thick beds with pebble and mud clast lag deposits. Occasional pebble beds occur within the sandstones which are cemented by calcite. The micaceous siltstones are purple to mottled green/purple in colour. Calcite nodules to 50 mm are common. Between 280 m and 285 m two beds of tuff are present.

In outcrop, similar lithologies are preserved and, in addition, lenses and thin beds of fine-grained limestone are present. Sedimentary structures include lamination in the siltstones and cross-stratification in the sandstone.

Rocks from the **'lower' Lyall Formation** above the Furry Hoop Member were partly intersected in GSQ Clarke River 5 (Figure 67) from 0 to 125 m. Coarse-grained volcanilithic sandstone and pebble conglomerates are dominant with minor siltstone and sandy siltstone. The uppermost part of the 'lower' Lyall Formation was intersected in GSQ Clarke River 3/4R from 584.75 m to 649.48 m (TD). The sequence consists of pebbly sandstone, medium-grained sandstone and minor siltstone. It is overlain by the Meath Rhyolite Member. Palaeocurrents from the top of the lower unit indicate transport towards the south west.

In the outliers near Niall homestead the 'lower' Lyall Formation comprises very thick, massive conglomerate, volcanilithic sandstone and very thick, massive siltstone. The sandstones are massive or horizontally stratified (marked by pebble bands) and have small-scale trough and medium-scale planar cross beds.

The **Meath Rhyolite Member** consists of several sheets of brown-pink-orange ignimbrite which contains pumice fragments and crudely aligned fiamme. Euhedral biotite and embayed beta-quartz are characteristic. A chemical analysis from the type section (Marlow, 1979) plots in the rhyolite field. Volcanilithic sandstone, siltstone and minor conglomerate are interbedded within the ignimbrite. In GSQ Clarke River 3/4R the Meath Rhyolite Member was intersected between 542.07 m and 584.75 m and consists of two ignimbrite sheets separated by medium-grained sandstone and siltstone.

In the Clarke River 6-7 km east of Craigie Outstation are several rhyolite bodies that possibly correlate with the Meath Rhyolite Member (Withnall & others, 1988b). At one locality, breccia consisting of angular to subrounded blocks of ignimbrite in a black vitric matrix unconformably overlying the Judea Formation (Plate 34b) is overlain by pebble to boulder conglomerate with a very coarse-grained volcanilithic matrix. At another locality, a 4-5 m thick ignimbrite sheet similar to the Meath Rhyolite Member is associated with a breccia to rounded cobble conglomerate (Plate 34c). The ignimbrite is overlain by 'upper' Lyall Formation. A unit of crystal-rich ignimbrite, rhyolitic breccia, tuff, and volcanic arenite up to 200 m thick extends north across the Broken River.

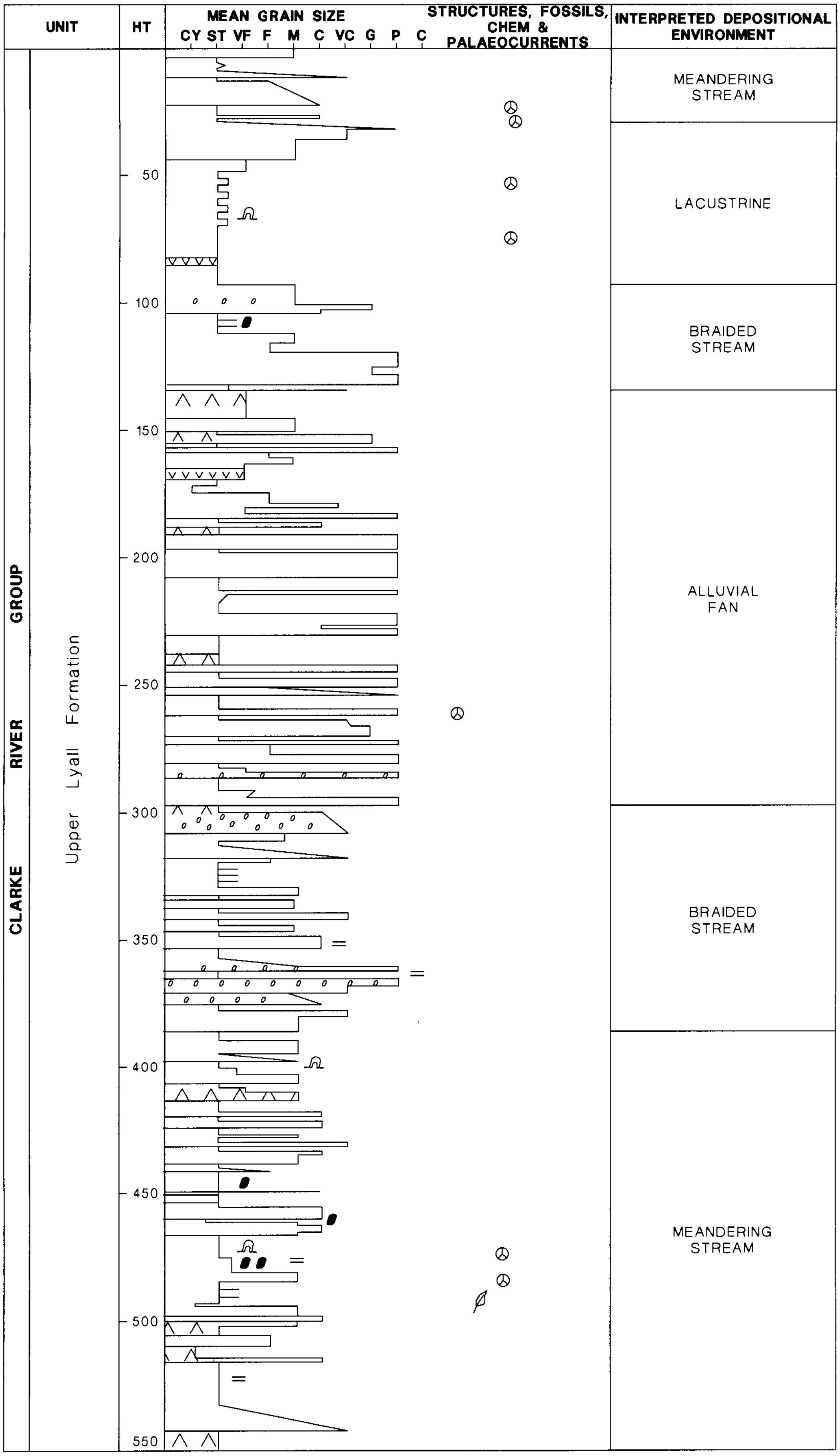


Figure 69. Generalised section through the upper part of the Lyall Formation in GSQ Clarke River 3/4R. See Figure 14 for reference.

The **'upper' Lyall Formation** has a basal sequence of calcareous siltstone, tuffaceous sandstone and sporadic impure limestone, overlain by coarse volcanilithic sandstone and boulder to cobble conglomerate.

The section in GSQ Clarke River 3/4R represents the most complete section of the 'upper' Lyall Formation (Figure 69), and five packages of sediment are recognised. From 385 m to 542.07 m, medium to coarse-grained sandstone with occasional pebbles and mud clasts are separated by siltstone and siltstone with sandstone interbeds and tuff beds. Calcareous nodules are present in the siltstone as well as irregular calcareous patches. The siltstone beds are laminated and contain soft sediment deformation. The thickness of the finer interbeds decreases upwards.

From 296 m to 385 m sandstone grain size is more variable and pebbles are more common. Siltstone is less common and tuffs are absent except at the very top. Calcareous nodules are still present. The overlying interval (93 m to 296 m) is dominated by conglomerate which is up to boulder in size. Beds are thick to very thick and show great variation in grain size. Clasts include jasper, rhyolite, and metamorphics. Interbedded siltstone contains calcareous nodules. Tuff beds are present.

Overlying the conglomeratic interval is a coarsening upwards sequence (from 30 m to 93 m) with siltstone passing upwards into interbedded sandstone and siltstone to silty sandstone and then pebbly sandstone. The remainder of the unit comprises fining upward sandstone and conglomerate with minor siltstone. The top of the unit is erosional.

Discussion

The total absence of marine fossils and the widespread presence of plant remains indicate an entirely terrestrial setting for deposition of the Lyall Formation. The extent of the original depositional basin is difficult to ascertain.

The **Furry Hoop Member** is predominantly of meandering stream origin. The sandstone and pebbly sandstones representing the channel facies often fine upwards and have gravel and mud clast lags. Generally, channels occur isolated from one another although multi-storied sands (stacked channels) are present. The fine-grained overbank deposits are of variable thickness and become thicker and more persistent in the upper part of the member. The siltstones are characteristically purple to purple and green mottled and contain variable sized calcareous nodules. In outcrop they appear to be typical 'redbeds'. The presence of red beds containing calcareous nodules suggests the development of soils in a semi-arid environment (Collinson, 1978). Limestones are very fine-grained and are probably of algal origin and deposited in flood plain lakes. The thick pebbly sequence near the base of the member is interpreted as a braided stream deposit because of the coarse grain size and the lack of overbank deposits. This may represent the progradation of alluvial fans into the area.

The remainder of the **'lower' Lyall Formation** was deposited in similar environments. The sequence in the Niall area is very gravelly and was deposited in braided streams possibly closely associated with alluvial fans.

The **Meath Rhyolite Member** consists of two ignimbrite sheets separated by fluvial sediments. Below the Meath Rhyolite Member, tuffs are present but not common. Above the member, tuffs are much more common so that the member represents a change in the volcanic environment. The source of the rhyolite may have been a number of rhyolite domes preserved in the area. The Meath Rhyolite equivalents in the Clarke River near Craigie outstation have been interpreted as vent collapse features with associated breccia pipes (Withnall & others, 1988b).

Rhyolite is widespread throughout the region, and the Meath Rhyolite Member may correlate with the Oweenee Rhyolite. Rhyolite intruding the Ruxton Formation is probably the same age, likewise the tuffs near Mount Dudley. However the Hells Gate Rhyolite in the Sybil Graben is probably younger because it post-dates the Malmesbury Microgranite. The Harry Creek Formation (Lang, this volume) is also a possible correlative. The onset of rhyolite extrusion and intrusion is associated with a major regional extensional event.

The **'upper Lyall Formation'** still has elements of red bed formation with calcareous nodules representing soil development in semi arid conditions.The lower part with its high proportion of siltstone to sandstone was deposited in a meandering stream system. The proportion of overbank sediments decreases upwards and with the variation in sand size indicates a change to braided stream conditions. The conglomerate sequence above this is probably of alluvial fan origin based on the very coarse poorly sorted nature of the sediments. Overlying the fan sequence is an upward coarsening sequence interpreted as a lacustrine sequence. The lake was infilled by the advance of a meandering steam system. The Lyall Formation comprises fluvial systems ranging from alluvial fan to lacustrine with tuffs scattered throughout.

Age

The age of the Lyall Formation is based on miospores recovered from GSQ Clarke River 5 (Playford, 1988) and outcrop (Playford, 1983, 1986, 1988). In the stratigraphic bore no palynomorphs were recovered from the Furry Hoop Member and a sample from the 'lower' Lyall Formation contained a scant palynoflora which was probably representative of the Visean *Anapiculatisporis largus* assemblage (Visean).The 'upper' Lyall Formation produced stratigraphically useful assemblages; these were clearly part of the *A. largus* Assemblage and in particular of the younger representation of that assemblage and hence of late Visean age. This last age matches that obtained by Playford (1986) for a sample now known to be from near the base of the 'upper' Lyall Formation. The latest Carboniferous - earliest Permian age reported by Jell & Playford (1985) and discussed briefly in Playford (1988) came from rocks now assigned to the Wade beds. The late Carboniferous to early Permian plant bearing rocks (White, 1965; Rigby, 1973) are also part of the Wade beds.

Given the thickness of sediment in the Lyall Formation, the 'lower' Lyall Formation may be of early Visean age although further work is required to refine the age further.

WADE BEDS

Introduction

Two areas of Late Carboniferous to Early Permian sedimentary rocks have been identified overlying the Clarke River Group. These were originally included in the Clarke River Group (Scott & Withnall, 1987) which was assigned an age ranging from latest Devonian to latest Carboniferous. Subsequent palynological studies (Playford, 1988) and additional field mapping have shown that a separate unit can be recognised overlying the Clarke River Group.

This informal unit ('Wade beds') crops out in two areas (Figure 63). The first area is in the vicinity of Cattle Creek and Back Creek in the south east corner of BURGES and the northeast corner of WANDO VALE. It is mainly exposed in the beds of creeks and in washouts and, away from the creeks, is obscured by laterite. The only massive outcrop is in the vicinity of the fault marking the northern limit of outcrop (Figure 63). The second area (23 km^2) of outcrop is adjacent to the upper reaches of Keppel Creek (north) on CLARKE RIVER. Outcrop is reasonable but, as with the first area, laterite obscures much of the unit. Outcrop is in creek beds and as dip slopes on hillsides. It is possible that small areas of the unit are present beneath laterite plateaux. The nature of the outcrop and the gentle folding has resulted in limited continuous outcrop so that meaningful sections are not available. Bores drilled for uranium exploration did intersect the unit in its northern outcrop area.

Lithology

In the **Cattle Creek area**, the unit comprises sublabile to labile sandstone, siltstone, carbonaceous mudstone, conglomerate. The sandstones vary in grainsize from very fine to coarse with sorting varying from poor to good; some of the sandstones are pebbly. Many of the sandstones are thick to very thickly bedded although thinner beds are present. The major sandstone bodies are massive or horizontal flat-laminated. Lamination is commonly outlined by fine carbonaceous matter. Cross-bedding types include large-scale low-angle trough, medium-scale trough, medium-scale planar, small-scale planar, and ripple cross-lamination. Sedimentary structures include convolute lamination, load casts, drag marks, and current lineation. Ripple trains occur on bedding surfaces and different types merge into one another on the same surface with linguoid, sinuous and straight crested types all present. In addition, symmetrical, slightly wavy bifurcating ripplemarks are present (wavelength 125 mm, amplitude 10-20 mm). Large rip up clasts are present. Palaeocurrents measured on cross beds indicate flow towards the east northeast (Figure 64).

Conglomerate is restricted to the Back Creek area where it appears to form the base of the unit. They are very similar to conglomerates in the Clarke River Group. The poorly sorted conglomerates are labile and range in size from granule to pebble. Clasts are quartz, rhyolite, quartz feldspar porphyry, metasediments, jasper and granite. They are very thickly bedded with medium and large-scale trough cross-stratification and minor medium-scale planar cross-bedding. Cross-stratification is marked by grainsize differentiation.Siltstone ranges from thin to very thickly bedded and is massive except for some lamination. It is micaceous. Plant remains are present as fine fragments, indeterminate stems and fragments, and well preserved leaf impressions including *Pseudorhacopteris*.Mudstone is carbonaceous and very thickly bedded with internal lamination. plant fragments and coalified wood are common. The overall sequence would appear to comprise a basal conglomerate overlain by sandstone beds interbedded with siltstone and mudstone. In small cliff sections it is possible to recognise upward fining sequences the sandstone to siltstone to carbonaceous mudstone.

In the **Keppel Creek area** the rock types are similar to those in the Cattle Creek area and are dominantly sandstone with lesser conglomerate, siltstone and mudstone. Sandstone is fine to very coarse-grained with coarse-grained sandstone most common. The sandstone are labile and contain both rhyolite and potassium feldspar grains. Bedding is medium to very thick and generally massive with rare flat lamination, marked by fine carbonaceous matter. Cross-lamination consists of low-angle trough, medium and large-scale trough, medium-scale planar, and ripple cross-lamination. Sedimentary structures include current lineation, streaming lineation, parting lineation, adhesion ripples, flasers, convolute lamination, megaripples, and sinuous asymmetric ripplemarks. Palaeocurrents were from the north- northeast (Figure 64).

Conglomerate is pebble sized and crudely stratified with low-angle trough cross-beds. Clasts are dominantly rhyolite and quartz with minor granite and metasediments.Siltstone is micaceous and thin to very thickly bedded. Internally the siltstones are massive or laminated. Ripple cross-lamination is present. Plant remains range from fine fragments to striated stems and other coarse fragments. Rootlets are present.Mudstone is carbonaceous, medium to thickly bedded, and either laminated or massive. Beds are up to 8 m thick. Plant remains are coalified including fronds of *Pseudorhacopteris* and striated stems. Rootlets are present.

The Wade beds were intersected in two uranium exploration wells drilled by AFMECO (Beams & others, 1976). No cores were cut and the lithological logs were prepared from cuttings. Gamma logs were run. In CR17, the interval from 3 m to 43 m is attributed to the Wade beds, and in CR18 the interval 5 m to 89 m is assigned to the Wade beds giving a maximum thickness of 84 m. In both wells there is a shift in the gamma baseline value and the unit contains no volcanic rocks. The basal rocks are conglomerate and sandstone. The sandstones in the unit are more arkosic than those in the Lyall Formation. The Wade beds unconformably overlie the Lyall Formation or are in faulted contact with it. The contact is difficult to determine in some areas because of similarities in composition between the Wade beds and the Lyall Formation. The Wade beds dip shallowly and commonly often contain visible K feldspar. The Wade beds are folded into very open synclines and anticlines with gentle dips. Faulting which postdated deposition is normal with near vertical faults trending NW-SE. This faulting is best displayed at 910510 where a rhyolite dome has been truncated.

Discussion

The Wade beds are entirely non-marine with plant remains being the sole fossils. Overall the sequence consists of interbedded sandstone, siltstone and mudstone. A fining sequence can be recognised with sandstones passing up into siltstone and then carbonaceous mudstone. In AFMECO CR18, several upward coarsening profiles suggest lacustrine deposits. The high proportion of fine-grained sediment and the fining patterns suggest deposition in a meandering stream system. The well-preserved plant remains and coaly beds attest to a humid climate. This contrasts sharply with the early Carboniferous Clarke River Group in which the overbank deposits are mainly red beds signifying more arid conditions. The palaeocurrents and probable depositional environment indicate that deposition was widespread and not confined to small basins. The Wade beds are of similar age to sediments in the Galilee Basin (Playford, 1988). Rocks of the same age were identified from stratigraphic boreholes in the Hughenden 1:250 000 Sheet area (McKellar, 1977), in GSQ Charters Towers 1 (McKellar, 1980) and in the Marshs Creek beds in the Sybil Graben (J. Rigby and J. McKellar, personal communication, 1990). These later occurrences are of fluvial and fluvio-lacustrine rocks.

Age

The flora from Cattle Creek was first described by White (*in* White, 1965) who suggested a lower Carboniferous age. The flora was reassessed by Rigby (1973) who proposed a Late Carboniferous age on the basis of the *Pseudorhacopteris* Flora which is now considered to range into the Early Permian. Palynological studies have been carried out on cuttings from AFMECO CR17 and CR18 in the Keppel Creek area by Playford (*in* Jell & Playford, 1985) who recognised an assemblage which was 'latest Carboniferous or possibly earliest Permian in age'. Several of

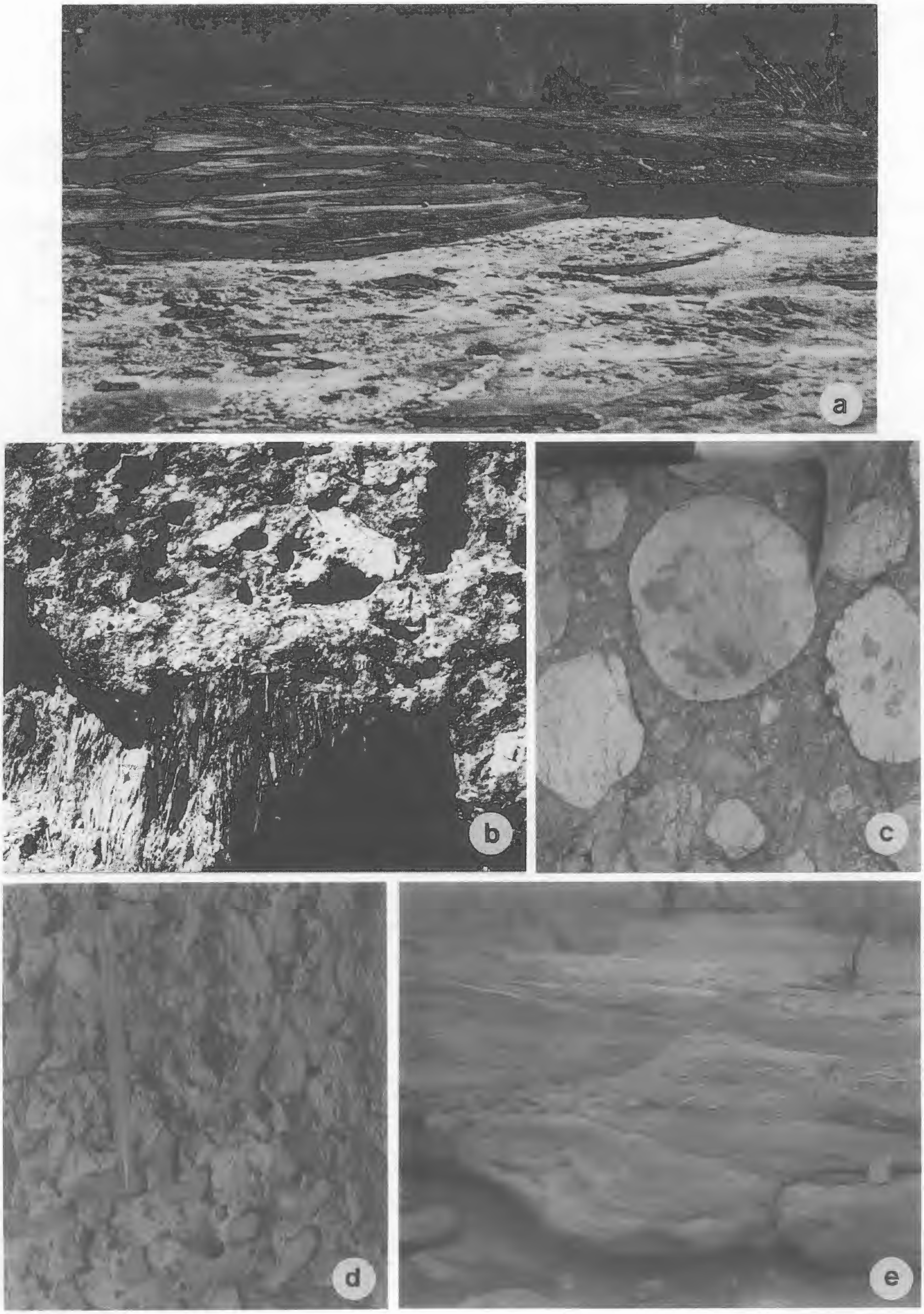


Plate 34. Clarke River Group.

Playford's samples came from below the Wade beds and appear to contain cavings.

OWEENEE RHYOLITE

Introduction

The Oweenee Rhyolite (Scott, 1988b) crops out southwest of the Sybil Graben, from near Spring Park homestead in the south for about 24 km north. It is exposed in an area of about 260 km^2.

The rocks were previously mapped in the Oweenee Granite by White (1959) and Wyatt & others (1976), but subsequent mapping indicated that much of the unit, including the nominated type area, is thick, welded and recrystallised ignimbrite (Scott, 1988b).

The type area for the Oweenee Granite nominated by White (1959) was "along the telephone line, 14 miles (23 km) south of Blue Range Station, in Stenhouse Gap". White's type area stands as the type area for the Oweenee Rhyolite. Three reference sections were given (Scott, 1988b): on the western slopes for Mount Mackay (7959-380545 to 389542); along the Kidston powerline (at 8059-449650, where the basal part of the unit is exposed); and along Gowrie Creek (8059-438589 to 425612).

Lithology and petrography

The Oweenee Rhyolite is mainly recrystallised, pink to grey, crystal-rich rhyolitic ignimbrite (30-35% crystals). The crystals, mainly quartz and feldspar, are 1 to 5 mm in size. Rare quartz clasts reach 7 mm. Biotite and possibly hornblende can be identified in hand specimen. The groundmass is completely recrystallised, or nearly so, destroying what is considered to have been an ignimbritic texture. The groundmass consists of microcrystalline intergrowths of quartz and feldspar. Rare fiamme can be identified in outcrop. Alteration of feldspar crystals is generally minimal.

Mafic minerals generally comprise 3-5% of the ignimbrite and include primary biotite and locally hornblende, with secondary biotite, epidote, and chlorite.

Biotite is present in most specimens and is commonly altered to chlorite. The extent of this alteration ranges from complete pseudomorphs to selective interlaying by chlorite epidote. Fine (<0.1 mm) chlorite is also intimately intergrown with elongate quartz (<0.1 mm). This assemblage forms at the expense of groundmass as fringes to mafic grains.

Hornblende, like biotite, may remain relatively unaltered or may be chloritised to varying degrees. In some samples uralitisation of hornblende is extensive and is associated with iron-staining and opaque clusters. Such alteration assemblages may be rimmed either by secondary biotite or hornblende. These later secondary mafic rims have a patchy appearance as a result of their intimate intergrowths with the matrix. Other alteration assemblages include clusters of secondary biotite flakes with feldspar, and clusters of chlorite and epidote. These assemblages, although totally replacing the primary mafic minerals, have mimicked their form, suggesting that hornblende was the original mineral.

More mafic ignimbrites contain up to 10% mafic materials which, in addition to hornblende and biotite, include various proportions of augite and hypersthene in different degrees of preservation. Some pyroxenes are completely altered to uralite. However, unaltered cores of augite are common, and are fringed by uralite which is, in turn, surrounded by platy hornblende. Hornblende is also found scattered throughout the matrix as isolated crystals and as small crystals. Hypersthene is commonly totally uralitised but rare unaltered cores are present; the grains have an outer reaction rim of small platy brown-green hornblende commonly intergrown with the groundmass and identical to that associated with augite.

Less recrystallised, crystal-rich, grey-pink ignimbrites has been identified in Sandy Creek, Snake Creek and north of the Silver Spray mine. Crystals constitute 30-35% of the rock and include quartz, feldspar, biotite and hornblende, and together with rare lithic fragments are set in a groundmass of devitrified shards. Along the Kidston powerline at 8059-449650, at the base of the unit, fiamme up to 10 cm long and eutaxitic textures are well preserved. Alteration is restricted to some chlorite-epidote replacement of biotite and limited sericitic replacement of feldspar.

Relationships and age

The Oweenee Rhyolite overlies the Lyall Formation (interpreted to be 'lower Lyall Formation') and is intruded by Malmesbury Microgranite.

The age of the Oweenee Rhyolite is not known precisely. However, the Oweenee Rhyolite may be co-magmatic with the Malmesbury Microgranite for which Webb (1969) suggested a middle Carboniferous age (342 ± 7 Ma) on the basis of a Rb/Sr isochron derived using samples from several different plutons. This age would be consistent with a correlation of the Oweenee Rhyolite with the Meath Rhyolite Member and/or other tuffs in the Lyall Formation.

MALMESBURY MICROGRANITE

Introduction

The Malmesbury Microgranite (Scott, 1988b) is a porphyritic microgranite which crops out directly to the southwest of the Sybil Graben for about 20 km from Gin Mill to the Daintree mine. It covers an area of about 280 km^2. These rocks were previously named Oweenee Granite (White, 1959; Wyatt & others, 1970). A 9.5 km section along the Gregory Developmental Road between 8059-542602 and 528618 is designated as the type area of the Malmesbury Microgranite.

PLATE 34:

a. **Fine-grained calcareous sandstone showing low-angle trough cross-bedding. The sandstone contains sporadic crinoid ossicles. Lower (marine) part of the Venetia Formation in Gill Creek.**

b. **Unconformity between Judea Formation(?) and a breccia consisting of large angular blocks of aphyric rhyolite and devitrified glass in a volcaniclastic matrix. The breccia is interpreted as a lahar infilling a palaeovalley. Lyall Formation. 7858-759364, in the Clarke River, about 6.5 km east of Craigie Outstation.**

c. **Conglomerate containing well-rounded, almost spherical pebbles and cobbles of rhyolitic ignimbrite in a very coarse-grained volcaniclastic matrix. The high sphericity may be due to milling of the clasts in the volcanic breccia which underlies the bed. Lyall Formation. Lyall Formation. 7858-764364, about 7 km east of Craigie Outstation.**

d. **Calcareous nodules in siltstone. Lyall Formation.**

e. **Chanelled very coarse-grained volcaniclastic sandstone and conglomerate. Lyall Formation.**

Lithology and petrography

The Malmesbury Microgranite is typically pale pink to greyish-pink. Large phenocrysts (2-5 cm long) of albite-rimmed K-feldspar (rapakivi texture) and sericitised plagioclase are set in a microgranite groundmass. K-feldspar is dominant (ratio 2-3:1).

Phenocrysts of quartz, commonly with irregular, embayed margins, occur locally. There are also small areas of graphic intergrowth between quartz and feldspar phenocrysts. Biotite, rare hornblende, and accessory zircon and apatite are also present. In the area around the Silver Spray mine the microgranite is slightly more plagioclase-rich, with K-feldspar and plagioclase being in roughly equal proportions.

K-feldspar is replaced by albite which occurs as rims around phenocrysts (rapakivi texture), or as small clusters of albite crystals within the groundmass (eg. porphyritic microgranite east of Daintree mine).

The Malmesbury Microgranite shows variation in the degree of alteration and in the dominance of specific alteration assemblages. Sericite is present in all of the plagioclase alteration assemblages. In addition, some plagioclase is extensively replaced by chlorite and epidote (for example, granite west of Silver Spray mine). Fine, granular prehnite chlorite clots epidote locally occur in crystal margins. The cores of such grains may be unaltered, or replaced by zeolite. Calcite accompanies extensive sericitic alteration in the Daintree mine area.

Biotite and hornblende are generally at least partly altered. Biotite is generally partly replaced by epidote chlorite. Hornblende is iron-stained and associated with iron-oxide clusters. In other specimens, mafic minerals are totally altered to chlorite epidote fine secondary biotite.

Relationships and age

The Malmesbury Microgranite intrudes the Oweenee Rhyolite and in the east is intruded by several unnamed granite and microgranite phases. A major rhyolite dyke swarm intrudes the Malmesbury Microgranite and is parallel to the faulted contact between the microgranite and the Late Carboniferous Sybil Group.

An Rb/Sr isochron of 342±7 Ma was obtained by Webb (1969) from samples of the Oweenee Granite as mapped by Wyatt & others (1970). Some of these samples come from the area north of the Sybil Graben from what have since been mapped as various different Carboniferous plutons. The age is therefore suspect as rocks from several different plutons have been used to construct the isochron. Despite this, the 342 Ma age fits in well with the suggestions that the Oweenee Rhyolite is co-magmatic with the Malmesbury Microgranite and that it may be equivalent of the Meath Rhyolite Member of the Clarke River Group.

UNNAMED INTRUSIONS

Granodiorite

Between the Ruxton Tin Mine and the Burdekin River about Cleanskin Creek is a weathered granodiorite body exposed over an area of 30 km^2. Several roof pendants of Ruxton Formation are present, as are minor silcrete and basalt cappings.

The granodiorite is medium-grained, rarely coarse-grained, and equigranular. It is normally green grey in colour with minor pinkish rocks possibly representing more granitic phases. Minerals present include quartz, plagioclase, potassium feldspar and altered ferromagnesium minerals. Biotite is sporadically present. The main alteration mineral is epidote. Small, fine-grained, mafic xenoliths are present in places.

The granodiorite is undeformed except near the southwest contact where it is foliated or possibly sheared. The foliation strikes at 60° and dips at 80° to the north. The granodiorite intruded the Ruxton Formation without any obvious contact metamorphism. Contacts are intrusive except on the western side where the granodiorite is in faulted contact with the Ruxton Formation and the Kangaroo Hills Formation. It is cut by rhyolite dykes.

Rhyolite

In and adjacent to the Blue Range area are a number of rhyolite and porphyry plugs and dykes. The rhyolites vary from fine-grained and aphanitic to porphyritic with very coarse-grained phenocrysts. They are generally cream to lime green, but occasionally have weathered to an orange colour. The main megascopic minerals are quartz and potassium feldspar with minor ferromagnesium minerals. Chlorite is present as an alteration mineral. Quartz veining is associated with the rhyolite. Flow bands and small spherulites are present.

The porphyries are dominantly quartz-K-feldspar porphyries with minor quartz porphyry. Both occur as large intrusions and dykes. Bipyramidal quartz is common. About 3 km northeast of the Ruxton Tin Mine, the quartz porphyry contains calcite crystals and sulphides (including pyrite and ?arsenopyrite). The rhyolites and porphyries intrude the Kangaroo Hills Formation, Ruxton Formation and the unnamed granodiorite.

Relationships and age

Both the rhyolites and the granodiorite postdate the Ruxton Formation which is of Early Carboniferous (Tournaisian) age. An upper age for the intrusives cannot be determined by superposition as the only overlying rocks are of Tertiary age. The relationship between the granodiorites and the rhyolites is unclear although rhyolite dykes do cut the granodiorite. The lack of metamorphism suggest that the granodiorite is a high level intrusive.

A possible age can be obtained by examining probable correlatives. Elsewhere in the Clarke River Basin the Visean Lyall Formation contains the ignimbritic Meath Rhyolite Member, numerous dykes and sills, and many tuffs. Rhyolite domes are common in the main basinal area and, in the Blue Range area, there is a dome at Mount Dudley and many of the larger rhyolite intrusions may also be unroofed domes. At Mount Dudley the dome is associated with rhyolitic ignimbrites. Therefore, a Visean age is likely for the intrusives in the Blue Range area. These rocks may correlate with the Oweenee Rhyolite and the Malmesbury Microgranite which have been dated (see above) as 342±7 Ma which is Visean.

Alternatively the rhyolite intrusions may be related to the Hells Gate Rhyolite in the Sybil Graben (Gunther & others, in preparation). The rhyolite intrusives can be traced to the margins of the Sybil Graben and the ignimbrites at Mount Dudley are reminiscent of those in the Hells Gate Rhyolite. The Hells Gate Rhyolite is faulted against the Malmesbury Microgranite and shows no contact metamorphism. It could be Late Carboniferous in age. The Marsh's Creek Formation which overlies the Hells Gate Rhyolite is a similar age to the Wade beds, that is, earliest Permian (J. McKellar, personal communication, 1990).

STRUCTURE

Basement to the Clarke River Basin and its associated rocks is the suite of rocks making up the Camel Creek

Subprovince. The mainly flyschoid rocks of the Camel Creek Subprovince were deposited from late Ordovician to early Devonian. Of the two deformations which affected the Camel Creek Subprovince, the first (D_1), the result of thrusting of the craton over the Camel Creek Subprovince along the Burdekin and Gray Creek Faults, may have been responsible for the widespread melange. A second period of folding (D_2) resulted in the development of a large orocline in the southern part of the Subprovince with a northeast trending axial plane (Withnall & Lang, 1990). D_1 is tentatively assigned an Early Devonian age and D_2 a Frasnian age based on events in the adjacent Graveyard Creek Subprovince; alternate ages are possible, but must lie between Early Devonian and latest Devonian (see Withnall, this volume).

Following the D_2 deformation, the unnamed unit in the Blue Range was deposited. The Clarke River Group overlies this unit unconformably. The original areal extent of the unit is unknown but must have been reasonably extensive as shown by numerous small outliers. The remnants of the basin are now grouped along the major fault directions, namely northeast and north.

The Clarke River Group is only weakly deformed; dips are mostly less than 20°. Exceptions are in the central northern part of the main outcrop area (dips up to 45° are recorded within laterite windows) and in the outliers in Gray Creek area (dips up to 70°) where they are folded with northeast to north-northeast axial planes. Tight folding with overturning is also evident in the southwest of the basin and steep dips occur along the western faulted margin. Dalgarno (1977) suggested that folding in the central northern area was active during deposition of the Lyall Formation and resulted in "thinning and wedging out of certain bands towards the anticlinal zones and the accumulation of some vastly thickened sequences (Meath Rhyolite Member) within the synclinal zones".

Two roughly circular domal structures are developed northwest of the Clarke River Flexure. The easternmost contains Venetia Formation in its core and the second contains the lower part of the Lyall Formation and is termed the 'Keppel Creek South Dome'.

Faulting in the Clarke River Basin is mainly vertical. Folding of faulted basement has also resulted in flexuring in the basin. An example is the 'Clarke River Flexure', which formed near the south-eastern margin of the basin and has a northeasterly trend. This monocline passes along strike into a fault and is the result of reversal of a pre-existing normal fault. The Clarke River Flexure may have been active during deposition of the lower Lyall Formation. Dalgarno (1977) pointed out that conglomerate beds which are common near the Flexure decrease in size and wedge out markedly to the north and west.

In the Blue Range area, structural trends are complicated by the intrusions. The folds in the northwest are gentle with the steep dips in the southeast associated with faulting. The faulted anticlines and synclines are aligned northeast-southwest. Other minor faults trend north-south or northwest-southeast.

In general, the trends of structures within the Clarke River Basin may be largely controlled by the configuration of the basement rocks as indicated by the development of monoclines in response to reversal of basement faulting and the general northeast to north-northeast trends in the alignment of structures.

The western edge of the main outcrop area appears to be fault-bounded, possibly along, or near, a southward extension of the Gray Creek Fault. The northern edge may also be partly fault bounded, as are some of the small outliers in the Gray Creek area.

At the southwestern corner of the basin near Craigie Outstation, the depositional edge of the basin was probably fault-controlled prior to the eruption of the Meath Rhyolite Member. This fault appears to have become inactive before the eruption; to the south of the fault, the rhyolite is underlain unconformably by Ordovician Judea Formation, whereas to the north, more than 1 000 m of Venetia Formation and lower Lyall Formation underlies it. The Meath Rhyolite Member is not displaced by the fault.

The Oweenee Rhyolite, forming the eastern limit for the main outcrop of Clarke River Group, is a strongly jointed unit. Most joint orientations are northwest and northeast. South of the Daintree mine eutaxitic layering, destroyed in most other placed by recrystallisation, indicates a local dip of 8° southwest. Along the Kidston power line dips of 15° south-southeast are indicated by large fiamme.

The main deformation in the basin affects the Lyall Formation and is therefore clearly post-Visean. The overlying Wade beds are only very gently folded and, therefore, the main folding must be Carboniferous. The Wade beds have been faulted subsequent to minor folding; the faulting and folding predate the Tertiary basalts and laterites, and are most likely of Permian age.

GEOLOGICAL HISTORY

Subsequent to the development of the orocline in the southern Camel Creek Subprovince, possibly in the Frasnian, there was a brief period in which localised deposition of valley fill sediments occurred, probably in the Frasnian or Famennian.

In the late Famennian the Clarke River Basin was initiated by an extensional event, caused either by dextral movement on the Clarke River Fault or regional arching, resulting in widespread braidplain and alluvial fan deposition. This was followed in the latest Famennian by an extensive transgression which is recorded in the Burdekin Basin, Clarke River Basin and the Graveyard Creek Subprovince. In the Blue Range area the distribution of these transgressive marine rocks appears to be controlled by the underlying structure.

In the main area of the Clarke River Basin, deposition in the Venetia Formation was entirely non-marine after the subsequent regression with sediments being derived predominantly from the southeast. Changes in style of deposition and the presence of tuffs indicate continuing tectonism. In the Ruxton Formation transgressive and regressive cycles continued with the major source of the sediment being from the northwest. Minor tuffs were deposited. A break in the upper part of both units probably represents tectonism with reactivation of normal faults resulting in renewed alluvial fan activity.

There is a break of indeterminate length between the deposition of the Venetia Formation in the Tournaisian and the Lyall Formation in the Visean. The latter formation is entirely non-marine and has a different distribution to the Venetia Formation, suggesting a different basin setting. Sediment was sourced from the northeast. The style of sedimentation is indicative of a graben-like setting. Volcanism was very active with major eruptions (Meath Rhyolite Member and Oweenee Rhyolite) and significant high level intrusion.

Following a period of folding and further rhyolitic volcanism in the Carboniferous, the Wade beds were deposited in an entirely terrestrial setting and may even represent outliers of the Galilee Basin to the southwest. The Wade beds were gently folded and faulted, probably in the Permian. The youngest rocks in the area are of Tertiary age and comprise basalts, sediments, silcretes and laterites (see Grimes, this volume).

DEVONIAN OUTLIERS

(I.W. Withnall)

Small outliers of Early Devonian rocks rest unconformably on the Georgetown Province in the Blue Rock Creek and Conjuboy areas (Figure 70). They are the Blue Rock Creek beds described by Arnold & Henderson (1976) and the Conjuboy Formation (Withnall, 1989b). In the Ewan area to the east, rocks of Early or Middle Devonian age overlie the Lolworth-Ravenswood Province close to the boundary with the Camel Creek Subprovince (Withnall, 1990). Outliers of probable Late Devonian rocks also overlie the Georgetown Province (Withnall, 1989b).

BLUE ROCK CREEK BEDS

The Blue Rock Creek beds (Figure 71), which were first described and defined by Arnold & Henderson (1976), occur in a small strip 3 km long by 0.5 km wide, 13 km west of Wairuna homestead. They consist of micaceous and feldspathic sandstone, red and grey mudstone, and minor conglomerate, which crop out poorly, and surround discontinuous, ridge-forming limestone outcrops. The limestone is massive, coarsely recrystallised, and somewhat silty with interbeds of calcirudite and calcareous shale.

A thin basal conglomerate overlies amphibolite and mica schist of the Halls Reward Metamorphics to the east. The Blue Rock Creek beds are faulted against the metamorphic basement to the west. Arnold & Henderson (1976) described a strong slaty cleavage and recognised some tight mesoscopic folds, but details of the structure are not known. Bedding dips both east and west, although younging and vergence relationships are consistent with an overall westward younging. The maximum preserved thickness is 500 m assuming minimal repetition by folding and faulting.

While mapping in CASHMERE, L.J. Hutton (GSQ) located two smaller, probable fault-bounded areas of limestone, respectively 5 and 10 km farther east. An area of hornfelsed rocks, including marble, about 40 km to the north-northeast, near the junction of Cameron Creek and the Herbert River, may also be equivalent to the Blue Rock Creek beds. White (1962a) originally assigned these rocks to the Mount Garnet Formation, which was a unit in the Hodgkinson Province, but is now disused (Bultitude & others, 1987). The rocks may be correlatives of either the Chillagoe or Hodgkinson Formations. The area is about 5 km long and 3 km wide, and is faulted against Halls Reward Metamorphics to the west; to the east the rocks are overlain by Cainozoic sediments and basalt, but are probably intruded by Carboniferous granite beneath this cover. Hutton (in Withnall & others, 1985) described massive, thick-bedded arenite, siltstone, shale, and minor conglomerate, some of which contains cobbles and boulders of limestone (now calc-silicate hornfels).

The Blue Rock Creek beds are probably Early Devonian. Corals identified by Professor D. Hill and Dr J.S. Jell (quoted in Arnold & Henderson, 1976) included *Pseudoplasmopora, Favosites, Hattonia?, Dictyofavosites?,* and a ptenophyllid and cystiphyllid; the fauna was regarded as probably Early Devonian or possibly Late Silurian. A specimen of *Pseudamplexus* was collected by the author in 1985, and together with a poorly preserved conodont fauna (B.G. Fordham, personal communication, 1989), supports an Early Devonian age.

CONJUBOY FORMATION

The Conjuboy Formation crops out within the area of the Georgetown Province, about 30 km west of the Burdekin Fault. It was first described and defined by Withnall (1989b) and also briefly by Withnall & others (1991). The unit crops out as a narrow, northeast-trending belt about 9 km long. It ranges from 1.5 km wide at its northern extent, along Eight Mile Creek near Conjuboy homestead, to about 200 m in the south, along Oaky Creek. A much smaller, roughly rectangular area, about 0.1 km^2, occurs about 2 km northeast of the Balcooma base metal prospect. The rocks are well exposed in and adjacent to Oaky Creek, but farther north the rocks are deeply weathered and crop out only sporadically where creeks cut across the belt.

The type section is from the unconformity with the underlying Einasleigh Metamorphics at 7860-556241, along a gully to its junction with Oaky Creek at 555242 (top of the lower sandstone-dominated sequence), and thence downstream through the upper shale/limestone sequence to 561253 where the rocks are in fault contact with the Einasleigh Metamorphics. The formation is about 150 m thick in the type section, and could be up to 800 m in the north, although outcrop is poor there and little is known about the structure.

In the Oaky Creek area (Figure 72), the lower part of the sequence consists of about 70 m of thick to very thick-bedded, commonly trough cross-bedded, medium to very coarse-grained, quartzose sandstone. The sandstone is moderately well sorted, is commonly micaceous, and contains sparse feldspar. Grains are subangular. The environment of deposition was fluviatile or shallow marine. The upper part of the sequence is poorly exposed, but is predominantly calcareous mudstone or shale. Sporadic outcrops of bioclastic limestone (calcarenite to calcirudite) occur in the Oaky Creek area in lenses up to a few tens of metres long. Large heads of tabulate and colonial rugose corals such as *Heliolites, Thamnopora Endophyllum,* and *Phillipsastrea* occur in the mudstone, which also locally contains a rich fauna of solitary rugose corals. Minor brachiopods and trilobites also occur.

Creeks to the north expose mainly quartzose sandstone similar to that described above. Limestone crops out in a few places, for example, in Eight Mile Creek at 600317 adjacent to the western faulted margin, where a thick-bedded calcirudite contains well-rounded limestone pebbles and cobbles (commonly coral heads).

In the area near the Balcooma prospect, a similar fauna to that in Oaky Creek occurs in limestone floaters in the soil and a creek bed. The enclosing rocks are not exposed, although minor quartz sandstone crops out elsewhere in the block. The Conjuboy Formation in the Oaky Creek area dips about 30° northeast. No folds have been recognised in the unit. Along its eastern margin it unconformably overlies the Balcooma Metavolcanics and Einasleigh Metamorphics in the Balcooma Mylonite Zone. The western margin against the Einasleigh Metamorphics is a fault. At its northern end the Tertiary-Quaternary McBride Basalt overlies the formation. The smaller area is probably entirely fault bounded against Ringwood Park Microgranite and Balcooma Metavolcanics, and is overlain by Carboniferous Bally Knob Volcanics.

The rich coral fauna has not yet been studied in detail, but contains the main elements of the *Phillipsastrea* fauna or lower fauna of the Chinaman Creek Limestone of the Broken River Group (Wyatt & Jell, 1967; Withnall & others, 1988b), which is Emsian to Eifelian. A conodont fauna obtained from a limestone sample from the Conjuboy Formation is from the Emsian *serotinus* zone (J.S. Jell, personal communication, 1984).

LATE DEVONIAN OUTLIERS ON THE GEORGETOWN PROVINCE

Sporadic, partly fault-bounded occurrences of sedimentary rocks of probable Late Devonian to Carboniferous age have been found in the southeastern Georgetown Province (Figure 70). They were previously described by Withnall (1989b). The largest is in the Maitland Creek area in LYNDHURST but smaller areas occur along Nine Mile Creek, and in the headwaters of Spring Creek in CONJUBOY, and along the Burdekin Fault in VALLEY OF LAGOONS and CASHMERE.

Maitland Creek area

Sedimentary rocks are exposed in an area midway between The Lynd and Lyndhurst homesteads, along and to the west of the Hann Highway. Just east of the highway, the rocks rest nonconformably on the McKinnons Creek Granite and Dido Tonalite. Quaternary basalt and alluvium obscures the sedimentary rocks between Maitland Creek and the Einasleigh River, but they crop out for 2 km west of the river where they are down-faulted against the Einasleigh Metamorphics. The total area of sedimentary rocks is about 80 km^2, but at least half of this is obscured

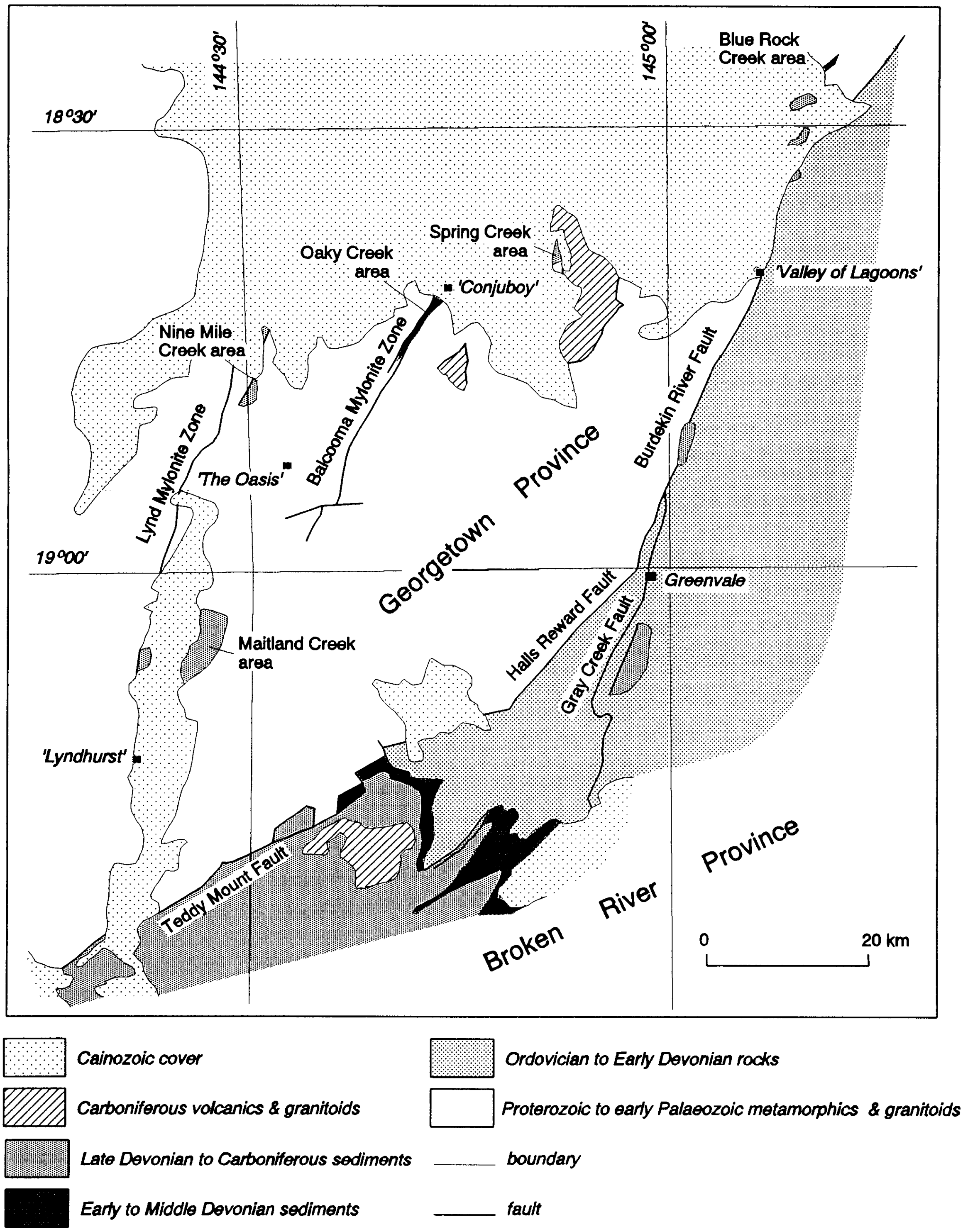


Figure 70. Distribution of Devonian outliers in the Einasleigh and Clarke River Sheet areas.

by the Quaternary cover. The rocks were mapped as Cretaceous Gilbert River Formation by White (1962a). Geologists from Urangesellschaft Australia Pty Ltd (UGA) first recognised that they were of Palaeozoic age and explored them for uranium (Osbourne & Pyke, 1979; Osbourne, 1980).

The total thickness is uncertain but is probably of the order of 1 000 m. The basal part of the sequence near the Hann Highway consists of pale grey, very thick-bedded, very coarse-grained, pebbly, feldspathic sandstone and polymictic cobble conglomerate. In the basal conglomerate, cobbles are well-rounded quartzite, granite, hornfelsed shale, gneiss, pegmatite, rhyolite, and quartz, but about 100 m above the base, red jasper and reddish brown quartzose arenite become the dominant clasts. This suggests a provenance from the Judea and/or Wairuna Formations in the Broken River Province, similar to that in the Stopem Blockem Conglomerate Member of the Bulgeri Formation in the Bundock Creek Group. The sandstones have abundant, medium to large-scale cross-bedding.

About 150 m from the base, medium-bedded, grey, red, and green, mottled mudstone typical of the Bulgeri Formation is interbedded with drab (grey) sandstone and pebble to cobble conglomerate containing arenite, jasper, quartzite, quartz, and granite clasts. Between this point and Black Rock, 500 m above the base, sporadic, medium to very thick-bedded, medium to very coarse-grained, pale greenish grey to reddish grey sandstone and greyish red mudstone crop out. Black Rock (the local name for a prominent bluff at 7759-332885, Plate 31c), consists of medium to thick-bedded, coarse to very coarse-grained, feldspathic sandstone. The sandstone is micaceous and is moderately well sorted, with local pebbly and cobbly bands containing quartz, black siltstone, quartzose arenite, mica schist, gneiss, amphibolite, and quartzite (Plate 31d). Medium to large-scale cross-bedding is common. Palaeocurrents, indicated by cross-bedding between the base and Black Rock, are to the north-northwest (60 readings). This is consistent with palaeocurrents in the Bulgeri Formation, and with the provenance indicated by the jasper and arenite clasts. The sequence above Black Rock was not studied. However, the work by UGA, including drilling, indicated a similar range of rock types throughout the area (Osbourne & Pyke, 1979).

Dips are generally shallow. The rocks dip about 30° west between the road and Black Rock, but westwards, dips decrease to about 10°. West of the Einasleigh River, dips of 75° east were recorded against the western margin, which is interpreted as a fault.

Nine Mile Creek area

Similar rocks crop out in a small (4 km^2), poorly exposed, partly fault-bounded block 10 km north-northwest of 'The Oasis' in the headwaters of Nine Mile Creek. Conglomerate is not as common as in the Maitland Creek area. The sandstones are generally red to purple, coarse to very coarse-grained, and medium to thick-bedded. They are well sorted and consist mostly of granite-derived material (probably from the McKinnons Creek Granite). They are interbedded with red to purple mudstone containing carbonate nodules. The sandstones are also commonly cemented by calcite. A few palaeocurrent directions were measured, which point to the northeast. The rocks are gently dipping, generally 20° to 30° north-northeast.

Another small area occurs about 6 km downstream along Nine Mile Creek to the north-northeast. The rocks are poorly exposed and overlain by Cainozoic superficial deposits, so their full extent is unknown.

Spring Creek area

In the headwaters of Spring Creek, about 12 km north of Wyandotte homestead, gently dipping, medium to thick-bedded, coarse to very coarse-grained, micaceous quartzose to feldspathic sandstone unconformably overlies mica schist. The sandstone crops out in a narrow valley incised in Cainozoic basalt, so its full extent is also unknown.

Burdekin Fault

Outcrops of gently dipping sedimentary rocks have been observed at several places along or adjacent to the Burdekin Fault. One area is about 6 km northeast of Lucky Downs homestead, and consists of gently dipping, coarse-grained quartzose to feldspathic sandstone in a narrow belt 6 km long and 1 km wide. The sandstones are thick to very thick bedded and cross-stratified.

Farther north, about 10 to 15 km north of Valley of Lagoons homestead, a small area of thick-bedded, medium to very coarse-grained quartzose arenite, mudstone, and some volcanolithic arenite and tuff(?) straddles the Burdekin Fault. The rocks are more steeply dipping than the rocks in the other areas, but are not as deformed as the adjacent Wairuna Formation. The steep dips could be due to proximity to faults. The rocks are overlain by alluvium and Cainozoic basalt, and are probably more extensive to the west and north under this cover. They could be continuous with similar rocks, farther north in the southern part of CASHMERE, briefly described by Hutton *in* Withnall & others (1985, page 77).

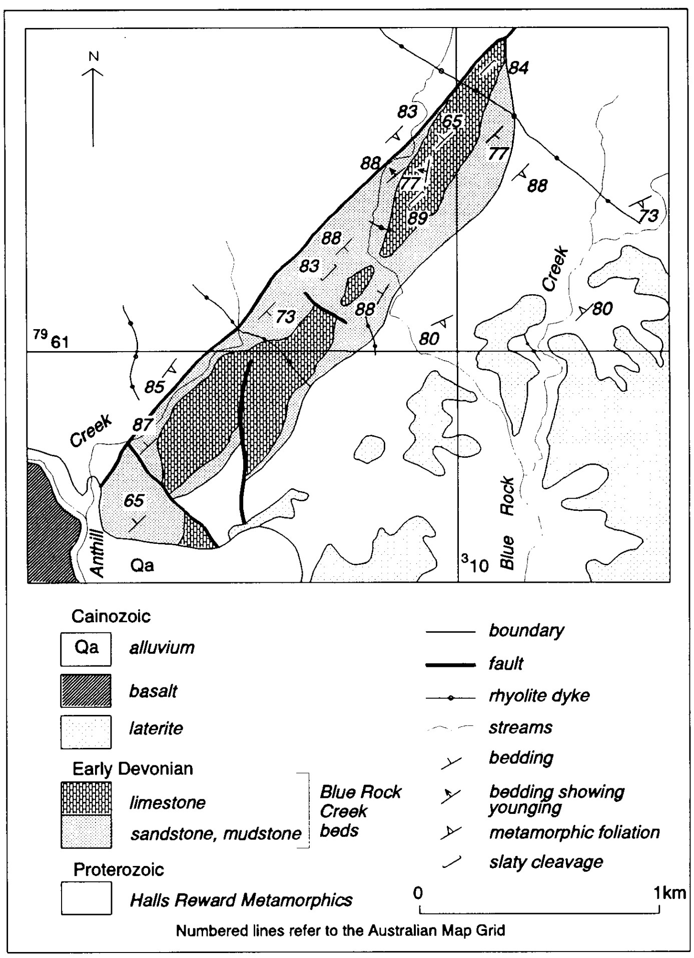


Figure 71. Geology of the Blue Rock area (after Arnold & Henderson, 1976).

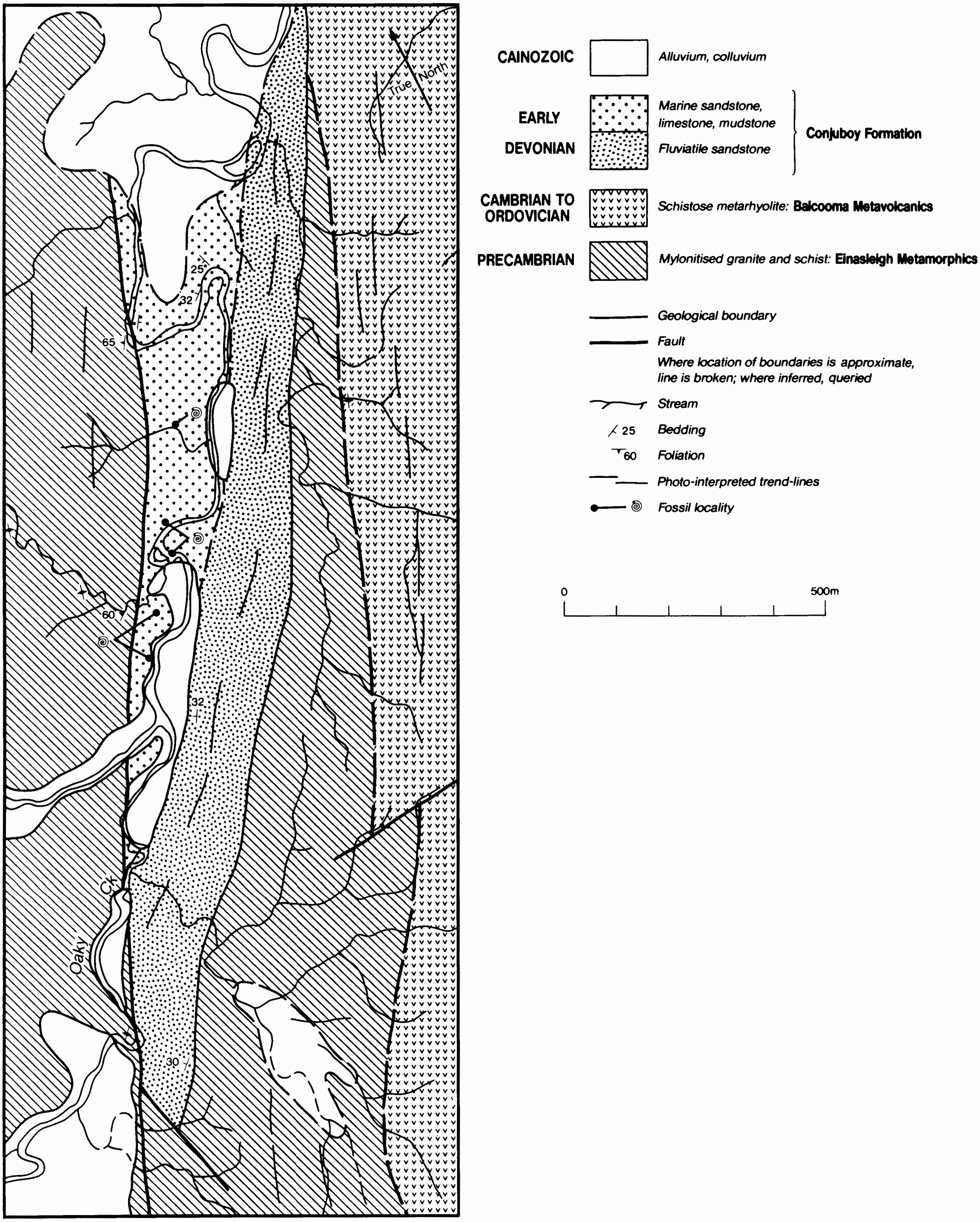


Figure 72. Geology of the Conjuboy Formation in the Oaky Creek area.

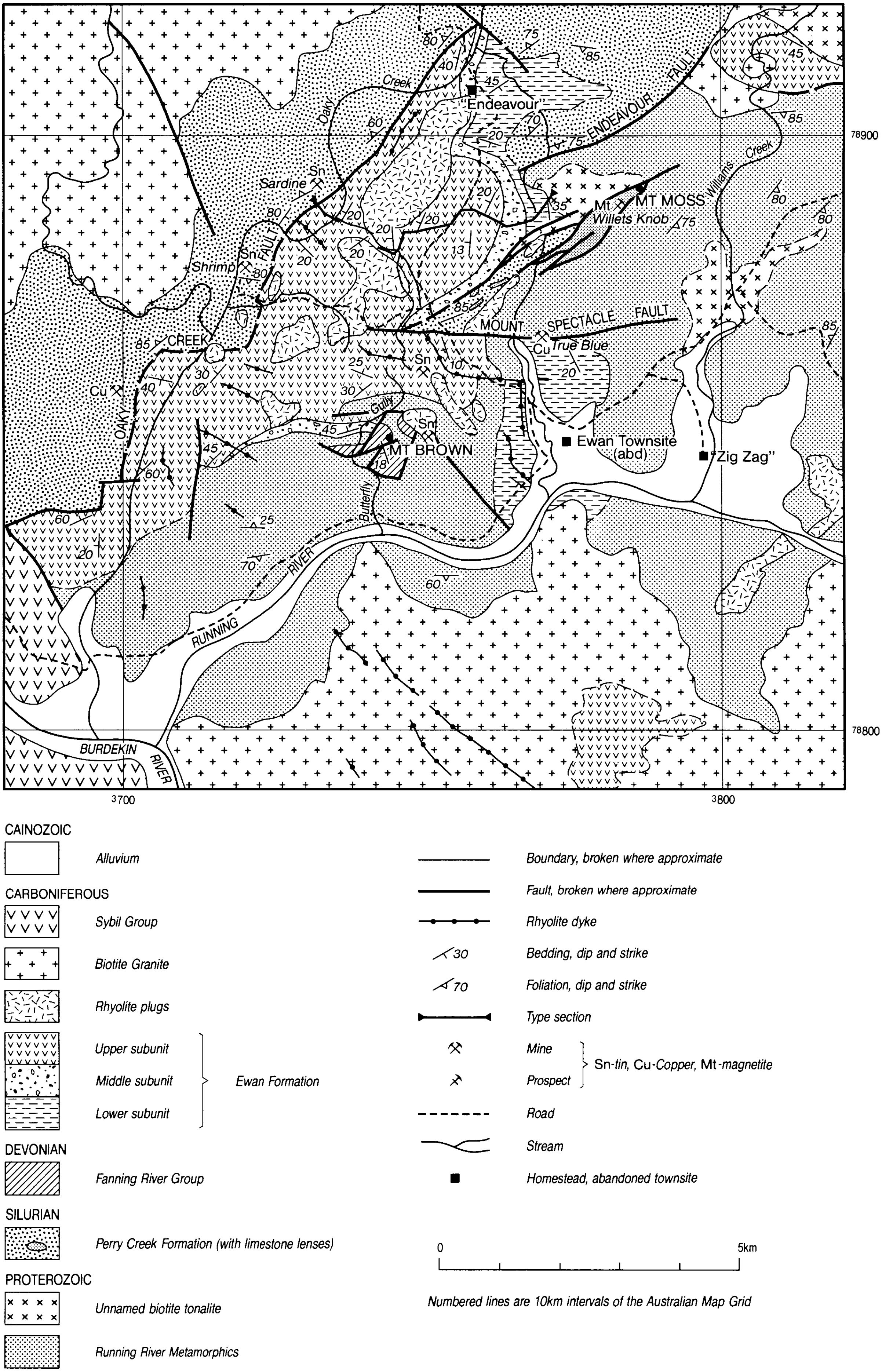


Figure 73. Geology of the Ewan area.

Relationships and age

The sedimentary rocks unconformably overlie the Proterozoic metamorphic rocks and Silurian-Devonian granitoids. They are overlain mainly by Cainozoic basalt and superficial deposits. They do not underlie the Carboniferous Bally Knob Volcanics, suggesting that deposition was localised or that erosion removed them before the volcanism.

No fossils have been found in the rocks. However, the presence of redbeds and northerly directed palaeocurrents in the Maitland Creek area suggests that these rocks are related to the Late Devonian Bulgeri Formation in the Bundock Basin. The Bulgeri Formation was deposited in a system of braided rivers which drained dominantly northwards. The sediment was derived from uplifted terrain to the south and southeast, including the Wairuna and Judea Formations. Withnall & others (1988b) suggested that the Bundock Basin may have been a sediment trap transverse to the main drainage direction. Likewise, the Maitland Creek area may have been a smaller trap, perhaps controlled by localised movement on or adjacent to the Lynd Mylonite Zone.

As suggested by Marsden (1972), it is likely that a Devonian-Carboniferous basin stretched across the whole area at least as far west as Gilberton in the central part of the Georgetown Province. Bain & others (1985) showed that largely fluviatile sedimentary rocks (assigned to the Gilberton Formation) are widespread over the Georgetown Inlier, preserved in small fault blocks or beneath Carboniferous ignimbrites. They include redbeds, and palynological data suggest ages ranging from Famennian to Visean (Jell & Playford, 1985). Field evidence from the Gilberton area indicates sediment transport from the southwest and northwest (Withnall & others, 1980b). The rocks are likely to be remnants of a large fluviatile system which may have connected with the systems draining north from the Broken River Province in the Famennian (Lang & Fielding, 1990), and later towards it.

EWAN AREA

Wyatt & others (1970) gave the name Ewan beds to unmetamorphosed sediments and volcanics in the Ewan area, and he regarded them as being of Silurian age on the basis of *Halysites* found in limestone in the area. Lemmon (1968) studied the southeastern part of the area between Ewan and Mount Brown, and recognised two somewhat different sequences in the western and eastern halves of his study area. Arnold & Henderson (1976) briefly examined the Ewan beds and concluded that they included three or four sedimentary suites juxtaposed by faults. Initial reconnaissance mapping and whole rock geochemistry during our study highlighted the presence of calc-alkaline basalt, andesite, and dacitic ignimbrite within the sequence. Because of the presence of these volcanics and the reported Silurian age, Withnall & others (1987) suggested that the Ewan beds may have represented a volcanic arc and that the Camel Creek Subprovince to the west was a backarc basin. These tectonic implications led to the area being mapped in more detail (Figure 73; Withnall, 1990). This work largely substantiated the conclusion of Arnold & Henderson, and indicated that the volcanic rocks do not represent a Silurian volcanic arc.

Withnall (1990) recognised that Wyatt & others (1970) included a large area of Perry Creek Formation in the Ewan beds. These are faulted against the ?Proterozoic Running River Metamorphics, along a possible extension of the Clarke River Fault. The Running River Metamorphics are mylonitised along the fault. About 1.5 km south of the fault and parallel to it, a belt of sheared limestone, mudstone, arenite, chert, and melange, up to 500 m wide, extends for about 5 km southwest from Mount Moss. The limestone is partly converted to skarn and marble around Willetts Knob. However, an outcrop of sheared limestone on the Ewan-Endeavour road at 8059-755867 is probably where the *Halysites* reported by Wyatt & others (1970) and Bush (1960) was found (Arnold & Henderson, 1976, quoting a personal communication by D.H. Wyatt). The belt is interpreted as a series of fault slices bounded mainly by Running River Metamorphics and partly by the Ewan Formation proper. In a gully at 766881, alternating slices of Perry Creek Formation melange and sheared granitoid or migmatite about 10 to 20 m wide crop out.

At Mount Brown, a sequence of very micaceous, quartzose sandstone is interbedded with limestone. The rocks mostly dip moderately shallowly to the south or southwest. They partly rest unconformably on the Running River Metamorphics, but are probably mainly faulted against them. The sandstone, which crops out poorly, is very thick bedded, coarse to very coarse-grained, and massive except for pebbly stringers. Pebbles are mainly subangular to subrounded quartz, quartzite, mica schist, and rare pegmatite. The sandstone is less than 20 m thick and is overlain by about 60 m of limestone with some interbeds of sandstone. The limestone is dark grey, thin to very thick-bedded and commonly very fine-grained. Some beds are almost completely silicified. Metasomatic replacement has resulted in the formation of magnetite bodies adjacent to the limestone lenses, but no intense skarn is developed. The limestone locally contains abundant stromatoporoids, particularly *Amphipora*, and also less common favositids and rare rugose corals. Detrital muscovite and quartz grains are common in some outcrops.

The presence of *Amphipora* in the limestone at Mount Brown suggests an Early to Middle Devonian age for this sequence. *Amphipora* is abundant in the Middle Devonian limestones of the Broken River Group as well as the Burdekin Limestone. Fossils collected by Lemmon (1968) were identified by Professor Dorothy Hill as *?Barrandeolites* and indeterminate favositids. Arnold & Henderson (1976) suggested a Silurian-Devonian age. Limestone samples collected in 1986 and 1987 contain fragments of simple cone conodonts consistent with a Silurian or Devonian age (B.G. Fordham, personal communication, 1990).

On the basis of this rather scanty palaeontological evidence, as well as lithological grounds, the rocks at Mount Brown can be equated with the Fanning River Group of the Burdekin Basin. The lowermost sandstone may correlate with the Big Bend Arkose, and the limestone with the Burdekin Limestone. Both of these units crop out at Mount Podge, about 20 km to the southeast.

The remainder of the Ewan beds was given formal status and redefined as the Ewan Formation by Withnall (1990). It consists of basaltic to andesitic lava and volcaniclastic rocks, polymictic conglomerate, dacitic tuff (including ignimbrite), volcanic arenite and siltstone. The rocks generally have only shallow to moderate dips, and straddle the bounding fault between the Perry Creek Formation and Running River Metamorphics. They both unconformably overlie and are faulted against these units. They are probably in fault contact with the Devonian rocks. An Early Carboniferous age is now considered likely for these rocks because of similarities to the Tareela Volcanics 25 km to the southeast.

The deposition of the Ewan Formation was possibly synchronous with the terminal stages of deposition of the Bundock Creek and Clarke River Groups (the Harry Creek and Lyall Formations). It is part of the widespread magmatism which characterised northeast Queensland from the Early Carboniferous through to the Permian.

MAJOR BOUNDING FAULTS

(I.W. Withnall)

The Burdekin, Halls Reward, Teddy Mount, Clarke River, and Gray Creek Fault Zones are major structural elements in North Queensland. They have had a fundamental influence on the depositional and structural history of the Broken River Province. The Burdekin, Halls Reward, and Teddy Mount Faults separate the Province from the metamorphic and plutonic rocks of the Precambrian and Early Palaeozoic Georgetown Province. The Clarke River Fault Zone forms the southern boundary of the Broken River Province, and separates the Broken River Province from the metamorphic and igneous rocks of the Precambrian and early to middle Palaeozoic Lolworth-Ravenswood Province.

The Gray Creek Fault Zone is a north-trending fault system which divides the Broken River Province into the Graveyard Creek Subprovince in the west, and the Camel Creek Subprovince in the east.

BURDEKIN FAULT

The Burdekin Fault (or Burdekin River Fault) was named by White (1961, 1962a, b, 1965) as the eastern margin of the Georgetown Province. However we restrict it to the fault separating the Georgetown Province from the Camel Creek Subprovince. It is probably not continuous with the faults which separate the Georgetown Province from the Graveyard Creek Subprovince. These have been named the Halls Reward and Teddy Mount Faults (Withnall, 1989b). However, the Burdekin Fault is probably continuous with the Gray Creek Fault (Arnold & Rubenach, 1976; Bell, 1980) which separates the Graveyard Creek and Camel Creek Subprovinces (see later in this chapter).

The Burdekin Fault is poorly exposed, being mostly overlain by Tertiary laterite and Quaternary alluvium and basalt along the Burdekin River. The fault is exposed between 7 and 9 km southwest of 'Valley of Lagoons', where it can be located to within a few tens of metres in tributaries of Redbank Creek. Mylonitic mica schist is juxtaposed against boudinaged quartzose arenite and mudstone. However further study is needed to determine the type of movement. Mylonite occurs in zones throughout the Halls Reward Metamorphics, although it is not known if these zones are related to the Burdekin Fault. The foliation in these zones ranges from vertical to sub-horizontal and stretching lineations trend north-northeast/south-southwest (Withnall, 1989b).

The Burdekin Fault may be a continuation of the Palmerville Fault, which is the western margin of the Hodgkinson Province and is interpreted as a thrust fault (Bell, 1980; Hammond, 1986; Shaw & others, 1987). If so, the rocks of the Georgetown Province were probably thrust over the Camel Creek Subprovince along the Burdekin Fault. A similar type of movement has been suggested for the Gray Creek Fault (Hammond, 1986) as discussed later in this chapter. The main movement was probably in the Early Devonian.

HALLS REWARD FAULT

The Halls Reward Fault extends for about 25 km south-southeast from near 'Lucky Downs', and separates the Halls Reward Metamorphics in the Georgetown Province from the Judea Formation in the Graveyard Creek Subprovince. It is an intense mylonite zone consisting of phyllonite derived from the coarse-grained muscovite schist of the Halls Reward Metamorphics, and probably some of the Judea Formation. The zone is up to 200 m wide and generally steeply dipping. It has not been studied in detail, but preliminary examination suggests 'east-side-up' movement, based on asymmetry of $F_m{}^m$? folds (Bell, personal communication, 1982).

The Halls Reward Fault is interpreted as a thrust, (now steepened by folding), along which the Judea Formation was thrust over the Halls Reward Metamorphics (the opposite sense of movement to that suggested for the Burdekin and Gray Creek Faults). The interpreted former easterly dip of the Halls Reward Fault is consistent with its position on the western limb of a synclinal core of Crooked Creek Conglomerate near the southern mapped extent of the fault.

Farther south, the Halls Reward Fault appears to be overlain by the Graveyard Creek Group. Its southward continuation beneath the Bundock Creek Group coincides with a pronounced northward thinning of units against what Lang (1985, 1986a) termed the Pandanus Creek-Gregory Springs ridge. During extension, reversal of movement along the Halls Reward Fault (which would thus become a listric fault) could have allowed a thicker accumulation of sediments in the south.

The main thrusting along the Halls Reward Fault predated the Graveyard Creek Group and is thus probably of Late Ordovician or Early Silurian age. This is consistent with an imprecise Rb-Sr isochron of 429±31 Ma (L.P. Black, unpublished data), obtained on mylonite from the fault near Greenvale, and the presence of mylonite pebbles in the Crooked Creek Conglomerate.

TEDDY MOUNT FAULT

The Teddy Mount Fault is a northeast-trending brittle structure which can be traced for about 65 km. It is the main boundary between the Georgetown Province and the Graveyard Creek Subprovince and was previously regarded as an extension of the Burdekin Fault (White, 1962a, 1965). Where it has been observed in outcrop against the Halls Reward Metamorphics and Dido Tonalite, it consists of less than a metre of fault gouge with no obvious mylonitisation on either side. However, mylonitised rocks with dextral shear sense occur in the Einasleigh Metamorphics adjacent to the fault at its southwestern extremity in the Hospital Creek area near Oak Valley homestead. It is not known whether these mylonites are related to the fault or are some older fabric in the Precambrian metamorphics. It is possible that the position of the Teddy Mount Fault is partly controlled by an older mylonite zone, in a similar manner to the Clarke River Fault, but that the mylonitised rocks lie, for the most part, south of the fault, and beneath the Graveyard Creek Subprovince rocks.

Movement on the Teddy Mount Fault was south-block-down probably, mainly in the Carboniferous, post-dating the main folding event. It may have been active earlier, during deposition of the Bundock Creek Group, particularly the upper part. However, northward directed palaeocurrents in the lower part of the Group, chiefly in the Bulgeri Formation and in outliers to the north of the fault, suggest that it was not a basin-margin fault at this time.

CLARKE RIVER FAULT ZONE

Along the southwestern edge of the Broken River Province, the Clarke River Fault Zone is a composite structure consisting of a steeply dipping mylonite zone and a brittle fault termed the Clarke River Mylonite Zone (CRMZ) and the Clarke River Fault (CRF) respectively by McLennan (1986).

The CRMZ is at least 1 km wide and can be traced for at least 120 km. It is best exposed near Craigie Outstation where a belt of mylonitised, fine-grained, metamorphic rocks retrogressed to greenschist facies, is juxtaposed against the northern edge of the Craigie Tonalite. In this area, the CRMZ is dominated by schistose and gneissic rocks containing various proportions of quartz, plagioclase, chlorite, muscovite, biotite, epidote, and actinolite. Relict garnet porphyroclasts, hornblende in metabasites, and the presence of migmatites within the CRMZ indicate that some of the rocks were originally amphibolite grade. It also contains narrow leucocratic pegmatite veins, and rare, foliated marble, metavolcanics, haematitic quartzite, metapyroxenite, and serpentinite. Most of these metamorphic rocks can probably be equated with the Cape River Metamorphics (Withnall & others, 1986).

Deformation within the CRMZ is variable, ranging from ultramylonite to narrow zones of cataclasis. The penetrative mylonitic foliation anastomoses 20° about the easterly trend of the CRMZ, and is vertical to steeply dipping. Stretching lineations are weak to strongly developed, and commonly dip shallowly (ca. 20°) east and west within the plane of the foliation.

The Craigie Tonalite crops out along the southern margin of the CRMZ. It is an Early to Middle Palaeozoic, medium to coarse-grained, foliated, hornblende-biotite tonalite (McLennan, 1986). It locally contains fine-grained diorite xenoliths, epidote veins, and rafts of metamorphic rocks similar to those seen in the CRMZ. The Craigie Tonalite itself exhibits a gneissic foliation, is locally sheared, and contains thin mylonites, which reflect movement along the CRMZ. The foliation is sub-parallel to the trend of the CRMZ. The gneissic foliation may be either a marginal flow foliation or it may have resulted from movement on the CRMZ.

An overall dextral sense of shear on the CRMZ is evident from various mesoscopic shear sense indicators. In the metamorphic rocks these indicators are: (a) steeply plunging asymmetric folds; (b) fragmented and rotated quartz veins; and (c) feldspar porphyroclasts in gneissic rocks, although the porphyroclasts locally exhibit both senses of shear. Type-I S-C planes (after Berthe & others, 1979) are well developed within the Craigie Tonalite adjacent to the CRMZ. Microstructural studies of augen porphyroclasts and Type-II S-C plane fabrics (Lister & Snoke, 1984) within the CRMZ and Craigie Tonalite also infer a dextral sense of shear.

Post-mylonite deformation is present in both the CRMZ and the Craigie Tonalite. Within the CRMZ small-scale faults and kinks are common. Two sets of kinks have been recognised. One set has subvertical, north-plunging axes; the other has subhorizontal to shallow, south-plunging axes.

The Clarke River Mylonite Zone also crops out 35 km farther west in the Gregory River, near its junction with the Clarke River. The Craigie Tonalite is also mylonitised there, and tails on feldspar crystals indicate a dextral shear sense. The discovery that the Clarke River Mylonite Zone continues to the west as a major ductile structure destroyed one of the major tenets of the "Big Bend Megafold" theory of Bell (1980). According to Bell, the Palmerville, Burdekin, Gray Creek, and Clarke River Faults were all part of a single structure, bent into a huge orocline with a hinge near 'Craigie'. Clearly, if the Clarke River Mylonite zone continues far to the west of 'Craigie' as a major ductile structure, it cannot also be bent around to become the north-trending Gray Creek Fault.

The CRMZ may continue to the west-southwest under the Quaternary basalt flow which followed the ancestral Gregory River. Its western extent is unknown.

Mylonitised schist has been located 70 km east of 'Craigie' in a window within Cainozoic and Carboniferous cover near Mount George (eastern edge of CLARKE RIVER), about 6 km south of the nearest exposed Camel Creek Subprovince rocks (Greenvale Formation). Shear sense has not been determined here, but these outcrops are interpreted to be the eastern continuation of the Clarke River Mylonite zone. They indicate that the overall trend of the zone is 080°.

The location of any eastern extension is not certain. A large batholith which includes the Malmesbury Microgranite (formerly Oweenee Granite - Scott, 1988b) obscures the fault east of Mount George. In the Ewan area a narrow mylonite zone separates the Lolworth-Ravenswood Province (there represented by the ?Proterozoic Running River Metamorphics) from the Broken River Province. If this is a continuation of the Clarke River Mylonite Zone, it is offset north by about 30 km from where the projection of the latter should pass. The Perry Creek Formation, not Greenvale Formation, is juxtaposed against the Running River Metamorphics. No offset of units is evident within the Broken River Province even if the margin is apparently offset. If the Clarke River Fault Zone and the mylonite zone near Ewan are both transcurrent faults, the connecting 'offset' could be a thrust or oblique-slip fault.

The CRF is a brittle fault which crops out adjacent to the northern edge of the CRMZ. The CRF is between 1 and 30 m wide, and separates the rocks of the Broken River Province from the CRMZ. Near 'Craigie', the CRF is a 30 m wide zone of brecciated and intensely boudinaged fine-grained quartzose arenite and shale. In this area, it separates the CRMZ from the Devonian Broken River Group. The rock type within the fault zone is similar to the flyschoid lithologies of the Ordovician Wairuna and Judea Formations. East of 'Craigie' in the Clarke River, the CRF is a 1 m wide zone of brecciated and silicified quartzose arenite and shale. Here the CRF separates the Wairuna Formation from the CRMZ. A similar brittle fault occurs along the northern side of the mylonite zone farther west, separating the Bundock Creek Group from mylonitised granitoids and metamorphic rocks. However, west of the junction of the Clarke and Gregory Rivers the brittle fault diverges to the north and the Bundock Creek Group is faulted against foliated but unmylonitised granite and metamorphic rocks which are regarded as part of the Georgetown Province because they are to the north of the CRMZ.

The dextral shear sense is opposite to that inferred by various authors such as Arnold (1975), Harrington (1981), and Henderson (1980, 1987). The sinistral movement was inferred largely from the apparent eastward displacement of the 'Tasman line' or edge of the craton, the position of which is itself only inferred to the south. Dextral displacement would displace the line to the west. However, if the Clarke River Mylonite Zone was a transform fault or tear fault marking the southern limit of a thrust belt, different parts could show dextral and sinistral shear sense, with nett sinistral movement.

The ages of movement on the Clarke River Fault Zone are not known. However, the fault may have developed during the Early Palaeozoic, prior to the deposition of the oldest known sedimentary unit in the Broken River Province (the Ordovician Wairuna Formation). The final major phase of ductile deformation along the CRMZ possibly occurred during the formation of the Graveyard Creek Subprovince in the Early Silurian with all subsequent fault movement being accommodated along the brittle CRF. The last main phase of brittle faulting may have occurred during the Middle Carboniferous folding event of the Graveyard Creek Subprovince. Dextral movement on the fault during this event could have produced the NE-trending folds.

GRAY CREEK FAULT

The Gray Creek Fault forms the boundary between the Camel Creek and Gray Creek Subprovinces and may be a continuation of the Burdekin Fault farther north. Because of the contrasting tectonic history and deformation styles across the fault, it is regarded as a fundamental discontinuity. It is best exposed south of Greenvale, where it forms the eastern margin of the Gray Creek Complex. There it is marked by a zone of mylonitised amphibolite up to 200 m wide. The mylonitic schistosity post-dates S_2, which is preserved in less deformed cores within anastomosing schistose zones. Complex mesoscopic folds and refolds occur within the zone. The mylonite consists of acicular actinolite and clinozoisite. A subhorizontal mineral elongation is developed in the mylonitised amphibolite suggesting that movement was transcurrent. The Carriers Well Formation on the other side of the fault is also sheared and boudinaged, but the metamorphic grade is much lower. It is therefore possible that the Gray Creek Fault resulted from reactivation of an older mylonite zone and the movement indicated by the lineation does not reflect the later movement.

East of Gray Creek, farther south, the fault is marked by a series of sheared serpentinite lenses which have probably been mobilised in the solid state and tectonically emplaced along the fault. Similar lenses occur in the Wairuna Formation, probably along subsidiary faults, up to 4 km east of the main fault. They were probably derived from the Gray Creek Complex.

The Gray Creek Fault disappears under the large laterite plateau. To the south of the plateau, Arnold & Henderson (1976) inferred that the western margin of the Clarke River Group was the Gray Creek Fault. We interpret the margin as a fault, but have named it the Poley Cow Fault, because it is probably not a continuation of the Gray Creek Fault. The Clarke River Group may overlie the Gray Creek Fault and hence overlap the boundary between the Graveyard and Camel Creek Subprovinces. The western edge of the Clarke River Group is more strongly folded, like other Carboniferous rocks in the Graveyard Creek Subprovince.

In the south of the Broken River Province near 'Craigie', McLennan (1986) mapped a fault that he interpreted as the southern extremity of the Gray Creek Fault. It is a 100 m wide shear zone dipping 70° west. Lineations with the fault zone pitch 20° to 60° north suggesting transcurrent to oblique movement. It separates strongly deformed and boudinaged quartzose arenite and mudstone (equated by McLennan with the Wairuna Formation) from less deformed (but folded) rocks correlated with the Devonian Broken River and Bundock Creek Groups. Projected north, the fault underlies the Clarke River Group east of the deformed zone mentioned above. Serpentinites intrude the Wairuna Formation, east of this fault and were probably mobilised in a similar manner to those mentioned above. It is possible, however, that the quartzose arenite and mudstone are equivalent to the Judea Formation, and that the Gray Creek Fault is still farther east.

The type of movement on the Gray Creek Fault is uncertain. Because of the subhorizontal lineations and shear sense indicators, Withnall (1985a) interpreted it as a dextral transcurrent fault. Henderson (1987) also regarded it as a transcurrent fault. However, Hammond (1986) suggested that it was a major thrust, a continuation of the Burdekin Fault, along which the rocks the Georgetown Province (represented by the Gray Creek Complex) were thrust over the Camel Creek Subprovince with the Graveyard Creek Subprovince riding "piggy-back" on the upper thrust sheet. If Hammond's interpretation is correct, the fault could be an older, reactivated mylonite zone, the lineation having formed during some earlier event, such as formed the gently dipping mylonites within the Halls Reward Metamorphics. These gently dipping mylonites have subhorizontal, roughly north-trending stretching lineations (Withnall, 1989b). If these mylonites were steepened to vertical by north-northeast-trending folding, the lineation would remain subhorizontal. Shaw & others (1987) proposed a similar complex history of movement on the Palmerville Fault. They documented both higher grade mylonites with shallow lineations and younger low-grade mylonite with a down-dip stretching lineation in the metamorphic rocks adjacent to the fault. They suggested that the Palmerville Fault was localised along a Precambrian mylonite zone.

North of Greenvale, the fault is difficult to trace because of poor outcrop, and because it juxtaposes similar lithologies (Judea Formation and Wairuna Formation). It should meet the Burdekin and Halls Reward Faults, under the alluvium of the Burdekin River near 'Lucky Downs'.

The timing of movement is uncertain. It post-dates the Carriers Well Formation (Late Ordovician) and pre-dates the Clarke River Group (Early Carboniferous). The main movement may have coincided with the thrusting and folding of the Camel Creek Subprovince ascribed there to D_1. This event, as discussed elsewhere, may have occurred in the Early Devonian. Some vertical movement may have occurred during the Late Devonian.

GEOCHEMISTRY OF THE ORDOVICIAN TO SILURIAN IGNEOUS ROCKS

(I.W. Withnall)

A geochemical study of the igneous rocks of the Broken River Province was made to aid in their classification and to attempt to assess their origin and tectonic setting. Thirty samples of volcanic rocks and five samples of plutonic rocks were analysed by the Queensland Government Chemical Laboratory for the major elements and a range of trace elements using X-ray fluorescence techniques. The analyses, along with fourteen analyses of volcanic and dyke rocks from Arnold (1975), are tabulated in the Appendix along with C.I.P.W. normative mineralogy, calculated on an anhydrous and CO_2-free basis using the method of Kelsey (1965). Only six of Arnold's samples were analysed for the full range of major elements and the range of trace elements is not as wide.

ALTERATION

To determine whether alteration is likely to have affected the geochemistry of the rocks significantly, the major elements have been plotted on the log molecular proportion ratio (LMPR) diagrams of Beswick & Soucie (1978), who demonstrated that a wide range of unaltered volcanic rocks from diverse tectonic environments fell into the narrow fields shown in Figure 74. Samples which diverge from those fields are likely to have been altered in elements other than alkalis, in this case K_2O. Mobility of the latter results in point migration along a 45° slope line, mainly within the field of volcanic rocks.

The LMPR plots indicate that most of the groups of samples have been altered to some extent. Because Al_2O_3 values are least likely to have been altered drastically, the reasonable correspondence with the unaltered field on the SiO_2-Al_2O_3 plot suggests that SiO_2 was not particularly affected by alteration either, except in some samples from the Donaldsons Well Volcanic Member of the Judea Formation, and the Everetts Creek Volcanics and Carriers Well Formation. Therefore the K_2O-SiO_2 diagram in Figure 74 (modified after Peccerillo & Taylor, 1976 and Gill, 1981) used to classify the samples into the major volcanic rock-types is likely to be reasonably reliable, although the K_2O levels may have been affected to some extent by alteration.

The divergence in the LMPR plots involving CaO and FM (total iron + MgO + MnO) may be due to depletion in those elements. On the CaO-FM plot the affects seem to have partly cancelled each other out. The Greenvale Formation samples show some depletion in FM but not CaO. Again the worst affected are the Donaldsons Well Volcanic Member and the Everetts Creek Volcanics and Carriers Well Formation. Such depletion, particularly of CaO and probably MgO, is likely to have occurred during albitisation of plagioclase and uralitisation and/or chloritisation of pyroxene. Samples from those units show a wide scatter on the Harker diagrams using the 'mg number' as the differentiation index. A selection of major and trace elements from the mafic rocks (SiO_2 < 63% volatile-free) are plotted on the diagrams (Figure 76). The 'mg number' or 'mg' is calculated as $Mg/(Fe^{2+}+Mg+Mn)$ (atomic) where Fe^{2+} is recalculated using a $Fe^{2+}/(Fe^{2+}+Fe^{3+})$ ratio of 0.85. The other units tend to define expected fractionation trends, although the range of 'mg' is not great.

These observations are generally consistent with petrographic evidence. Volcanic rocks from the Everetts Creek Volcanics and Carriers Well Formation are usually extensively altered with saussuritisation and albitisation of plagioclase and complete alteration of pyroxene to uralite and chlorite. The rocks from the Donaldsons Well Volcanic Member are commonly similarly altered, although relict pyroxene is more common. Alteration is less extensive in the basalts from the Wairuna, Pelican Range, and Perry Creek Formations, the pyroxene generally being only partly altered, although plagioclase is commonly saussuritised or albitised. Pyroxene in the basalts from the Greenvale Formation is completely altered, but the plagioclase is not obviously altered; some of the alteration of the pyroxene in these rocks may be due to contact metamorphism by adjacent granites rather than low temperature interaction with seawater during emplacement or connate water during burial.

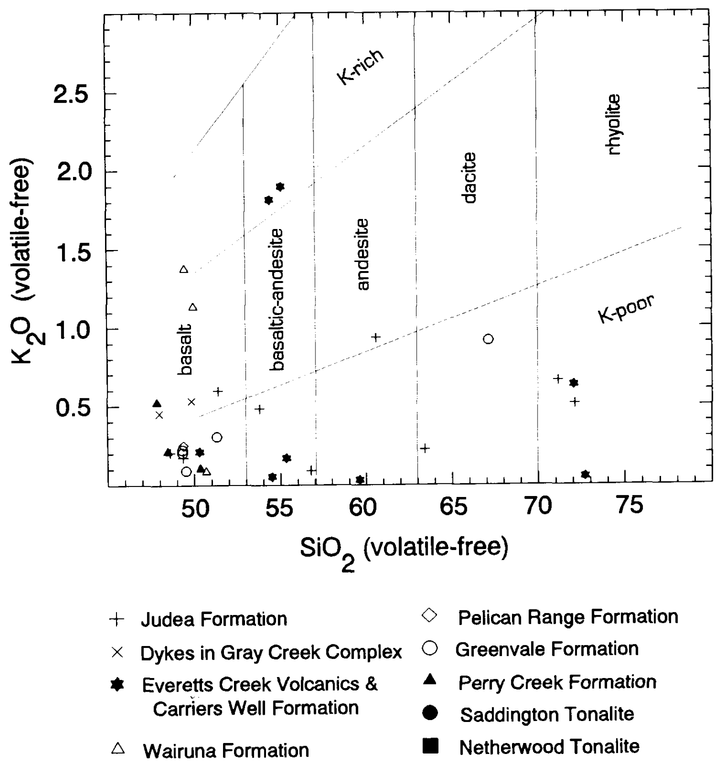


Figure 74. K_2O vs SiO_2 (volatile-free) for Ordovician to Silurian volcanic rocks. Fields are from Peccerillo & Taylor (1976) and Gill (1981).

Apart from the depletion of CaO and MgO, it is likely that the alkalis have also been affected by alteration. Enrichment in K, Rb, Sr and possibly Ba as a result of low-temperature interaction between basalt and seawater has long been recognised (Hart & others, 1974; Saunders & Tarney, 1984). The samples from the Everetts Creek Volcanics and Carriers Well Formation show higher Na_2O than the other units (Figure 76), suggesting that they were spilitised. One sample from the Perry Creek Formation with higher Na_2O and K_2O and normative nepheline was possibly also spilitised. It is strongly altered and weakly foliated, but this does not appear to have affected its geochemistry as drastically as some other altered samples.

The consequence of the alteration is that use of the geochemistry (particularly the major elements) to determine affinities or tectonic setting should be used with caution. However, the supposedly relatively immobile

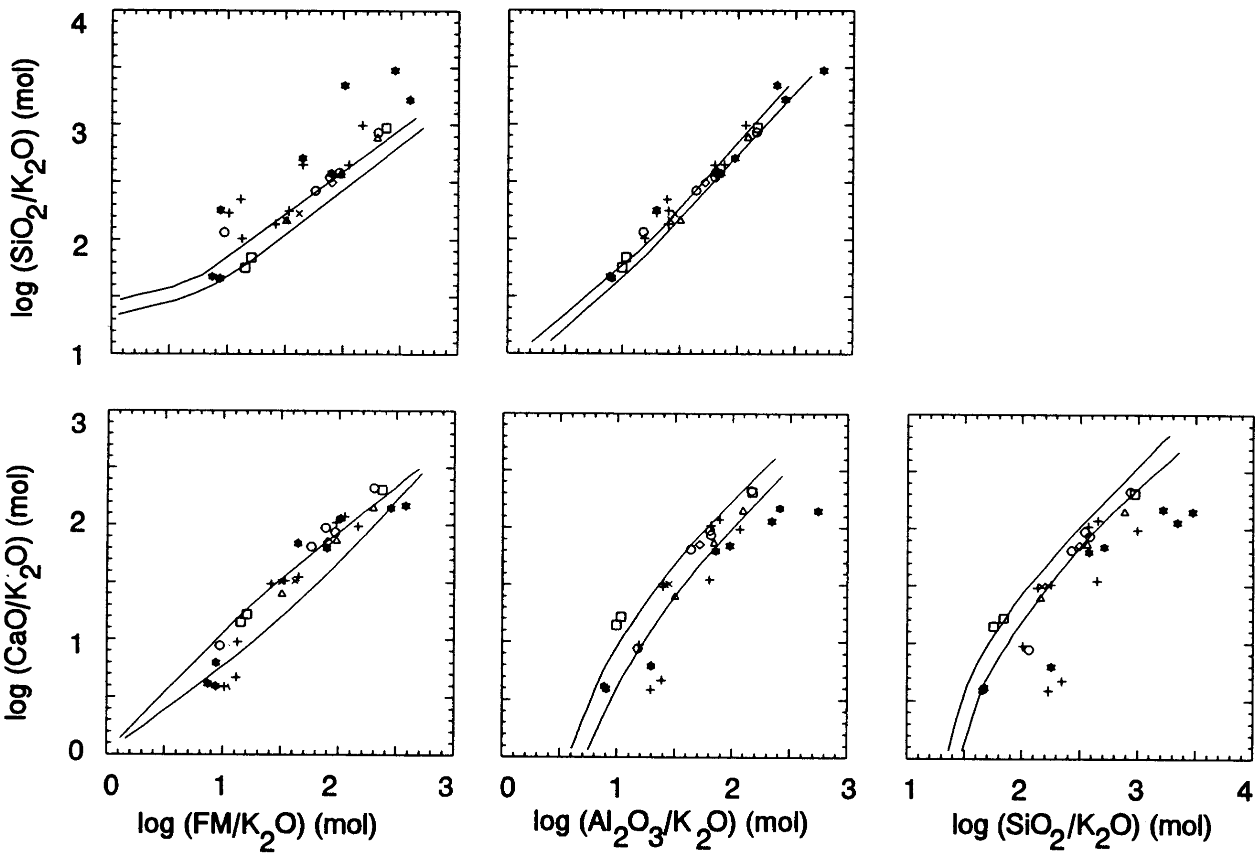


Figure 75. Log molecular proportion ratio (LMPR) plots for Ordovician to Silurian volcanic rocks. Fields shown are for least altered modern volcanic rocks after Beswick & Soucie (1978). Symbols as in Figure 74.

trace elements, in particular Ti, Zr, Y, Nb, P, Cr, and Ni are regarded as useful for discriminating between magma types in altered rocks. The analyses have been plotted on various discrimination diagrams using some of these elements, such as those of Pearce & Cann (1973), Pearce (1975), and Meschede (1986) for the basalts and basaltic andesites (Figures 77, 78 and 79), and those of Pearce & others (1984) for the granitoids and felsic volcanic rocks (Figure 80). For comparison with the other diagrams, all samples are also plotted on the AFM diagram (Irvine & Baragar, 1971) (Figure 81). Although it uses major elements which are likely to have been affected by alteration, the AFM diagram is generally in agreement with the others.

CAMEL CREEK SUBPROVINCE

Wairuna, Pelican Range, and Greenvale Formations

The analyses from these formations are discussed together, because they are generally similar, and the rocks are probably largely of Ordovician age, in particular the Wairuna and Pelican Range Formations.

The rocks are all basalts (mainly olivine normative) (Figure 74, and Appendix), with the exception of a volcanic arenite of dacitic composition interbedded with the lavas east of 'Niall'. The basalts in the Greenvale and Pelican Range Formations plot in the low-K field, whereas those in the Wairuna Formation are somewhat higher in K, some being in the high-K field. The rocks show a narrow range of 'mg', and are not particularly fractionated, so that although they plot in the tholeiitic field of the AFM diagram (Figure 81), the iron enrichment characteristic of tholeiites is not demonstrable. The position in the tholeiitic field could conceivably be due to alkali depletion during submarine alteration. On the various discriminant diagrams, which use the more immobile elements, the rocks plot mostly in the fields of ocean-floor basalts (OFB), with some in the fields of island arc tholeiites (IAT) (Figures 77, 78 and 79).

The spider diagram (Figure 82a) on which average analyses of the mafic rocks for each unit are plotted, the rocks show similar levels of immobile incompatible high-field strength (HFS) elements (Nb-Y on Figure 82) to 'normal' mid-ocean ridge basalts (N-type MORB), but are enriched in the large-ion-lithophile (LIL) elements (K, Rb, Ba, Sr and Th). Although enrichment in K, Rb and Sr can be caused by reaction with seawater, Th (which shows significant enrichment) is considered to be less mobile (Saunders & Tarney, 1984). This suggests either that the source was different to that beneath modern mid-ocean ridges or there was crustal contamination (Thompson & others, 1984). Saunders & Tarney (1984) point out that such LIL enrichment is characteristic of basalts erupted in back-arc settings, resulting in their being transitional between N-type MORB and island arc tholeiites or even calc-alkaline basalts. It may be due to either selective contamination of the mantle wedge by LIL-enriched hydrous fluids from the dehydrating subducting slab of oceanic lithosphere, or alternatively repeated melt extraction during basalt genesis depleting the mantle in incompatible elements with respect to the LIL elements. The average analysis for the Greenvale Formation shows relative Nb depletion, supposedly a feature of subduction-related basalts (Thompson & others, 1984).

On the Harker diagrams (Figure 76), the rocks from the three formations plot on trends of increasing TiO_2, P_2O_5, Zr, and Y with decreasing 'mg', and consistently depleted values of Ce, La and Nb. However, the data are too few to positively indicate that the rocks are genetically related. The main difference between the units is the unusually high MnO in the samples from the Greenvale Formation.

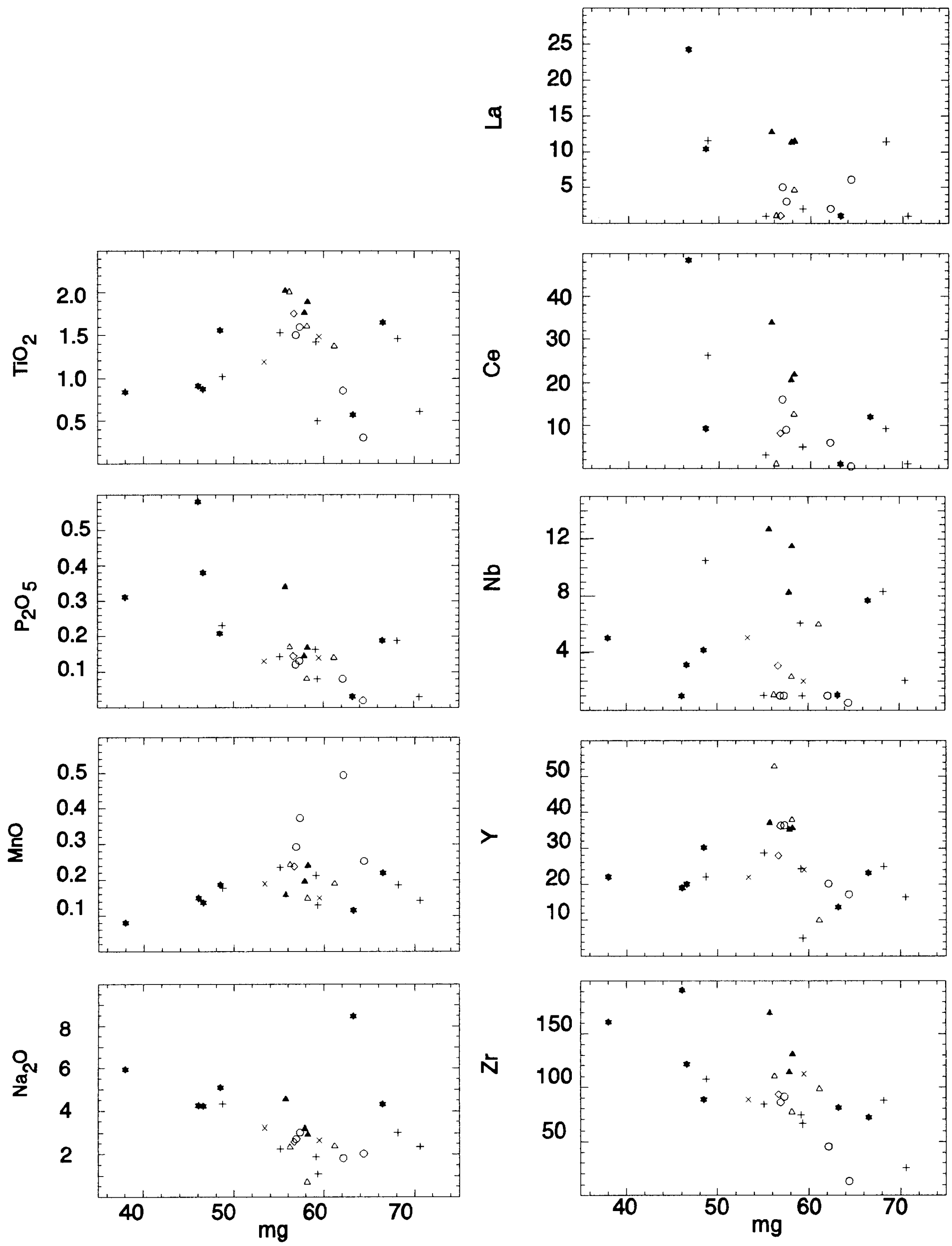


Figure 76. Harker variation diagrams for selected major element oxides in weight percent and trace elements in parts per million vs 'mg' (100 Mg/(Mg + Fe^{2+}) atomic for Ordovician to Silurian mafic rocks (SiO_2<57% volatile-free). Fe^{2+} recalculated using a Fe^{2+}/Fe_{total} ratio of 0.85. Symbols as in Figure 74.

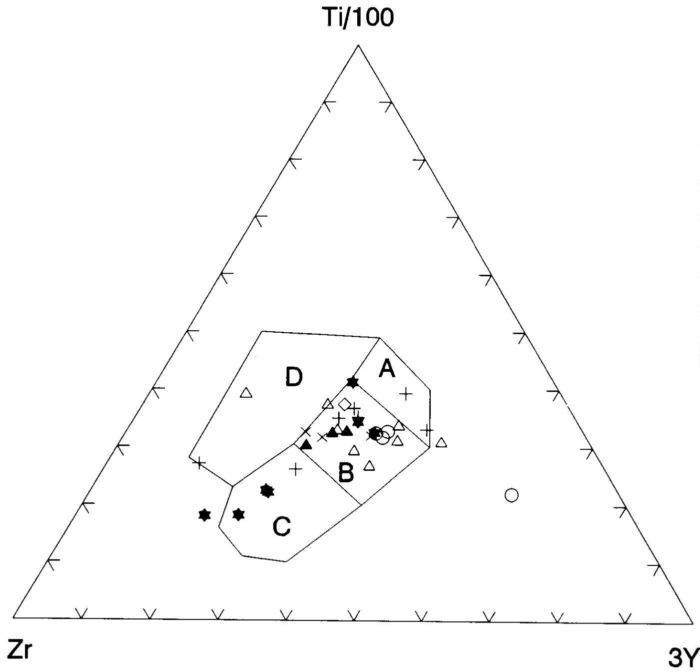


Figure 77. Ti-Zr-Y diagram for Ordovician to Silurian mafic rocks (SiO_2<57% volatile-free). Fields are low-K tholeiites (A & B), ocean-floor basalts (B), calc-alkali basalts (B & C), and within-plate basalts (D) after Pearce & Cann (1973). Symbols as in Figure 74.

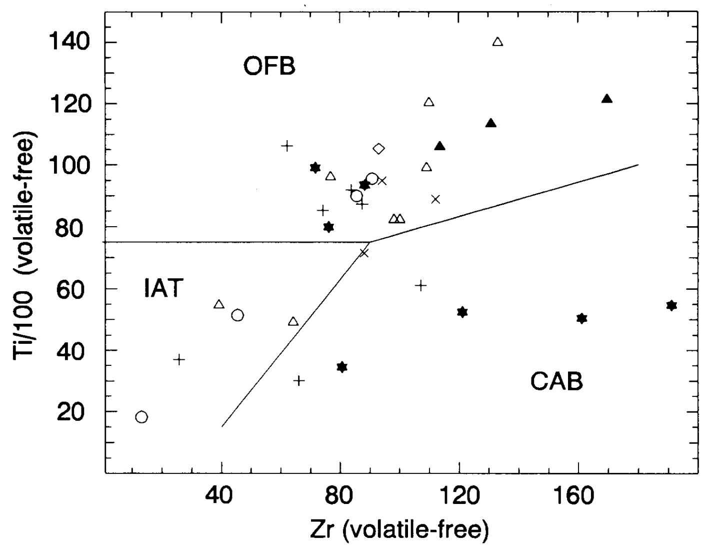


Figure 78. Ti-Zr plot for Ordovician to Silurian mafic rocks (SiO_2<57% volatile-free). Fields are island arc tholeiites (IAT), ocean-floor basalts (OFB), and calc-alkaline basalts (CAB) from Garcia (1978). Symbols as in Figure 74.

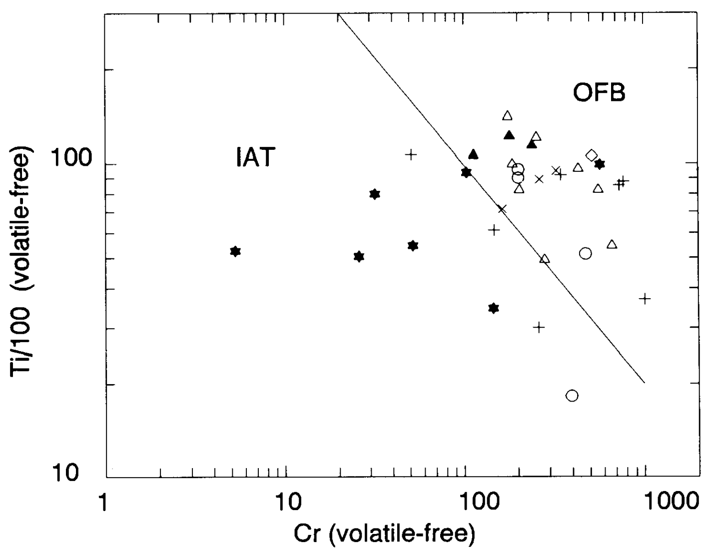


Figure 79. Ti-Cr plot for Ordovician to Silurian mafic rocks (SiO_2<57% volatile-free). Fields are island-arc tholeiites (IAT), and ocean-floor basalts (OFB) from Pearce (1975). Symbols as in Figure 74.

Perry Creek Formation

The three samples are olivine-normative basalt (Figure 74 and Appendix), and have relatively low K. One of the samples (GSQR 13556) is nepheline normative, because of higher K and Na, but this is probably due to alteration rather than its primary magmatic affinities. On the AFM diagram, it plots in the calc-alkaline field, probably due to the alkali enrichment. The samples plot mainly in the OFB or MORB fields of the various discrimination diagrams using the immobile elements (Figures 77, 78 and 79).

The three samples show a narrow range of composition on most of the Harker diagrams (Figure 76). They have the same narrow range of 'mg' as the Wairuna, Pelican Range, and Greenvale Formations (i.e. they show a similar degree of fractionation), and show similar LIL enrichment relative to N-type MORB in the spider diagram (Figure 82a). However, they show generally higher values of the incompatible HFS elements (Figures 76 and 82a). This difference in geochemistry is consistent with their belonging to a separate suite of different age (i.e. Silurian rather than Ordovician).

Everetts Creek Volcanics/Carriers Well Formation

These two units are discussed together, and are given the same symbol on the plots, because they appear to have a gradational contact in the field, and are difficult to separate. Lithologically, they differ from the units discussed above in containing abundant volcaniclastic rocks as well as lavas, and in ranging from mafic to felsic in composition. Only samples from outcrops which were clearly lavas were analysed.

The rocks in the Everetts Creek Volcanics and Carriers Well Formation show a wide range of composition from olivine and quartz-normative basalt through to rhyolite (Figure 74 and Appendix). The rocks plot largely in the low-K fields, with the exception of two basaltic andesite samples from the Everetts Creek Volcanics. The samples all plot in the calc-alkaline field of the AFM diagram (Figure 81), but in the case of the basaltic rocks, this could be partly due to the spilitisation noted above. On the discrimination diagrams (Figures 77, 78 and 79), particularly the Ti-Zr plot, the samples separate into two groups. Most plot in the fields of calc-alkaline or volcanic arc basalts, but three samples, possibly representing a different suite, plot in the OFB field. On the Harker diagrams (Figure 76), the mafic samples show a much wider range of 'mg', than the units discussed above, but as already mentioned, this may be partly due to alteration as well as original magmatic fractionation. Values show generally wide scatter with no clear fractionation trends, probably also reflecting the alteration, as well as the possible presence of more than one suite. On the spider diagram (Figure 82a), the average analysis for the mafic rocks shows enrichment in most elements with respect to MORB except for Nb, Zr, Ti and Y. The spidergram also shows the characteristic relative Nb depletion of subduction-related basalts (Thompson & others, 1984). The felsic rocks also show Nb-depletion (Figure 82b).

GRAVEYARD CREEK SUBPROVINCE

Judea Formation

Samples from the Donaldsons Well Volcanic Member of the Judea Formation also show a wide range of composition from olivine-normative basalt to rhyolite (Figure 74 and Appendix). Samples tend to lie in the low-K fields.

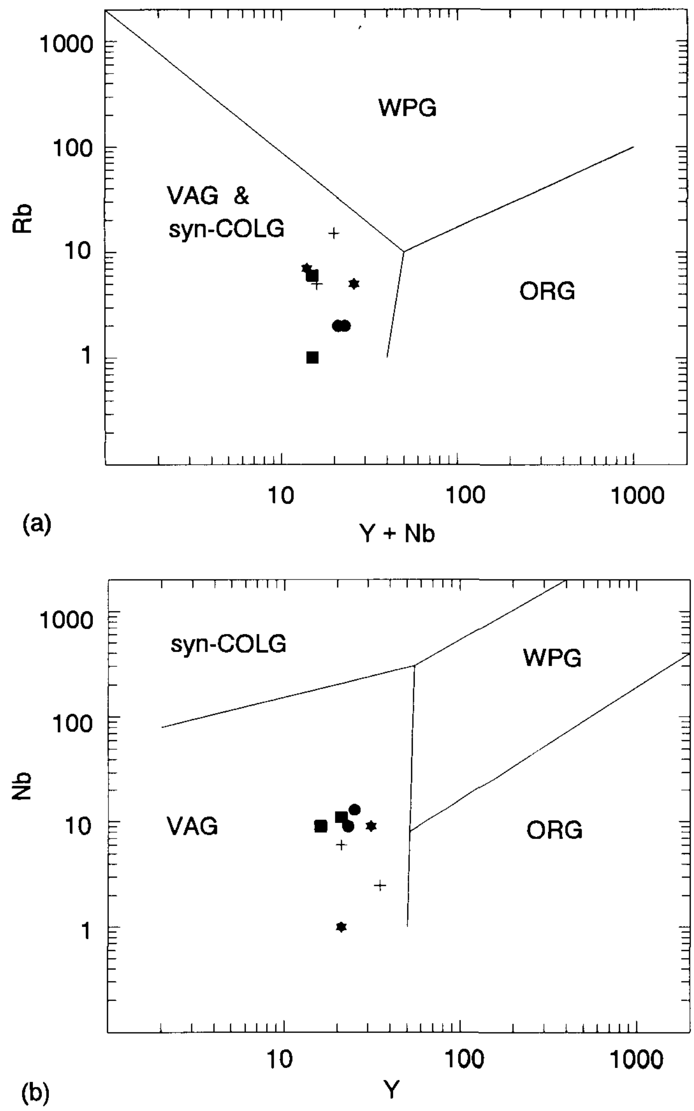


Figure 80. Rb-Y+Nb and Nb-Y plots for Ordovician tonalites and felsic volcanic rocks. Fields are syn-collision granitoids (syn-COLG), volcanic-arc granitoids (VAG), within-plate granitoids (WPG), and orogenic granitoids (ORG) from Pearce & others (1984). Symbols as in Figure 74.

Most of the basalts plot in the tholeiitic field of the AFM diagram (Figure 81), but there is limited iron enrichment, and alteration could account for this position. The andesite to rhyolite samples plot in the calc-alkaline field. On the discrimination diagrams using the immobile elements (Figures 77, 78 and 79), most of the mafic samples plot in the OFB field, but some fall in the IAT and just within the CAB fields. The felsic lavas plot in the field of volcanic arc granites (Figure 80) as do the tonalite plutons.

Most elements are in the same range as for the basalts in the Wairuna, Pelican Range, and Greenvale Formations, as shown by the similar spidergrams (Figure 82a - LIL enrichment and similar HFS element values to N-type MORB). Neither the basalts or rhyolites show the characteristic Nb depletion of subduction-related rocks (Figure 82). Like the samples from the Everetts Creek Volcanics and Carriers Well Formation, the mafic samples show a wide range of 'mg' and a wide scatter for the various elements on the Harker diagrams (Figure 76), again possibly due to alteration or the presence of more than one suite. The only clear trends are decreasing Cr and Ni with fractionation.

Dykes from the Saddington Tonalite

Arnold (1975) analysed three samples of dykes which intrude the Saddington Tonalite. These dykes have been suggested as possible feeders for the Donaldsons Well Volcanic Member (Arnold & Rubenach, 1976). They are olivine-normative basalt or dolerite (Figure 74 and Appendix), and plot mainly in the OFB fields on the discrimination diagrams (Figures 77, 78 and 79), and in the tholeiite field of the AFM diagram (Figure 81). However, it is not possible to determine from the geochemistry, whether they are feeders to the Donaldsons Well Volcanic Member because of the wide scatter of element values in the latter and the small data set.

Tonalite plutons

Two samples from the Netherwood Tonalite (both hornblende tonalite or quartz diorite) and three from the Saddington Tonalite (ranging from hornblende diorite to

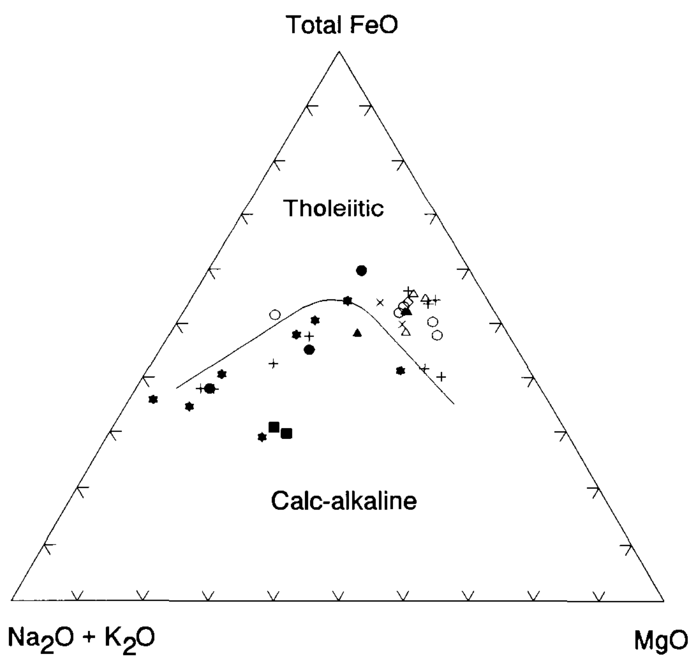
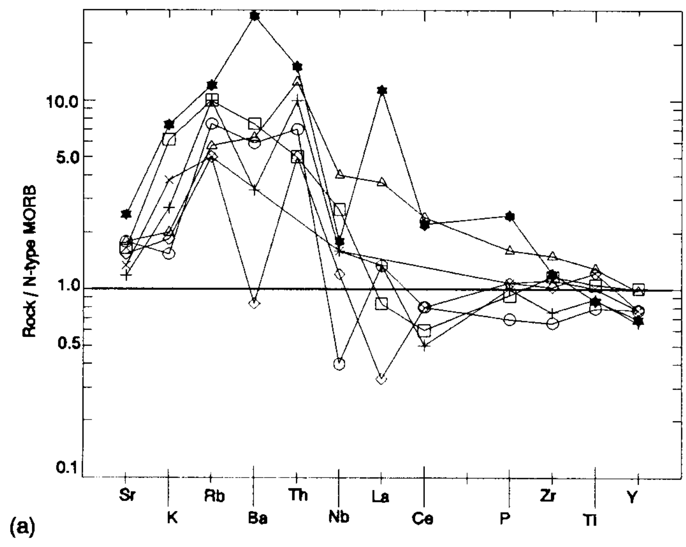


Figure 81. AFM diagram for Ordovician to Silurian volcanic rocks. Fields are from Irvine & Baragar (1971). Symbols as in Figure 74.



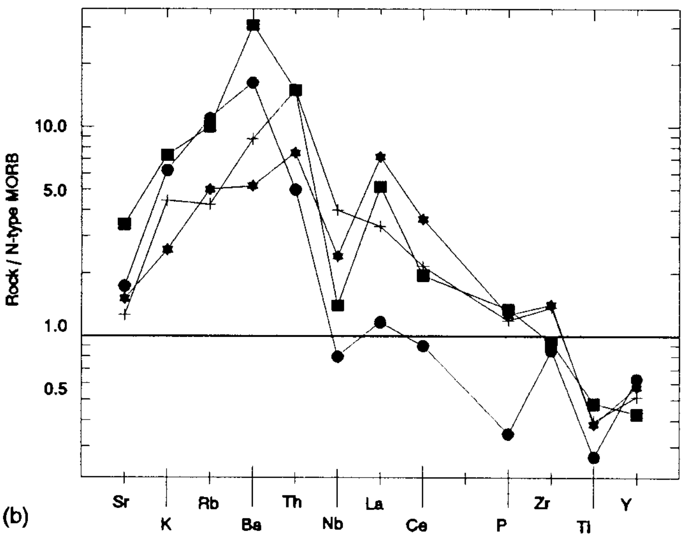


Figure 82. Multi-element plot (spider diagram) for average analyses of the groups of Ordovician to Silurian igneous rocks normalised against 'N-type MORB': (a) mafic rocks (Si02<57% volatile-free); (b) felsic rocks (Si02>62% volatile-free). Normalising values from Saunders & Tarney (1984). Symbols as in Figure 74.

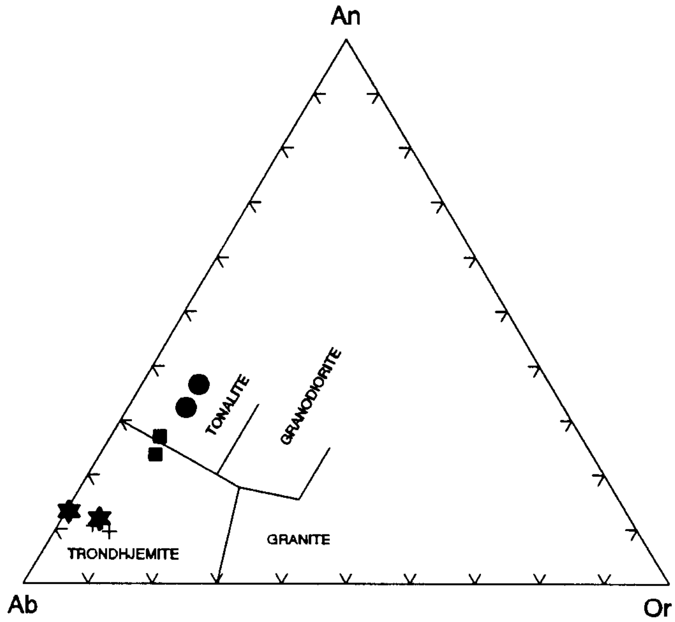


Figure 83. Ab-Or-An plot for Ordovician tonalites and felsic volcanic rocks, showing the fields for felsic plutonic rocks from Barker (1979). Symbols as in Figure 74.

tonalite) were analysed. The analyses and C.I.P.W. normative mineralogy are presented in the Appendix. They have the typical low K_2O/Na_2O ratios of tonalites and plot mainly in the tonalite field on the Ab-Or-An plot of Barker (1979) (Figure 83). They have low Zr, Y, Nb, Th, La, and Ce. The spidergram (Figure 82b) indicates that the two units are significantly different geochemically. The Saddington Tonalite is lower in Sr, Ba, Th, Nb, La, Ce and P than the Netherwood Tonalite. Zr, La, and Ce in both units are lower than in the Dido Tonalite, which crops out in the southeastern part of the Georgetown Province (Sheraton & Labonne, 1978; Withnall, 1989b), and is probably of Early Silurian age. The presence of modal hornblende indicates that the rocks are I-type granitoids (Chappell & White, 1974), and this is reflected in the geochemistry, with SI indices of less than 1.1 and normative diopside in three of the samples (Appendix).The samples are plotted on the discrimination diagrams derived by Pearce & others (1984) for granitic rocks (Figure 80), and these suggest that the rocks are representative of a volcanic arc setting. They do not belong to the oceanic plagiogranite group (Figure 84), which are evolved rocks associated with ophiolites and characterised by extremely low Rb contents. For comparison, the felsic volcanic rocks from the Judea Formation and Everetts Creek Volcanics are also plotted, and fall in the same fields as the tonalites on diagrams of Pearce & others (1984) (Figure 80), but are depleted in Rb, causing some to plot in the plagiogranite field in Figure 84. The depletion in Rb may be due to later alteration rather than a primary feature.

DISCUSSION

Although the volcanic suites are altered to various degrees, it is still possible, by use of the immobile element discrimination diagrams, to make suggestions about the possible tectonic settings of the igneous rocks in the Broken River Province.

The basalts in the ?Ordovician Wairuna and Pelican Range Formation, and the Silurian Perry Creek Formation have affinities with modern basalts formed in spreading centres in mid-ocean ridge or, more particularly, back-arc basin settings. However, some authors (e.g. Holm, 1982) have pointed out that most undisputed continental tholeiites also plot in the OFB and CAB fields on the Ti-Y-Zr diagram of Pearce & Cann (1973) and even the Ti-Zr diagram. Therefore an oceanic setting need not necessarily apply to the basalts of the Camel Creek Subprovinces, and it is possible that they could have formed in an intra-cratonic setting, or on a rifted continental margin. Nevertheless, the important common factor between these different settings is the rifting environment, suggesting that a convergent margin (i.e. a forearc basin or accretionary prism) is unlikely. The enrichment in K, Rb, Ba and Th may be due to contamination by continental crust or by generation from mantle material that had been previously modified, perhaps in a former subduction setting, e.g during the Late Cambrian or Early Ordovician. As noted previously, the

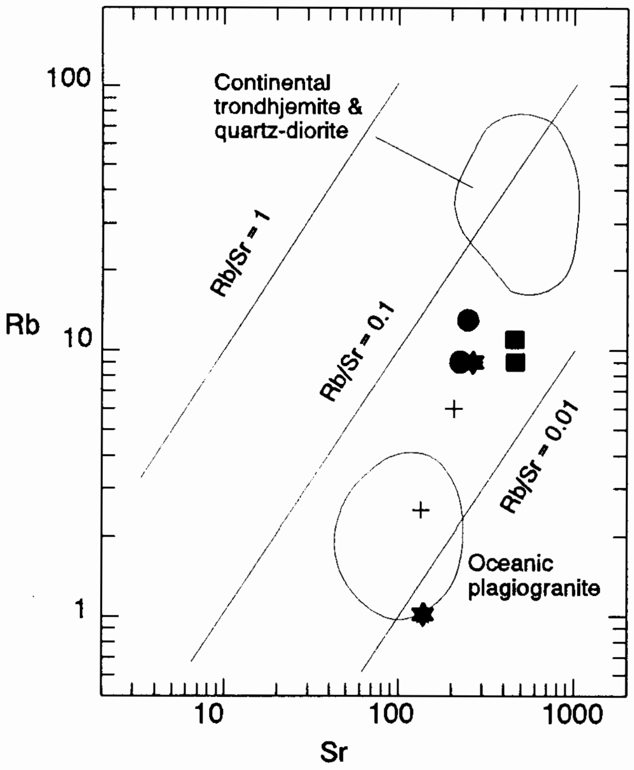


Figure 84. Rb-Sr plot for Ordovician tonalites and felsic volcanic rocks showing the fields of Coleman & Peterman (1975). Symbols as in Figure 74.

Greenvale Formation basalts, although similar in many respects to the basalts in the Wairuna and Pelican Range Formations, show Nb-depletion, characteristic of subduction related basalts. These basalts crop out along the southern margin of the Camel Creek Subprovince are possibly separate from the Greenvale Formation sediments, and could in fact be related to the Everetts Creek Volcanics which crop out on the western margin. Alternatively, as mentioned in the chapter on tectonic history, the Greenvale could be contemporaneous with the Everetts Creek Volcanics; subduction-related basalts within the formation could be consistent with this.

The Early Ordovician Donaldsons Well Volcanic Member of the Judea Formation is more difficult to interpret. The basalts have similarities to ocean-floor basalts (or at least basalts formed in a rifting environment). However, the andesite and rhyolite are more suggestive of an arc environment, although the rhyolite does not show any Nb depletion on the spider diagram (Figure 82b). Ignoring the one andesite sample, which could be anomalous, the basalts and rhyolites could represent a bi-modal suite, more characteristic of a rifting environment.

The tonalites that intrude the Judea Formation (both the volcanics and overlying quartz-rich turbidites), appear to be more like granitoids associated with volcanic arcs than plagiogranites formed in an ocean-ridge environment. Perhaps the Donaldsons Well Volcanic Member formed in a back-arc environment, but close enough to the arc so that lavas generated in both environments were emplaced together. The lack of volcaniclastic sediments suggests that the arc, if it existed, had not built substantial volcanic edifices, and may have been short-lived, as the volcanics are succeeded by quartz-rich arenites and mudstone suggestive of a passive margin.

The Late Ordovician Everetts Creek Volcanics and Carriers Well Formation, however, are more likely to have formed in a volcanic arc environment. Although some basalts with similarities to ocean-floor basalts are present, the majority of the rocks show calc-alkaline affinities and range from basalt through andesite to dacite and rhyolite. The field associations (e.g. the abundant volcaniclastic rocks) are also consistent with an arc environment. However, just as there appear to be two suites of volcanic rocks, the volcaniclastic sedimentary rocks in the Carriers Well Formation are interbedded with quartzose sediments, like those in the Judea and Wairuna Formations, suggesting mixing of rocks from the arc with those deposited in a back-arc environment, adjacent to a passive margin.

MESOZOIC AND CAINOZOIC STRATIGRAPHY OF THE BROKEN RIVER REGION

(K.G. Grimes)

MESOZOIC STRATIGRAPHY

The edge of the Mesozoic Carpentaria and Eromanga Basins extends into the south-western part of the region and there is also an outlier of Mesozoic sandstones on the Dividing range north of Graveyard Creek. The sediments thin towards the edge of the basin, and within the map area thicknesses are generally less than 65 m. The sequence is assigned to the late Jurassic to Cretaceous **Gilbert River Formation** (Smart & others, 1980). At the base is the fluvial **Yappar Member** composed of interbedded conglomerate, medium to very-coarse grained quartz sandstone and granule conglomerate that is locally cross-bedded, and minor ferruginised micaceous siltstone and fine grained sandstone. The conglomerates are composed of well rounded pebbles and small cobbles of quartz and quartzite. Near the basal unconformity the pebbles are more angular. Above this is the fluvial to paralic **Coffin Hill Member** composed of interbedded clayey medium to fine and locally coarse to very-coarse grained quartz sandstone, ferruginised siltstone and mottled mudstone, and rare pebbly sandstone beds. The sandstones are locally cross-bedded, and ripple marks are also seen in places. The mudstones and siltstones are thin bedded to laminated, but the deep weathering has obliterated the bedding in places. A marine influence is indicated in places by the presence of trace fossils, including *Rhizocorallium* and browsing trails, and possible weathered glauconite grains.

CAINOZOIC STRATIGRAPHY

The Cainozoic stratigraphy comprises small discontinuous areas of sediments of old valleys, lakes and broader flood plains, colluvial and residual deposits derived from the underlying rocks, as well as deep weathering profiles and duricrusts of several ages, and extensive basaltic lava flows.

Early to mid Tertiary sediments

The oldest Cainozoic sediments in the area (mapped as **Ts** on Maps 1 and 2), consist of fluvial and colluvial sandstones and mudstones with local conglomerates. Some small areas of lacustrine clay and possible low grade diatomite are interbedded with fluvial sediments and basalts in the Spear Creek area, southeast of Basalt Yards. The Ts deposits have been deeply weathered in most places. Well sorted and cross-bedded sandstones occur locally but the fluvial deposits are generally poorly sorted and poorly bedded. This might be in part due to the deep weathering, which would have obscured the bedding and converted any labile grains into a clay matrix. However, some of the massive and poorly sorted deposits are low order valley deposits which are of mixed colluvial and low energy fluvial origin. These form small, discontinuous deposits which are hard to identify on the air photos and difficult to map on the ground as they can grade into *in situ* regolith on deeply weathered basement rocks.

The morphostratigraphic setting in some areas indicates that there are several ages of deposits mapped as 'Ts'. The oldest predate the formation of the undulating Featherby Surface, and now occur as isolated patches on the higher parts of the surface. Younger deposits lie in depressions within the surface and probably formed as the surface evolved. Still later deposits appear to bury parts of the Featherby Surface, and are interbedded with the basalts (see Ta below). These morphostratigraphic based distinctions are not possible in most areas, and so a single 'Ts' unit has been used on the maps. No diagnostic fossils have been found. Most of the 'Ts' areas cannot be assigned a reliable date beyond that of 'early to late Tertiary'.

In the eastern part of the Broken River Province tin bearing sediments with associated silcretes occur in a series of belts following old drainage lines (Burger, 1987). Though now dissected, the palaeo-drainage was probably part of the Featherby Surface. In places, as at the Ruxton deep lead, the old drainage runs in the opposite direction to that of the present rivers. The Ruxton deposit underlies a basalt dated at 26 Ma and the tin bearing deposit at Ugly Corner, 8 km west of Camel Creek homestead, is associated with two plugs dated at 21-22 Ma (Stephenson, 1989; Sutherland, 1977 and personal communication).

Deep weathering profiles and duricrusts of the Featherby Surface

Erosion and local deposition in the late Cretaceous and early Tertiary ultimately formed an undulating land surface, the Featherby Surface of Grimes (1979). This surface and the underlying Mesozoic and Tertiary sediments and older rocks were deeply weathered to form thick mottled and pallid zones and ferruginous or siliceous duricrusts. The weathering profile has been partly or wholly stripped from large parts of the area. The Featherby Surface and its weathering profile are best preserved on the Mesozoic sandstones in the Chudleigh Plateau, and adjacent to the Lucy Tableland in the north of the region (Figure 2).

The weathering profile is over 50 m thick in places but the base is gradational and irregular. Belts of deeper than normal weathering are interpreted as being areas of deeper weathering beneath old drainage lines. At Greenvale the deep weathering of a serpentinite body has formed an economic nickel-cobalt orebody (Burger, 1979), and deep weathering has affected several of the serpentinite bodies within the map area. The upper part of the profile is generally a thick ferruginised zone, locally indurated to form massive ferricrete or undifferentiated duricrusts. Silcretes occur locally and are commonly associated with Tertiary sediments in palaeo-drainage lines. They generally occur as solid silicified bands several metres thick, but cut out abruptly at the margins of the valleys. In some places the silcrete occurs as discrete nodules up to two m in diameter. In the Lake Lucy area silcreted palaeo-valleys have been filled by basalt flows dated at 19 and 27 Ma (Stephenson, 1989). Some of the silcretes may have formed at a different time to the main weathering profile. Other silcretes appear to grade into ferruginous profiles, suggesting that the nature of the duricrust may have been controlled by changes in the topography and groundwater conditions.

Where the deep weathering profile is well preserved and extensive it is generally concealed beneath a thick soil cover (mapped as **'TQr'** on Maps 1 and 2). Duricrusts (mapped as **Td**) are exposed on scarps, as small mesas and in the floors of palaeo-drainage lines. Areas which have been dissected, but in which the mottled or pallid zone is still extensively preserved, are shown by a screen pattern overprinted on the colour of the underlying rock unit.

Basalt provinces

The Tertiary to Quaternary basaltic rocks of the area are discussed in regional reviews by Stephenson & others (1980) and by Stephenson (1989, pp 93-96). Three main basalt provinces, McBride, Wallaroo, and Chudleigh, are represented in the sheet area, as well as some smaller areas of generally older rocks.

The main basalt provinces are of late Tertiary and Quaternary age and are described below. Older dissected basalt remnants occur in several areas.

Older basalts: An isolated lava field occurs south of the Lucy Tableland where two flows dated at 19 and 27 Ma (Stephenson, 1989, p 96) define complex branching patterns suggesting flow northwards down an ancient drainage system. There is an eruption centre at Noname Hill, but the source of the western flows is not known. Sutherland (1977) recognised two small plugs at Ugly Corner, 8 km west of Camel Creek, and later dated these at 21.6 and 21.2 Ma (Sutherland, personal communication). Nephelinite cropping out in a low lying basalt area 10-15 km west of Greenvale township has been dated at 11.0 Ma (unpublished AMDEL report to GSQ, 1985). Older basalts also occur farther south. Those adjacent to the lateritic plateau near Basalt Yards have nodular ferricretes developed on them, but their relationship to the main (Featherby Surface) weathering profile is uncertain. Southeast of Basalt Yards these basalts overlie lacustrine sediments and possible low grade diatomite mapped as 'Ts'. High level basalts north of the Clarke River at Cragie were dated by K/Ar at 7.89 and 8.8 Ma (unpublished AMDEL report to GSQ, 1985) and 7.78 Ma farther west near Dosey (J. Stephenson, personal communication). K/Ar dates of between 8.9 and 5.9 Ma have been obtained from high mesas farther south within the Nulla Province (Stephenson, 1989).

The **McBride Basalt Province** lies mainly outside the study area to the northwest. It was named by Twidale (1956a) and described by Best (1960) and White (1965), but the most comprehensive study was by Griffin (1977), who recognised 164 volcanic centres. The geochronology was studied by Griffin & McDougall (1975). Available data was also summarised by Withnall & Grimes (1991). The province is a large basaltic dome about 80 km across and up to 500 m thick. The basalts range in age from 2.7 to up to the relatively recent lavas erupted from the Kinrara Crater which yielded an apparent K-Ar age of 70 000 to 50 000 years that was regarded as a maximum by Griffin & McDougall (1975).

The **Chudleigh Province** occurs mainly in the southwestern part of the area, but a long flow erupted from Barkers Crater runs northwards along the Einasleigh River (Twidale, 1956a; Stephenson & others, 1980; Stephenson, 1989; Withnall & Grimes, 1991). The province is the northwestern of a group of three which also includes the Sturgeon and Nulla Provinces. There are many dissected basalt mesas and some younger basalt flows in the headwaters of the Clarke River, between the Chudleigh and Nulla Provinces. Stephenson & others (1980) included these in the Chudleigh Province. The province has several lava shields and many valley filling flows. There are many pyroclastic cones and several composite cones. It is smaller than the McBride Province and the lava piles are thinner with many inliers of basement rocks still exposed. The 100 km flow along the Einasleigh River was erupted from Barkers Crater near the head of the river. Stephenson (1989) reported an age of 0.25 Ma from the crater. Other long flows extend down valleys to the east and south-west. Flows in this province have not been given formal names: on the Broken River Special map (Map 2), they are divided into three age groups shown as 'Tb', '**TQb**', and '**Qb**'. The oldest dated basalts in the Chudleigh Province are on the lava shield of Umbrella Mountain in the Stopem Blockem Range which Stephenson (personal communication) dated at 8.03 Ma. He also obtained dates from a few of the younger vents in the province which ranged between 2.08 and 0.25 Ma. The isolated basalt mesas in the Clarke River headwaters gave dates of 8.9 to 7.8 Ma; a younger set of **Qb** flows in this area, that can be traced for at least 85 km down the Clarke River, were dated at 0.7 Ma near the source vent (Stephenson, 1989) and at 0.64 Ma near the eastern edge of the map sheet some 75 km downstream (unpublished AMDEL report to GSQ, 1985).

Stephenson (1989) reported that the dominant rocks in the province are moderately to strongly nepheline-normative basalts. Rock types include nephelinite, basanite, and mildly undersaturated alkali basalt, hawaiite, and minor mugearite. Upper-mantle and lower-crustal xenoliths are common at several localities.

The **Nulla Province** was first described by Wyatt & Webb (1970) who named many of the individual flows in its eastern part. It lies to the east of the Chudleigh Province. Stephenson & others (1980) dated many of the vents in this province and published a map of the major lava flows in the western part of the province. Ages range from 5.2 Ma up to the very young Toomba Flow which could be only 13 000 years BP (Stephenson & others, 1978). The province is built up of many superimposed east and north-east trending lava flows, with relatively inconspicuous lava cones and craters confined mainly to its western half. The oldest flows, which are exposed in gorges cutting through the basalts, have been deeply weathered.

Stephenson (1989) reported that the basalts in this province are predominantly nepheline-normative and have 'mg' ratios greater than 60. Xenoliths are rare. The younger flows are systematically richer in K_2O than the older ones.

Late Tertiary sediments

A widespread area of Tertiary sediments occurs in the north of the region around and partly including the Lucy Tableland. The sediments consist of high energy, very coarse to granule sized sandstones and conglomerates and lower energy sandy mudstones, together with a few lacustrine kaolinitic claystones and a bed of impure diatomite (Mockett, 1984). Mockett postulated an arid to semi-arid climate with high energy streams forming fan like deposits. The lacustrine deposits might be the result of basalt damming of the streams. The late Tertiary sediments could be up to 100 m thick, based on drilling by North Broken Hill (Young, 1979), but the thickness is variable because of an irregular basal topography and is generally less than 60 m. Some scarp sections show a series of well defined terraces, but these seem to be the result of zones of induration rather than lithological bedding.

The unit appears to have buried the Featherby Surface and hills of the latter protrude through it in places. Areas of older 'Ts' sediments beneath the Featherby Surface in this area are lithologically similar and in places show a similar degree of deep weathering effects. No unconformities have been recognised in the field, but the morphostratigraphy of the area suggests that older sediments could well be extending under the late Tertiary ones. The latter appear to overlie deeply weathered red 'mud' with possible relict basalt textures, at several points along the scarp north of Lucy Creek. A linear body of fresh basalt at Lake Lucy Hut, on line with the westernmost of these occurrences, yielded a K/Ar date of greater than 18.52 Ma. Stephenson (1989) reported another date of 27 Ma from this area. The basalts in this area sit in a bifurcating series of north-south trending palaeo-valleys and overlie valley floor silcretes developed on earlier Tertiary sandstones.

The top of the late Tertiary deposits is a flat depositional surface, which Grimes (1979) correlated with the Campaspe Surface that occupies a similar morphostratigraphic position in the Charters Towers area. However, the generally greater degree of deep weathering here might indicate an older age. To the west of the Burdekin River the late Tertiary sediments underlie basalt flows of the late Pliocene to Pleistocene McBride Province. The local flows that overlie the sediments have not been dated, but Griffin & McDougall (1975) reported a K/Ar date of 1.3 Ma from similar flows 20 km to the west which indicates a likely upper age limit for the sediments. The sum of this evidence suggests a late Tertiary age for the unit.

Residual soil and colluvium

Thick soil covers are associated with the weathering profiles on the Featherby Surface and the Campaspe Surface throughout the region. Younger soil cover and colluvium obscures the older rocks in several other areas.

Late Tertiary to Quaternary alluvial and colluvial deposits

Dissected high level alluvial plains and colluvial slopes occur in several places in the valleys of the major rivers and their tributaries, for example near the junction of the Clarke and Gregory Rivers. The depositional surface of these units is correlated with the Campaspe Surface in the Charters Towers area, and the sediments are of a similar age to the Campaspe Formation. However it is possible that these deposits may have formed at several stages during the late Tertiary and early Quaternary. Nodular ferricretes are commonly found on these surfaces and the deposits have been affected by some deep weathering, though not to the same extent as the older Cainozoic units.

Swampy and lacustrine areas associated with basalt flows

Swampy flats on the Chudleigh Plateau are the result of damming of prior drainage by the basalt flows. They are areas of clay and mud. Fine grained spring or lake deposits also occur associated with basalts in the Maryvale area. P. Burger (personal communication) reports vertebrate fossils from several sites in this area.

Late Tertiary weathering

In the late Tertiary and possibly into the early Quaternary, deep weathering continued, though to a lesser degree, and formed nodular ferricretes with poorly developed weathering profiles. These occur on the stable land surfaces which existed at that time: the Campaspe Surface on the TQa unit, the surface of the Lucy Tableland and also on the undissected remnants of the Featherby Surface. The effects of this weathering are generally overprinted on the older weathering profiles, and are difficult to recognise. However, the nodular ferricrete is a distinctive feature of this younger weathering event.

Quaternary alluvium

Alluvial deposits occur along the main drainage lines of the area. The characteristics of the deposits tend to reflect the local provenance. On the Broken River Special (Map 2), the modern stream deposits are mapped as 'Qha', and 'Qa' is used for the main alluvium.

BIOSTRATIGRAPHIC SUMMARY

(J.S. Jell, A. Simpson, R. Mawson & J.A. Talent)

Broken River Province strata, in particular the carbonate sequences of the Graveyard Creek Subprovince, have long been known to contain rich tabulate, rugosan, stromatoporoid and occasionally diverse brachiopod faunas. Studies of these faunas, and more recently investigation of the extensive conodont faunas, have produced a biostratigraphic framework for the Broken River Province. This has allowed intrabasinal correlation and the recognition of many of the international system, series and stage boundaries, especially for the Silurian and Early to Middle Devonian (Figures 85 and 86). Rich sponge, crinoid, trilobite, and fish faunas have also been collected from the carbonate rich sequences. Scattered graptolite, trilobite and shelly faunas from the siliciclastic sequences have provided useful faunal horizons. Systematic descriptions of these faunas are being documented by various specialists.

Daintree (1872) was the first to record fossiliferous Palaeozoic limestones in the region, and Etheridge (1872) described the first fossils, mainly corals. Hill (*in* White, 1965) listed several of the coral faunas collected by the joint BMR-GSQ field party in the late 1950s. This work provided other field parties with broad ages for the many Palaeozoic carbonates in the region. Ages were also known with some precision low in the sequence from a small number of graptolite localities (Thomas, 1960). Jell (*in* Wyatt & Jell, 1967) listed five coral faunas which have assisted in the correlation of Devonian units.

Telford (1975) undertook the first conodont study in the region and discriminated a succession of eight Silurian to Devonian faunas. This pioneering work, and the use of conodonts internationally to precisely identify stage boundaries, have led to extensive sampling for conodonts, and a corpus of data has been amassed. Simpson (in preparation) has discriminated four Silurian conodont zones, and has identified the approximate position of the Silurian-Devonian boundary. Mawson & others (1985) and Mawson (1987) presented data on the Early Devonian-Middle Devonian boundary in the Broken River Group. Mawson & Talent (1989) presented further data on the Emsian-Eifelian and Eifelian-Givetian boundaries. Conodont data has also formed part of a number of other studies, Talent & Yolkin (1987), Mawson & others (1989), and Talent (1989).

Other fossil groups recently studied from particular intervals within the Broken River Province, include corals (Yu & Jell, 1990), trilobites (Lane & Thomas, 1978; Hollaway, in press), crinoids (Jell & others, 1988) and vertebrates (Turner, 1982, 1993; Kemp & Turner, in press; Young, 1990). Previous summary accounts of the biostratigraphy are by Jell & others (*in* Withnall & others, 1988b; Jell & Talent, 1989; and Mawson & Talent, 1989).

ORDOVICIAN

Ordovician faunas in the Broken River Province are sparse. One graptolite specimen identified by A.H.M. VanderBerg as *Pendeograptus* cf. *pendens* (Elles & Wood) was collected in 1987 from the Judea Formation of the Graveyard Creek Subprovince at 7859-693485 in the vicinity of the gold washing plant near Diggers Creek (Withnall & others, 1988b). This graptolite has a range of Bendigonian to Chewtonian, i.e. lower Arenig. Two limestone outcrops bordering the eastern margin of the Georgetown Inlier at 7859-771890 and 753820 have been questionably included in the Judea Formation and have yielded conodonts (Palmieri, 1984) but they are not stratigraphically significant. No Late Ordovician rocks have definitely been identified from the Graveyard Creek Subprovince.

The Carriers Well Formation of the Camel Creek Subprovince has yielded rich coral and conodont faunas. The corals include: Rugosa - *Tryplasma* sp., *Bowanophyllum* cf. *pilatum* McLean & Webby, *Bowanophyllum* sp., *Palaeophyllum* sp. nov., *Proterophyllum?* sp., *Grewingkia* sp., *Streptelasma* spp.; Tabulata - *Agetolitella* sp., *Favosites* spp., *Pachyfavosites?* sp., *Heliolites* cf. *digitalis* Hill, *Heliolites* spp. nov. (2), *Navoites* spp. nov. (2), Pseudoplasmoporid gen. et. sp. nov., *Eolaminoplasma* spp., *Plasmoporella bacilliforma* Hamada, *Plasmoporella* spp. nov., *Neowormispora?* sp., *Propora* sp., *Sibiriolites* sp., *Catenipora* cf. *obliqua* Webby, *Catenipora* sp. nov., *Schedohalysites* sp., *Acanthohalysites* sp. nov., and *Quepora?* sp. Many of these corals also occur in the Fork Lagoon Beds of central Queensland. They indicate an Ashgil age for the fauna.

Telford (1972) listed eight species of conodonts from the Carriers Well Formation and suggested an Ashgil age for this unit. Palmieri (1978) reported a number of additional forms, correlating the assemblage with the upper faunas he described from the Fork Lagoon Beds, again indicating an Ashgil age. Further collections and a revision of nomenclature extends the list to include: *Walliserodus amplissimus* (Serpagli), *Ozarkodina sesquipedalis* Nowlan, McCracken & Chatterton, *Nordiodus italicus* Serpagli [MA], *Aphelognathus* cf. *floweri* Sweet, *Belodina? beiguoshanensis* Yu & Wang, "*Spathognathodus*"? *dolboricus* Moskalenko, "*Pseudooneotodus mitratus*" Moskalenki, *Panderodus gracilis* (Branson & Mehl) [MA], *P. panderi* (Stauffer), *Paroistodus mutatus* (Branson & Mehl), *Belodina compressa* (Branson & Mehl), *Pseudobelodina* aff. *profunda* (Branson & Mehl), *P.* aff. *longxianensis* Wang & Luo [MA], *P. dispansa* (Glenister), "*Rhodesognathus elegans*" (Rhodes), "*Strachanognathus parvus*" Rhodes, *Protopanderodus liripipus* Kennedy, Barnes & Uyeno, *Pseudooneotodus* aff. *beckmanni* (Bishoff & Sannamann), *Hamarodus* sp. indet.

Conodonts and corals from other limestones mapped as Carriers Well Formation are not well preserved nor as abundant, but they are not inconsistent with a Late Ordovician age (Palmieri, 1984).

Telford (1972) reported the occurrence of nautiloids from the Carriers Well Formation. Savory (1987, p. 32) observed poorly preserved Ordovician ostracodes from the Judea Formation.

SILURIAN TO BASAL DEVONIAN

Only isolated Llandovery horizons are known within the Quinton, Poley Cow and Crooked Creek Formations. These are based on scattered outcrops from which corals, trilobites, graptolites and conodonts have been recovered.

No unequivocal Wenlock strata have been identified within the Broken River Province.

The shelf carbonates of the Jack Formation are richly fossiliferous and include rugose and tabulate corals, stromatoporoids, conodonts, and locally brachiopods, gastropods, crinoids and trilobites. A sequence of three Ludlow conodont zones and the basal Devonian *woschmidti* Zone have been identified near the Broken River crossing (7859-695445) (Simpson, in preparation). Age data for the Jack Formation in other areas are less compelling.

Graptolites: White & Stewart (1959) and Thomas (1960) made the first reports of Silurian graptolites from the Broken River crossing (7859-695445) and further north (726507). Their localities have since been recollected and several new localities have been discovered. Dr R.B. Rickards has identified most of the material, which is from the Poley Cow Formation. One locality near the junction of Diggers Creek and the Broken River (7859-726447), 30 m from the base of the Poley Cow Formation, contains *Monograptus proteus* Barrande, *M. rickardsi* Hutt, *M.* cf. *halli* Barrande, *M. ?turriculatis* Barrande, *M.* cf. *marri* Perner, *Pristiograptus regularis* Tornquist, *Monoclimacis? galaensis* Lapworth, *Petalograptus ?kirki* Rickards and *Glyptograptus* sp. Another collection from the Broken River crossing (equivalent to BRS100 of Thomas, 1960), 200 m above the base of the formation, includes *?Monograptus proteus, M. rickardsi, M. marri, Pristiograptus regularis, ?Monoclimacis galaensis* and *Petalograptus palmeus* Barrande. Several other localities have been discovered near the crossing. *Monograptus* cf. *parapriodon* (Boucek) and *Monoclimacis griestoniensis griestoniensis* (Nicol) were identified from 7859-726507 from near Jessey's Lookout (equivalent to BRS101 of Thomas, 1960), but the stratigraphic position within the unit here is not as well controlled.

All the graptolite faunas from the Poley Cow localities indicate Late Llandovery (Telychian) ages from low in the *turriculatus* Zone to *greistoniensis* Zone.

Dr R.A. Henderson has collected a Late Llandovery graptolite fauna dominated by *Monograptus exiguus* from Gray Creek near Top Hut (7859-753715) in the Quinton Formation. This indicates a slightly younger age to those faunas in the Poley Cow Formation. Recently, more Early Silurian graptolite occurrences have been discovered, but these have not been studied in any detail.

Conodonts: One limestone locality from the Poley Cow Formation southeast of the Broken River crossing has yielded *Distomodus staurognathoides* (Walliser) and *?Astropentognathus irregularis* Mostler (Simpson, in preparation). These are indicative of the Late Llandovery *celloni* Zone and are in general accord with ages from graptolites in nearby pelitic rock types. A fauna of a similar age is reported from limestone clasts which outcrop towards the base of the Quinton Formation in Gray Creek (Aldridge *in* Lane & Thomas, 1978). Work on other isolated Early Silurian conodont faunas is continuing.

Ancoradella ploeckensis Walliser is found in basal samples of the Jack Formation near the Broken River crossing. This species has been regarded as a cosmopolitan Ludlow zonal indicator. However, recent work by Kleffner (1989) on northern hemisphere sections shows this species first appears in the latest Wenlock. Therefore, it is possible that the base of the Jack Formation may be as old as latest Wenlock. *A. ploeckensis* occurs through 95 m of section and overlaps with the Ludlow zonal indicator, *Polygnathoides siluricus* Branson & Mehl (Simpson, in preparation). Other species include: *Kockelella variabilis* Walliser, *K. absidata* Barrick & Klapper, *Ozarkodina excavata excavata* (Branson & Mehl), *Ozarkodina* sp., *Oulodus* sp., *Belodella anomalis* Cooper and *?Pedavis latialata* (Walliser). Telford (1972, 1975) reported *"Spathognathodus steinhornensis eosteinhornensis"* Walliser from the Jack Formation, which indicates a Pridoli age. However, this result has not been repeated in the most recent work.

Icriodus woschmidti hesperius Klapper & Murphy is found higher in the sequence in massive limestones of the Jack Formation. In the absence of graptolites, in particular the incoming of *Monograptus uniformis*, the first appearance of *I. w. hesperius* indicates the approximate position of the Silurian-Devonian boundary.

The type section of the Jack Formation in the Jack Hills Gorge differs from the sequence exposed at the Broken River crossing. Conodont faunas are sparse and age data equivocal. Some of the identified species recovered from the type section by Simpson (1983) include *Oulodus* sp., *Ozarkodina* sp., *O. excavata excavata, Panderodus unicostatus* (Branson & Mehl) and *Pseudooneotodus beckmanni* (Bischoff & Sannemann).

Preliminary examination of conodonts from the large limestone lens along the eastern margin of the belt of Perry Creek Formation near Christmas Creek homestead indicates that they are of Early Silurian age (*amorphognathoides* Zone) (B.G. Fordham, personal communication, 1987). Limestone clasts from conglomerates at 7959-213866 in Thatch Creek near the Lynd highway near the western margin of the belt may be earliest Devonian (*woschmidti* Zone). This is consistent with the westward younging indicated by sedimentary structures throughout the unit.

Corals: Munson (1987) studied corals from limestone units within the Quinton Formation and concluded that the faunas were Late Llandovery. Species include: *Tryplasma* sp., *Aphyllum* sp. nov., *Stortophyllum* sp., *Holmophyllum* sp. nov., *Dentilasma honorablis* Ivanovskiy, *Dentilasma* sp. cf. *honorablis, Dentilasma* sp., *Rhizophyllum* sp., *Cystiphyllum* cf. *breviaculeatum* Sytova, *Cystiphyllum* sp., *Palaeophyllum?* spp., *Pycnostylus* cf. *guelphensiformis* Zheltonogova, *Amplexoides* sp. nov., *Amplexoides* sp., *Lindstroemophyllum* sp., *Grewingkia* sp., *Cyathactis* sp., Gen. et sp. nov. 1-4, and tabulates. Faunas from limestone clasts within the Poley Cow Formation cropping out in the Broken River also indicate a Late Llandovery age. Coral faunas in allochthonous limestone lenses in the Crooked Creek Formation are not as well preserved, but may be slightly older than those from the Quinton and Poley Cow Formation.

Munson (1979) studied the rugose coral fauna from the middle section ("coral gardens" sequence of thin bedded limestone and siltstone) of the Jack Formation. This fauna closely resembles that of the Silverdale Formation at Yass and indicates a broad Ludlow age for this part of the Jack Formation which is in accordance with conodont evidence. Tabulate corals are also abundant in the "coral gardens" sequence, but have not been documented.

The youngest coral faunas in the area are from the upper 10 m of the Jack Formation at the western end of the Broken River Gorge (7859-655455), and as yet are undescribed. They are probably early Lochkovian in age.

Coral faunas from the upper section (massive limestone) of the Jack Formation and the Magpie Creek Limestone Member of the Quinton Formation have not been documented.

Corals occur in some of the allochthonous limestone blocks and limestone clasts in conglomerates in the Camel Creek Subprovince (eg., Perry Creek and Kangaroo Hills Formations). They have not been studied in detail, but are generally assigned to the Silurian or Early Devonian (Hill *in* White, 1965; Arnold, 1975). Halysitids in limestone blocks from the Perry Creek Formation indicate a Silurian age for at least some of them.

Other fossils: Lane & Thomas (1978) described a small trilobite fauna from a locality 600 m above the base of the Quinton Formation in Gray Creek at 7859-785738. Brachiopods, corals and bivalves from the same locality (Arnold & Henderson, 1976) remain undescribed. A small number of poorly preserved trilobite and brachiopod localities are known from the Poley Cow Formation (Jell & others *in* Withnall & others, 1988b). Hollaway (in preparation) has described a rich late Llandovery trilobite fauna from the Poley Cow Formation 1.2 km southeast of the Broken River

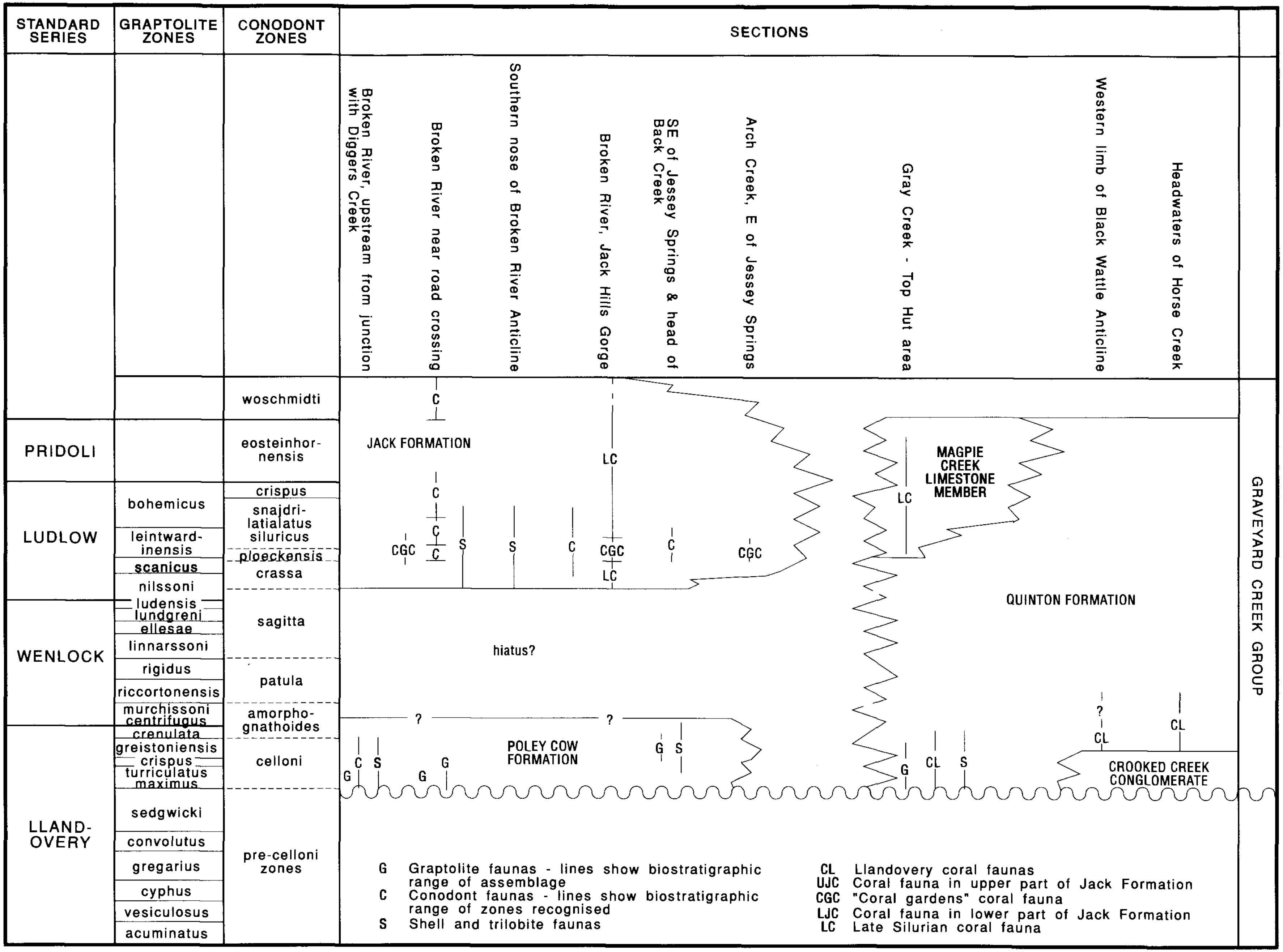


Figure 85. Summary of the biostratigraphy of the Graveyard Creek Group.

crossing at 7859-703434. He identified *Kosovopeltis* sp., *Proetus* (s.l.) sp., *Warburgella* sp., *Conoparia* sp., *Harpidella* sp., *Scharyia* sp., *Yoiungia* sp., *Sphaerocoryphe* sp., Encrinuridae n. gen., *Pacificurus* sp., *Coronocephalus*? sp., *Sthenarocalymene* sp., *Gaotania* sp. and *Ceratocephala* sp. Savory (1987) noted the occurrence of trace fossils in the Poley Cow Formation including *?Scalaratuba missouriensis, ?Chondites* sp., *?Helminthopsis* sp. and *?Zoophycus* sp.

The shelf carbonates of the Jack Formation are richly fossiliferous, in particular the "coral gardens" sequence. In the type section of the Jack Formation, the lowermost limestone unit contains large pentamerid brachiopods. Occasional atrypids are also found throughout the formation. Less calcareous horizons near the top of the "coral gardens" in the type section contain as yet undescribed faunas of brachiopods, bivalves and encrinurid trilobites. P.A. Jell (*in* Savory, 1987) identified the trilobites *Encrinurus* sp., *Cheirurus* sp. and *?Metacalymene* sp. indicating a broad Ludlow to Pridoli age. Apart from those groups already outlined, the "coral gardens" sequence also contains, stromatoporoids, medium and high spired gastropods, crinoid ossicles and calical plates, bryozoans and ostracodes.

Simpson (1983) reported dasycladacean algae, the codiacean algae *Lancicula* sp., foraminifera, sponge spicules, scyphozoans, molluscs, scolecodonts, disarticulated phyllocarid remains, and vertebrate remains including the acanthodians *?Gomphoncus* sp. and *Nostolepis striata*, from the Jack Formation at the Broken River crossing. These flora and fauna await formal description.

EARLY DEVONIAN (LOCHKOVIAN TO PRAGIAN)

As indicated above, the uppermost Jack Formation is Lochkovian, but how far it extends into the Lochkovian is questionable. Following a significant time break, the Shield Creek Formation with its two carbonate members, Martins Well Limestone Member and Arch Creek Limestone Member, span the Lochkovian/Pragian boundary. Late Pragian rocks have not been recognised.

Only sparse brachiopod, coral, stromatoporoid and conodont faunas have been collected from the uppermost Jack Formation. The arkosic sandstones of the Shield Creek Formation have yielded scant brachiopod and coral collections of little biostratigraphic significance. The limestone members the other hand have provided rich coral and brachiopod faunas which have been useful for detailed intrabasinal correlation of the limestones. Sequences of conodonts from both members have provided a chronostratigraphic framework for this interval. Locally in these members, there are rich assemblages of crinoids, sponges, and algae.

Corals: The Martins Well Limestone Member is characterised by the *Pseudamplexus* fauna of Jell (*in* Wyatt & Jell, 1967). Currently, the rugosans are being described and it seems that two assemblages will be recognisable. The fauna contains species of the following genera: *Pseudamplexus, Tryplasma, Cystiphylloides, Rhizophyllum, Calceola, Radiastraea, Martinophyllum, Gurievskiella, Radiophyllum, Tipheophyllum, Sinospongophyllum, Carlinastraea, Acanthophyllum, Dohmophyllum, Lyrielasma, Embolophyllum, Xystriphyllum, Favosites, Squameofavosites, Hattonia,* branching favositids, alveolitids, and heliolitids. The fauna indicates a late Lochkovian to Pragian age.

A similar fauna but not as extensive has been obtained from the Arch Creek Limestone Member, to the east of Jessie Springs Yu & Jell (1990) described the rugosans from a series of limestone lenses to the north of Pandanus Creek homestead (around 7859-610700) and equated this assemblage with the fauna of the Martins Well Limestone Member. Previously, Jell (*in* Wyatt & Jell, 1967) had referred to this assemblage as the *Spongophyllum* fauna, considering it as older than the *Pseudamplexus* fauna. At that time, the lenses were mapped at the top of the Graveyard Creek Formation, but recent mapping has shown them to occur in the Shield Creek Formation, and thus the *Spongophyllum* fauna is dropped.

Conodonts: Telford (1975) indicated that the Shield Creek Formation spanned the *pesavis-sulcatus* boundary based on the occurrence of *Pedavis pesavis* in the lower part of the Martins Well Limestone Member, but Klapper & Ziegler (1979) pointed out that some of the elements identified by Telford as *Pedavis pesavis* were closer to their new species *Pedavis* n. sp. B known from younger strata. Mawson & others (1989) showed that their extensive collections from the Martins Well Limestone Member and the Garra Formation of central New South Wales indicate that although the I element of the Martins Well form is different to that of *Pedavis pesavis* it is closer to a new species from the *pesavis* Zone of the Garra Formation than to *Pedavis* n. sp. B of Klapper & Ziegler, and that the sections of the Martins Well Limestone Member commence in the *pesavis* Zone. One specimen of *Kimognathus alexeii* occurred at 84.6 m above the base of the section indicating that this level is still in the *pesavis* Zone. The base of the *sulcatus* Zone has not been distinguished in the sections of the Martins Well Limestone Member, whereas *Eognathodus sulcatus* has been recovered at 28 m above the base of the section through the Arch Creek Limestone Member which is 2 m above the last occurrence of *Pedavis pesavis*.

Other fossils: The Shield Creek Formation contains rich algal floras, and sponge, brachiopod, crinoid (Jell & others, 1988), trilobite, and microvertebrate faunas.

Conodonts have been recovered from limestone clasts in a conglomerate and larger limestone blocks (olistoliths) in the Kangaroo Hills Formation cropping out in Perry Creek near 'Gadara' homestead (B.G. Fordham, personal communication, 1987); preliminary examination has identified possible Pragian forms, but other broken elements resemble forms from the *latialatus* Zone of the Late Silurian. More material is needed. Corals are present, but are mostly favositids and heliolitids which indicate a broad Late Silurian to Early Devonian range (Hill *in* White, 1965).

LATE EARLY TO EARLY LATE DEVONIAN (EMSIAN TO FRASNIAN)

The calcareous sequences of the Broken River Group have rich tabulate and rugose coral, stromatoporoid, brachiopod, crinoid, sponge, micro-invertebrate, and conodont faunas. Most groups apart from the conodont faunas (Telford, 1975; Mawson, 1987) and the crinoid calices (Jell & others, 1988) are still in the process of description. The extensive collecting for conodonts, in spite of the very low yields, have provided a biostratigraphic framework for the taxonomic studies of the various groups. Summaries of the recent conodont biostratigraphic work are given in Mawson & others (1985, 1988) and Mawson & Talent (1989).

Distributional data from the Broken River region is proving of prime significance for improving conodont correlations through the numerous Devonian carbonate units elsewhere in eastern Australia, and tightening correlation of the intricate pattern of transgression-regression events during the Early and Middle Devonian.

Following a considerable hiatus spanning the late *sulcatus* to *inversus* Zones, the conodont evidence indicates that sedimentation of the Broken River Group commenced in the late *inversus* Zone and continued almost

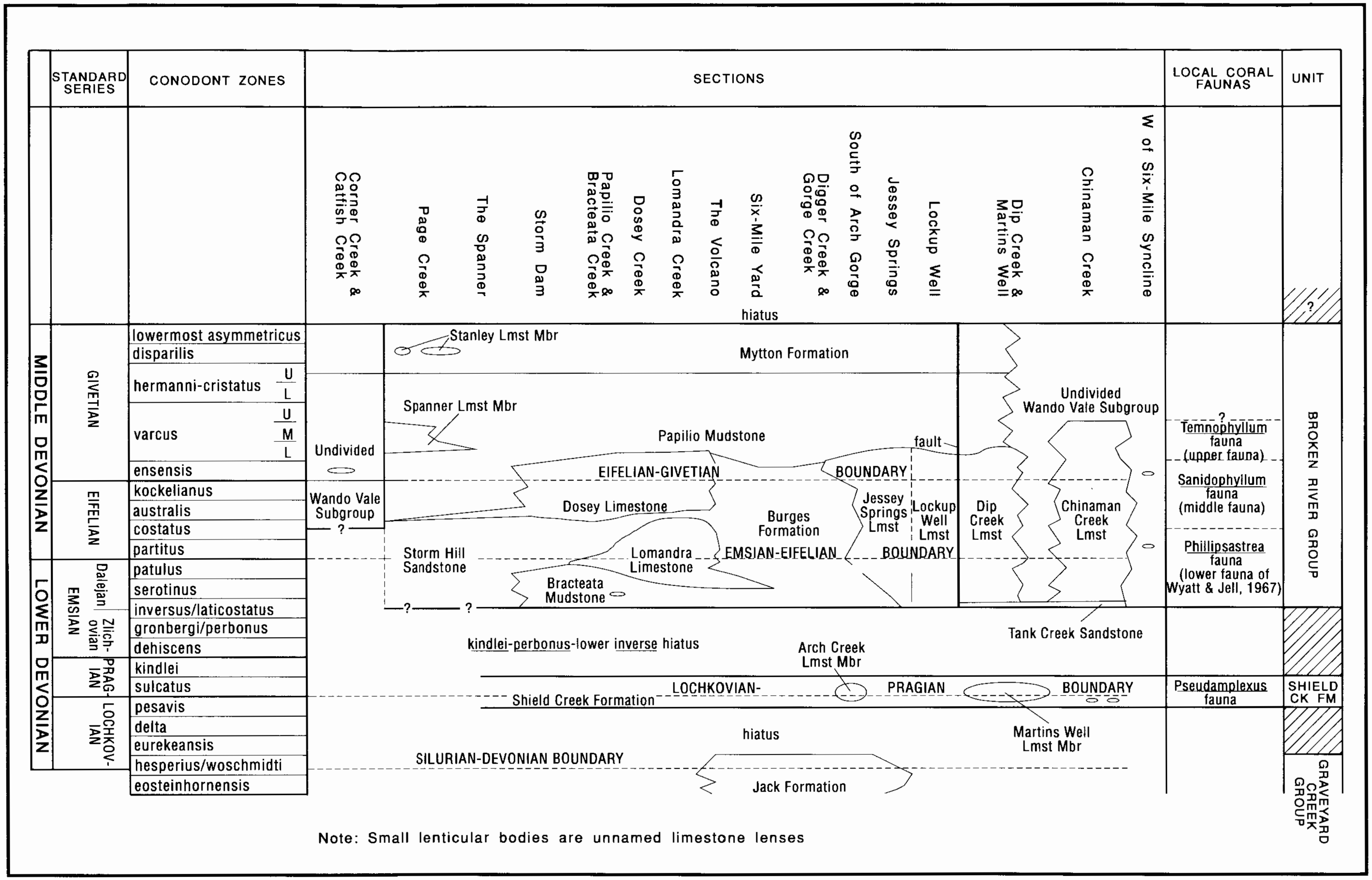


Figure 86. Summary of the biostratigraphy of the Devonian units in the Graveyard Creek Subprovince.

uninterrupted until at least the early *asymmetricus* Zone as shown in Figure 86.

Conodonts: In a general way, the conodont faunas from the carbonate units of the Gray Creek-Pandanus Creek area in the north, ie. the Chinaman Creek, Dip Creek and Lockup Well Limestones have especially sparse low diversity faunas, with predominance of simple cones and a dearth of polygnathids and icriodids that are vital for making precise stratigraphic correlations. The name *Pandorinellina* biofacies was proposed for these very shallow water faunas (Mawson & others, 1988). Polygnathids and icriodids are more prominent southwards in the Jessey Springs-Arch Creek area, with the polygnathid biofacies becoming better developed eastwards from Jessey Springs. In the Dosey Creek-Page Creek area, very shallow water faunas are characteristic of the Spanner Limestone, the Stanley Limestone Member of the Mytton Formation, and the Lomandra Limestone west of Dosey Creek; there is an appreciable increase in polygnathids towards the northeast.

In summary, the overall picture presented by conodont biofacies is fairly persistent shallow platform faunas in the north ('Pandanus carbonate platform') and southwest ('Dosey-Craigie platform') and significantly deeper eastwardly-deepening polygnathid biofacies occurring through the centre of the region ('Burges submarine valley' of Mawson & Talent, 1988).

Conodont work is documenting a distinctive transgression-regression pattern (Wyatt & Jell, 1980; Talent & Yolkin, 1987). An abrupt, widespread and well- documented transgressive event occurred in eastern Australia, corresponding with the late *inversus* Zone in the Broken River area. A discrete *inversus* interval occurs in the lowest levels of the Lockup Well and Chinaman Creek Limestones in the Broken River Group in the northern Broken River region. In Lomandra Creek, south of the Broken River, most of what is taken to be equivalent to the *serotinus* and upper *inversus* Zones farther north is represented by up to 230 m of shales and siltstones of the Bracteata Formation. A minor development of carbonates about 175 m above its base in Lomandra Creek has a rich *serotinus* fauna. Overlying these shales, and having commenced accumulation before the end of the *serotinus* Zone, is an extensive carbonate development, the Lomandra Limestone, taken to represent a further transgressive event which is believed to be especially significant because of precise correlation with one of the most widespread transgressive events on the Euramerican continent, the inception of the major transgression Ic of Johnson & others (1985).

The most important carbonate units that continued accumulation through the Eifelian into the Givetian, ie. the Dosey, Chinaman Creek, Lockup Well and Jessey Springs Limestones all seem to have terminated during the middle *varcus* Zone. In the Dosey Creek-Storm Dam area where this event has been best studied, it corresponds with a rapid change to deeper and quieter water biofacies, from very shallow *Pandorinellina* biofacies to polygnathid biofacies and to macro-faunas of greatly increased diversity. It seems to align rather well with global eustatic rise that occurred within the middle *varcus* Zone.

Icriodids that compare well with *Icriodus symmetricus* have been recovered from the highest calcareous horizon in the Mytton Formation, including a juvenile specimen from high in the Stanley Limestone Member (Mawson & Talent, 1989). This dates the Mytton Formation as possibly *disparalis* or, more probably, *asymmetricus* Zone, ie late Givetian or early Frasnian.

Corals: Jell (*in* Wyatt & Jell, 1967) differentiated three coral faunas within the Chinaman Creek Limestone. These have been used for correlation of the other limestone sequences of the Wando Vale Subgroup. The lowest fauna is characterised by diverse phillipsastreaid elements including species of *Phillipsastrea*, *Phacellophyllum*, *Thamnophyllum*, and *Protomacgeea*. Other common genera include *Acanthophyllum*, *Xystriphyllum*, *Lyrielasma*, *Taimyrophyllum*, *Endophyllum*, *Stringophyllum*, *Sociophyllum*, *Calceola*, *Cystiphylloides*, *Sinospongophyllum*, as well as numerous tabulate genera. This fauna is referred to as the *Phillipsastrea* fauna and is of Late Emsian-Early Eifelian age.

The middle fauna is characterised by endophyllids including the genera *Endophyllum* and *Sanidophyllum*, and is named the *Sanidophyllum* fauna. Other coral genera include *Dendrostella*, *Spongophyllum*, *Australophyllum*, *Xystriphyllum*, *Acanthophyllum*, *Taimyrophyllum*, *Thamnophyllum*, *Disphyllum*, *Cystiphylloides*, and numerous tabulates. In this part of the sequence, the cylindrical or stick-like stromatoporoid *Amphipora* forms thick beds interbedded with thick beds of massive stromatoporoids. Towards the top of the interval the large brachiopod *Stringocephalus* sp. is first encountered. This fauna is Eifelian to earliest Givetian in age.

The uppermost fauna is not as rich and is called the *Temnophyllum* fauna, a common genus in the more limey beds. The other elements include tabulates, and species of *Dendrostella*, *Stringophyllum*, *Endophyllum*, *Calceola*, *Cystiphylloides*. *Amphipora* is also common, as is *Stringocephalus*. The fauna is Early to Middle Givetian in age. It shows strong similarities to the upper rugose coral faunas of the Fanning River Group of the Burdekin Basin.

South of the Broken River the *Sanidophyllum* fauna is found in the Dosey Limestone. The overlying fauna of the Papilio Formation is equivalent of the *Temnophyllum* fauna and is characterised by large solitary rugose corals more adapted for muddy conditions than those of the *Sanidophyllum* fauna. This fauna includes large species of *Dohmophyllum* and *Cystiphylloides*. *Disphyllum*, *Calceola*, and numerous small solitary forms are common; platy *Alveolites*, domal heliolitids, and *Thamnopora* spp. are scattered throughout the sequence.

The youngest coral fauna of the Broken River Group is from the Stanley Limestone Member of the Mytton Formation. This fauna has only recently been found and has not yet been assessed.

Other fossils: The Broken River Group contains rich brachiopod faunas and these are currently being described. The fish faunas have been studied by Young (1990), Kemp & Turner (in press) and Turner & Jell (in preparation). Crinoids have been described by Jell & others (1988). A variety of other invertebrates and plants is awaiting description.

LATE DEVONIAN

Only a few Late Devonian faunas are known. *Cyrtospirifera* sp. and other brachiopods from the Bulgeri Formation suggest a Frasnian or early Famennian age. Conodonts from a dark limestone in the Teddy Mount Formation include *Bispathodus aculeatus* (Branson & Mehl), *B. aculeatus aculeatus* (Branson & Mehl), *B. aculeatus plumulus* (Rhodes, Austin & Druce), *B.* cf. *bispathodus* Ziegler & others and *B. stabilis* (Branson & Mehl) and suggest latest Famennian age (Lang, 1985, 1986a).

Turner (1982) studied microvertebrates from what is now the Teddy Mount Formation, and found shark teeth which she correlated with similar elements from Late Devonian faunas in North America, Europe, north Africa and India. The same elements were found in the Myrtlevale Formation of the Burdekin Basin, dated by conodonts as late Famennian (Pickett, 1981).

Leptophloeum australe (McCoy) is locally common in the Bulgeri Formation and lower part of the Venetia and Ruxton Formations. It is generally regarded as Late Devonian or Tournaisian in age, but the fact that it has not been observed in the plant-rich part of the Teddy Mount Formation above the late Famennian conodont localities suggests that it is restricted to the Devonian.

CARBONIFEROUS

Jell & Playford (1985) summarised the known palaeontological evidence for the age of the Clarke River Group. The marine rocks near the base of the Venetia Formation contain good faunas, but they have not been described. The faunas at Gill Creek and Gray Creek were initially assigned to the Tournaisian and "Devonian or Lower Carboniferous" respectively (Hill in White, 1965). Henderson (*in* Arnold, 1975) considered a fauna from the Gray Creek area to be of Tournaisian age. Conodonts recovered from the Clarke River Group in the Gray Creek area (Mawson, unpublished data) are *Bipathodus aculeatus plumulus* and *Pseudopolygnathus primus*, suggesting a latest Famennian to earliest Tournaisian age. Conodonts from impure limestones at the base of the Ruxton Formation near Blue Range are probably of a similar age (B.G. Fordham, personal communication, 1987), but have not been studied in detail.

The Ruxton Formation also has a diverse marine fauna which has not been studied in detail. Woods (1960, unpublished) identified a fauna from the Francis Creek area and suggested a Tournaisian age. Edwards (1977) described the marine fauna in an unpublished thesis, which was the basis for the Tournaisian age for the unit given by Wyatt & Jell (1980). Edwards (1977) identified two faunas for which he proposed a range of earliest to late middle Tournaisian based on the scheme of Roberts (1975).

Abundant lepidodendroid plant fossils in the Dyraaba Member, the upper part of the Teddy Mount Formation are presumably of Tournaisian age.

Playford (1988) examined poorly preserved, sparse microfloras in the Venetia Formation from GSQ Clarke River 5. A Tournaisian age is indicated for the unit and a sample at 713 m contains an assemblage with an implied late Tournaisian age.

The age of the Lyall Formation is based on miospores recovered from GSQ Clarke River 5 (Playford, 1988) and outcrop (Playford, 1983, 1986, 1988). A sample from the 'lower' Lyall Formation contained a scant palynoflora, probably representative of the Visean *Anapiculatisporis largus* assemblage (Visean). The 'upper' Lyall Formation in GSQ Clarke River 5 produced stratigraphically useful assemblages, clearly part of the *A. largus* Assemblage, and in particular of the younger representation of that assemblage of late Visean age. This last age matches that obtained by Playford (1986) for a sample now known to be from near the base of the 'upper' Lyall Formation. The latest Carboniferous - earliest Permian age reported by Jell & Playford (1985) and discussed briefly in Playford (1988) came from rocks now assigned to the Wade beds.

The flora from the Wade beds in Cattle Creek was first described by White (*in* White, 1965) who suggested a lower Carboniferous age. The flora was reassessed by Rigby (1973) who proposed a Late Carboniferous age on the basis of the *Pseudorhacopteris* flora which is now considered to range into the Early Permian. The flora included *Pseudorhacopteris ovata* (McCoy) and *Calamites peruvianus* Gothan.

A SEQUENCE STRATIGRAPHIC FRAMEWORK FOR THE GRAVEYARD CREEK SUBPROVINCE

(S.C.Lang & C.R.Fielding)

Since the late 1980s, the concepts of sequence stratigraphy have had a major impact worldwide on stratigraphic and sedimentologic thought. Sequence stratigraphy grew largely from developments in seismic stratigraphy during the 1970s (Payton, 1977), although the concepts were built on older work by Sloss (1963, 1972) and Frazier (1974). Initial work on sequence stratigraphy was mainly carried out by EXXON Researchers under corporate seclusion, and it was only in the late 1980s that the concept received a major advance with the publication of several symposium proceedings and books including Nummedal & others (1987), Bally (1987), Wilgus & others (1988), James & Leckie (1988) and Van Wagoner & others (1990).

Sequence stratigraphic concepts have fundamentally changed our assessment of the geological history of the Graveyard Creek Subprovince. The concepts provide a predictive framework for modelling basin development on a regional and inter-regional scale. Lithostratigraphic and biostratigraphic data can now be better integrated to view the basin succession as complex, chrono-stratigraphically constrained units, deposited as a direct consequence of factors such as changes in relative sea level, absolute water depth, and sediment supply (Van Wagoner & others, 1988). A sequence stratigraphic framework for the relatively complete succession of the Graveyard Creek Subprovince enables us to determine the effects of eustacy versus tectonism, and allow more accurate regional correlations with surrounding basins.

The sequence stratigraphic terminology used in this chapter follows the definitions of Posamentier & others (1988) and Van Wagoner & others (1988). The term "sequence" has been used in previous chapters of this report without the specific meaning it has in the context of sequence stratigraphy. Walker (1990) suggested that the term "succession" should be used instead of "sequence", if a sequence stratigraphy connotation is not intended. This approach is adopted in this chapter.

In the previous chapters, the Silurian-Carboniferous strata of the Graveyard Creek Subprovince are shown to comprise a thick, carbonate and siliciclastic succession containing complex vertical and lateral facies variations. The interpretation of these facies illustrate vertical and lateral changes in depositional environments. Many of these changes have been interpreted in terms of transgressive and regressive events by most previous workers (White, 1965; Jell, 1967; Marsden, 1972; Wyatt & Jell, 1980; Simpson, 1983; Jell & Playford, 1985; Withnall, 1985; Lang, 1985, 1986a; Law, 1985; McLennan, 1986; Talent & Yolkin, 1987; Mawson, 1987; Withnall & others, 1988b; Talent, 1989; Mawson & Talent, 1989; Jorgensen, 1990; Blake, 1990; Humphries, 1990; Aung, 1991).

This considerable volume of data has been re-evaluated in the light of sequence stratigraphic concepts and recently acquired biostratigraphic data. As a result ten major cycles of sedimentation have been recognised. Each cycle may contain several sequences. Cycles 1 and 2 comprise five sequences in the Graveyard Creek Group, labelled GR1 to GR5. Cycle 3 comprises most of the Shield Creek Formation and contains only one sequence (SC1). Cycles 4 and 5 represent the uppermost Shield Creek Formation and the Broken River Group, and contain seven sequences labelled BR1 to BR7. The Bundock Creek Group contains Cycles 6 to 10, which are in turn divided into ten sequences labelled BU1 to BU10. The cycles and their constituent sequences are summarised in Figures 87 to 93.

The main criteria used to distinguish between major cycles of sedimentation include (i) regional unconformities, (ii) abrupt change of facies, (iii) gross stratigraphic architecture, and (iv) time gaps in the stratigraphic record or "condensed sequences".

For most of the cycles, where eustatic sea level fluctuations are considered important controls, especially Cycles 1 to 5, each sequence will be described in terms of the nature of the sequence boundaries, the styles of sedimentation in the interpreted low stand (LST), shelf margin (SMW), transgressive (TST), and high stand (HST) systems tracts, and the stratigraphic and temporal relationships with related sequences outside the basin. Where tectonic controls are considered the dominant process controlling relative sea level, the cycles are divided into cyclothems (eg Cycles 6, 7 and 10). Important to the recognition of both types of cycles is the recognition of bounding unconformities and their correlative conformities.

Van Wagoner & others (1988, 1990) recognised two types of sequences defined on the arrangement of system tracts and the nature of sequence boundaries. Type-1 sequences comprise LST, TST and HST, bounded beneath by Type-1 unconformities and their correlative conformities. Type-1 unconformities are recognised by subaerial exposure and erosion, onlap of overlying strata, and a basinward shift in facies, such that shallow marine or non-marine facies overlie deeper marine facies. Type-1 boundaries form when the rate of eustatic fall exceeds the rate of subsidence, resulting in a relative fall in sea level at the depositional shoreline break. Type-1 unconformities may be tectonically controlled. They are associated with a relative fall in sea level and local or widespread subaerial erosion. These boundaries cannot be precisely correlated with global sea level falls, but can be correlated with local or regional tectonic events.

Type-2 sequences are composed of SMW, TST and HST bounded by Type-2 unconformities and their correlative conformities. Type-2 unconformities are also recognised by subaerial exposure, a basinward shift in facies, and some onlap of overlying strata, but typically lack associated widespread subaerial erosion. Type-2 boundaries form when the rate of eustatic fall is slightly less than or equal to the rate of subsidence, resulting in no relative fall in sea level at the depositional shoreline break.

GRAVEYARD CREEK GROUP

Cycle 1 - Early to Middle Silurian lower Graveyard Greek Group

Cycle 1 comprises the Poley Cow and lowermost Jack Formation, and contains two sequences (Sequences GR1 and GR2; Figure 87). The lower boundary of Cycle 1 is a major regional unconformity which overlies the Judea Formation and Netherwood Tonalite. The upper boundary is marked by the disconformity beneath the clastic sediments of the middle Jack Formation.

Sequence GR1 begins with cobble and pebble conglomerates, which range in thickness from a few metres to many tens of metres, and clearly fill an irregular surface cut into the basement. In the southern part of the area (eg Broken River) these conglomerates are extensive, and comprise

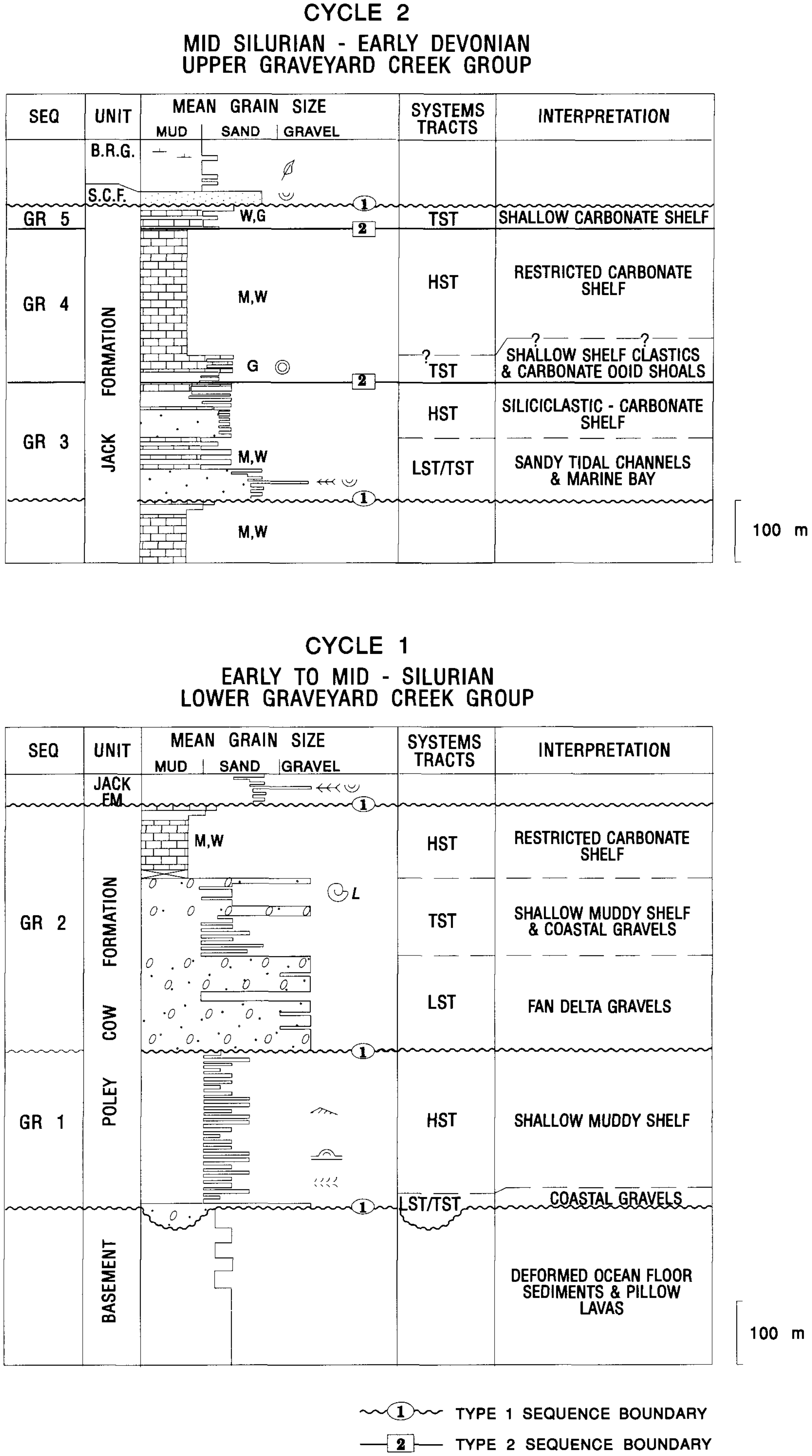


Figure 87. Sequence stratigraphy of the Graveyard Creek Group (Cycles 1 and 2).

clast-supported pebble and cobble polymictic conglomerate containing clasts derived from the underlying basement. The equivalent of these conglomerates in the northern part of the area is the Crooked Creek Conglomerate, which underlies the Quinton Formation. These conglomerates are abruptly overlain in the southern area by a thick succession of interbedded mudstone and arenite of the lowermost Poley Cow Formation. The important feature of the succession is that it represents deposition in a shallow, muddy shelf environment, as indicated by hummocky cross-stratification, tracks and trails, and ripple cross-lamination.

Sequence GR1 is interpreted as a thin LST or TST at the very base, overlain by a thick HST. The low stand conglomerates are interpreted as coastal gravels deposits, overlain by transgressive and high stand, shallow muddy shelf deposits.

The age of Sequence GR1 is poorly constrained, but graptolites from the lower Poley Cow Formation near the Broken River crossing suggest a late Llandoverian age. Sequence GR1 can be correlated with similar Early Silurian sequences in the Hodgkinson Basin.

Sequence GR2 begins with a thick conglomerate succession in the middle of the Poley Cow Formation. The nature of the bounding surface between these conglomerates and the underlying lower Poley Cow Formation of Sequence GR1 is sharp and erosional. This succession represents a thick LST and TST, which are interpreted as mainly fan delta gravels and shallow muddy shelf and thin coastal gravels. *Lingula* has been recovered from the upper part of this succession. This clastic succession is abruptly overlain by the lower limestone member of the Jack Formation. The boundary is sharp but appears to be conformable. The lower limestone member of the Jack Formation consists mainly of grey carbonate mudstones and wackestones and is interpreted as a restricted carbonate shelf HST succession.

The age of Sequence GR2 is considered on stratigraphic grounds to be Llandoverian to Ludlow. This sequence may be comparable to Early to Middle Silurian successions in the Hodgkinson Basin to the north.

Cycle 2 - Middle Silurian to Early Devonian upper Graveyard Creek Group

Cycle 2 comprises Sequences GR3 to GR5. The base of cycle 2 is marked by a sharp boundary at the top of the lower limestone member of the Jack Formation, and the top is marked by the disconformity at the base of the Shield Creek Formation.

Sequence GR3 begins with pebbly conglomerates, which are overlain by mainly pebbly sandstones with bidirectional cross-bedding and trough cross-bedding. These are overlain in turn by a succession of thin-bedded siltstone and micaceous arenite which have *in situ* corals and become more carbonate-rich up section ('coral garden' facies). The lower part of GR3 is interpreted as sandy tidal channels and marine bay deposits that accumulated as part of a LST/TST succession overlying a Type-1 unconformity. The upper part of Sequence GR3 comprises HST siliciclastic and carbonate shelf deposits.

Sequence GR4 overlies Sequence GR3 apparently conformably, although there is a sharp change in facies from siliciclastic-carbonate shelf deposits of the upper part of GR3 to shallow shelf clastics and carbonate ooid shoals of lowermost GR4. The latter are interpreted as TST deposits that overlie the HST deposits of GR3, without relative sea level having fallen beyond the shelf break. The ooid shoals are overlain by a very thick succession of carbonate mudstone and wackestone (upper limestone member of the Jack Formation) which are interpreted as strictly carbonate shelf facies deposited in a HST.

Sequence GR5 is just below the top of the Jack Formation in the Jack Hills Gorge, and is a coarse-grained carbonate succession that contains large stromatoporoids and corals. The succession is interpreted as shallow carbonate shelf deposits in a HST.

The ages of Sequences GR3 to GR5 are constrained by conodont data (Simpson, 1983). Sequence GR3 is considered to be early Ludlow in age, whereas GR4 is probably mid Ludlow and the uppermost part of the Jack Formation, Sequence GR5, is probably late Ludlow to Lochkovian. Simpson (1983) determined that the uppermost sequence (GR5) is much thicker in the Broken River crossing area. This indicates that the upper part of the succession in the Broken River Gorge area has been largely eroded by the overlying cycle. Cycle 2 can be correlated with the Middle Silurian to Early Devonian successions of the Hodgkinson Basin to the north.

SHIELD CREEK FORMATION AND BROKEN RIVER GROUP

Cycle 3 - Early Devonian lower Shield Creek Formation

Cycle 3 comprises the lower Shield Creek Formation which includes one sequence (SC1) consisting of the lowermost siliciclastic rocks, the Martins Well Limestone Member, and overlying calcareous siliciclastic rocks (Figure 88). Mawson & Talent (1989) reported a significant time break between the base of the Shield Creek Formation and the uppermost Graveyard Creek Group. This boundary between Cycle 3 and Cycle 2 is marked by a sharp introduction of siliciclastic sediments and is therefore considered to be a major Type-1 sequence boundary. Pebbly sandstones and coarse clastics in the uppermost part of the Shield Creek Formation, in the south, may be part of Cycle 4.

Sequence SC1 begins with cross-bedded clastics, including bi-directional cross-bedding, which are interpreted as sandy tidal channels, and assigned to a LST. These are overlain by slightly shaly and calcareous sandstones which are interpreted as a shallow siliciclastic shelf succession deposited in a TST. The development of Martins Well Limestone Member and associated limestone lenses is considered to represent carbonate production in the uppermost part of the TST and the HST. The TST/HST formed a carbonate and siliciclastic shelf succession including bioherms and algal rich shoals. This succession shallows upward into calcareous shale and sandstones deposited on a shallow marine shelf.

The age of Cycle 3 is Lochkovian to Pragian. Conodont data suggests significant time-breaks between the Martins Well Limestone Member and the carbonate units in the underlying Graveyard Creek Group and overlying Broken River Group. However, it is not known to what extent these breaks can be accounted for by the intervening unfossiliferous siliciclastic units.

Cycle 4 - Early to Middle Devonian uppermost Shield Creek Formation and lower Broken River Group

In the north in the Dip Creek and Chinaman Creek areas, the uppermost boundary of Cycle 3 is marked by a Type-1 unconformity at the top of the Shield Creek Formation. This is at the base of quartzose sandstones immediately underlying limestones of the Broken River Group. These include the Tank Creek Sandstone and a thin unmapped quartzose sandstone at the base of the Dip Creek

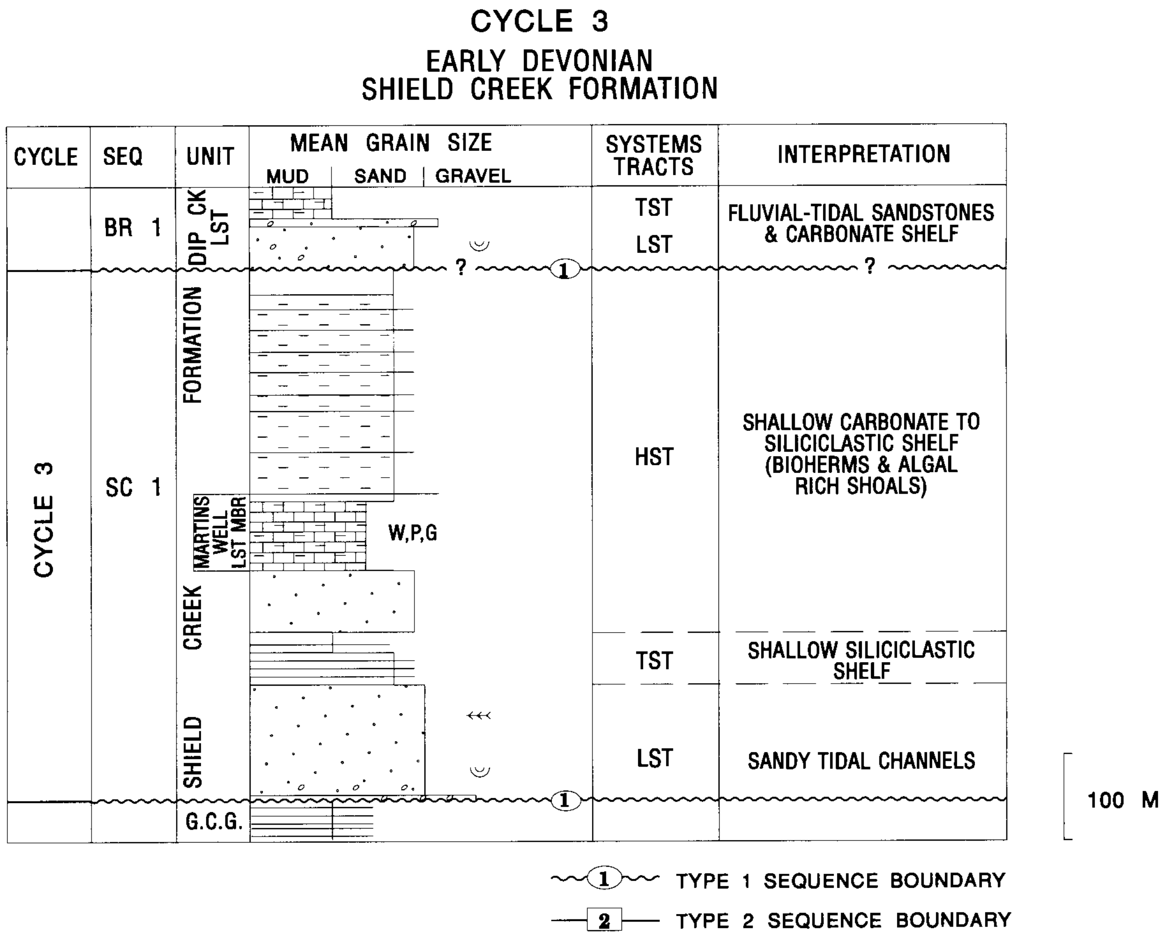


Figure 88. Sequence stratigraphy of the Shield Creek Formation (Cycle 3).

Limestone. Conodont data indicate a significant hiatus between samples from the Martins Well Limestone Member and from the lowermost part of the Broken River Group (Mawson & Talent, 1989).

Cycle 4 (Figure 89) comprises three sequences, BR1, BR2 and BR3, making up a major unconformity bounded sequence of siliciclastics and carbonates ranging in age from Emsian to Eifelian (*inversus* to *costatus* Zones). Cycle 4 can be mapped across the basin using a combination of lithostratigraphic, biostratigraphic and facies mapping. Mawson & others (1985), Withnall & others (1988b), Mawson & Talent (1989), Talent (1989), and Aung (1991) have extensively documented the variety of facies and biofacies within Cycle 4 rocks. Cycle 4 has been interpreted in this volume as representing a ramp complex and can be probably be divided into three main system tracts.

On a broad scale, BR1 comprises a LST and TST, whereas BR2 represents essentially a HST.

Sequence BR1 consists of cross-bedded, quartzose, fluvial/tidal sandstones of the Shield Creek Formation in the south near the Broken River, and quartzose sandstone of the Tank Creek Sandstone in the north. These are overlain by TST/HST shelf mudstone and minor clastics and carbonates of the Bracteata Mudstone and lowermost Burges Formation in the south, and marly equivalents in the north.

Talent (1989) and Jell & others (this volume) suggest that the transgressional event represented by BR1 correlates with widespread transgression on the Euro-American Continent. Johnson & others (1985) referred to this transgression as T-R Cycle Ic. However Cycle Ic begins late in the *serotinus* Zone immediately following a distinctive relative sea level low (Figure 91). This relative sea level low appears to be slightly younger than the *inversus* Zone to *serotinus* Zone transgression, which is probably best correlated with Sequence BR1. Therefore it is considered that Sequence BR1 is more likely to be related to T-R Cycle Ib of Johnson & others (1985), with a maximum flooding event occurring in the *serotinus* Zone just beneath the overlying Sequence BR2, which is best correlated with T-R Cycle Ic.

Sequence BR2 starts at the base of the Lomandra Limestone on the southern limb of Dosey Syncline. At the base of the limestone, a Type-2 sequence boundary can be recognised, separating a TST of mainly shelf carbonates (lagoonal and shelf facies) from the underlying deeper water shelf mudstones of the Bracteata Mudstone. However, in most places this boundary appears conformable. The upper part of Sequence BR2 comprises a thick HST succession of mainly carbonate shelf.

The best known location to observe the sequence boundary between BR1 and BR2 is at 7858-621414, where lithofacies of the lower 30 m of the Lomandra Limestone form a coarsening upwards succession. The succession includes calcareous arenite and sandy limestone at the base grading up to limestone conglomerate. The clasts include limestone boulders and cobbles, large bioclasts and coarse lithic pebbles. The matrix is a mixture of quartzose sand and carbonate mud mixed with intraclasts and various bioclasts (in particular crinoid ossicles). This facies is clearly indicative of erosion of an underlying carbonate siliciclastic shelf, and can only be rationalised by a relative drop in sea level. The difficulty is determining whether this boundary at the base of the Lomandra Limestone represents a Type-1 or Type-2 sequence boundary. The latter is preferred because it cannot be directly related to a major relative drop in sea level, unless one argues for a tectonically induced sequence boundary.

On the northern side of the Dosey Syncline and northeast of the Broken River to at least Gorge Creek, the boundary is marked by the abrupt entry of thick polymictic conglomerate-calcirudite-arenite lithofacies typical of the Burges Formation (Figure 89). These conglomeratic rocks were laid down during a period of relative sea level lowering. This lowering resulted in the erosion of the underlying carbonate and muddy shelf sequence, and the release of terrigenous siliciclastics across the shelf, contributing to a shelf margin wedge (SMW). Much of this material would have been reworked by the incoming transgression at the base of BR2. Conglomeratic facies thin out towards the northeast, and, on the southern side of the Jessie Springs Anticline, the boundary appears to lie within a sequence of shale and thin-bedded limestone low in the sequence (section SAG W of Mawson & Talent, 1989).

Clearly a basinward shift in facies occurred before the end of the *serotinus* Zone and this appears to coincide closely with the marked shallowing event at the base of T-R Cycle Ic.

In the north, the sequence boundary is marked by the abrupt entry of siliciclastics within the lower parts of the Chinaman Creek Limestone. However, it has not been located as yet within the other units of the Pandanus-Jessie Springs area, or within the undifferentiated Wando Vale Subgroup.

Sequence **BR3** begins with a sharp boundary at the base of the Storm Hill Sandstone. The Storm Hill Sandstone which consists of coarse-grained siliciclastics, is interpreted as a fan delta and shallow marine, clastic succession. The abrupt entry of siliciclastics into the basin can only be rationalised in terms of a major relative drop in sea level. Therefore the base of the Storm Hill Sandstone is interpreted as a Type I sequence boundary, where relative sea level has dropped below the shelf margin. Immediately overlying the Storm Hill Sandstone, which is interpreted as a LST, is a thick succession of relatively fine-grained carbonates (wackestones, packstones and mudstones), interpreted as a TST. These carbonates, which form the lower Dosey Limestone, are interpreted as shelf carbonates deposited in shallow lagoons, with minor carbonate build-ups.

The upper part of Sequence BR3 comprises mainly grainstones, packstones, and some limestones and wackestones of the upper Dosey Limestone. These are interpreted as mainly shelf carbonates (particularly carbonate shoals) deposited in a HST. Numerous thin siliciclastics intervals occur within the succession, implying a relatively proximal supply of siliciclastics sediments. Taken together the whole Dosey Limestone represents a major shallowing upwards succession with a TST in the lower half and a HST in the upper half.

Correlating Sequence BR3 across the Broken River area is difficult outside the southern Dosey Platform. In the Pandanus-Jessie Springs area the boundary at the base of Sequence BR3 is less obvious. It is reflected only by thin sandstone and sandy limestone beds in the middle of the Chinaman Creek Limestone (at 348 m in section CCD of Mawson & Talent, 1989), between the two major siliciclastic intervals described by Jell (1967).

The age of Sequence BR3 is defined by conodont data mainly from the Dosey Creek Syncline area, and some from the Pandanus area. Mawson & Talent (1989) determined that the break occupied by the Storm Hill Sandstone is probably somewhere in the upper part of the *costatus* Zone and lowermost *australis* Zone. Sequence BR3 therefore mostly corresponds to the *australis* and *kockelianus* Zones, and possibly extends into the *ensensis* Zone.

Sequence BR3 therefore may correlate with T-R Cycles Id and Ie of Johnson & others (1985). As there is no major lowering of sea level between T-R Cycles Ic and Id, the sequence boundary at the base of Sequence BR3 may be controlled by tectonism. The Storm Hill Sandstone represents a wedge of siliciclastics derived largely from the Lolworth-Ravenswood Block, which therefore is inferred to have been uplifted in the Eifelian. Nevertheless, the lower part of the Broken River Group from BR1 to BR3, reasonably coincides with the entire series of events in Euro-America from T-R Cycle Ib through to Ie.

Cycle 5 - Middle Devonian to Late? Devonian upper Broken River Group

This cycle (Figure 89) comprises the upper part of the Broken River Group, and includes the uppermost siliciclastic facies of the Dosey Limestone (Phar Lap Member and its equivalents in the Pandanus area), the Papilio Mudstone, and the Mytton Formation. It contains four sequences, BR4 to BR7.

Sequence **BR4** includes the Phar Lap Member and the lower half of the Papilio Mudstone. In the Broken River area, it begins with quartzose sandstones of the Phar Lap Member. These sandstones are calcareous, cross-bedded and interbedded with limestone lenses in places. Palaeocurrent data suggests that they were deposited in siliciclastic-carbonate tidal channels (Lang & others, this volume). Mapping of the Phar Lap Member by Blake (1990) determined that the unit is an extensive sheet overlying a significant erosional surface within the uppermost Dosey Limestone, and that locally it fills a deep incised channel in the Phar Lap area. Limestone clasts in the Phar Lap Member are derived from the underlying Dosey Limestone. The Phar Lap Member is therefore interpreted as a incised valley-fill sequence, and represents a LST overlying a Type-1 unconformity.

Transgressive, calcareous mudstones of the lowermost Papilio Formation abruptly overlie calcareous sandstones of the Phar Lap Member, and are interpreted as quiet muddy shelf deposits of a HST. Where the Phar Lap Member is missing, the Papilio Mudstone overlies limestones of the Dosey Limestone or Burges Formation with apparent conformity. However, in most areas there is some evidence of siliciclastic sandy facies along the contact. The precise nature of this contact requires further study, but it appears to represent a transgressive surface, overlain by TST and HST mudstones and thin carbonates.

Sequence **BR5** begins at the base of the Spanner Limestone Member and its lateral lithological equivalents in the Papilio Mudstone. Blake (1990) described a thin siliciclastic sandy interval beneath ooid-bearing, shoaling-upward carbonate facies of the Spanner Limestone Member. The introduction of siliciclastics into the Papilio Mudstone, concomitant with a basinward shift in facies is interpreted as resulting from a relative drop in sea level and dispersal of siliciclastics across the shelf. Because no significant erosional surface has been recognised along this boundary, it is interpreted as a Type-2 sequence boundary beneath a predominantly carbonate TST. The uppermost part of the Papilio Mudstone abruptly overlies the Spanner Limestone Member, and is interpreted as quiet muddy shelf deposits of a HST.

Sequence **BR6** begins at the base of the Mytton Formation, and marks the arrival of a major siliciclastic wedge

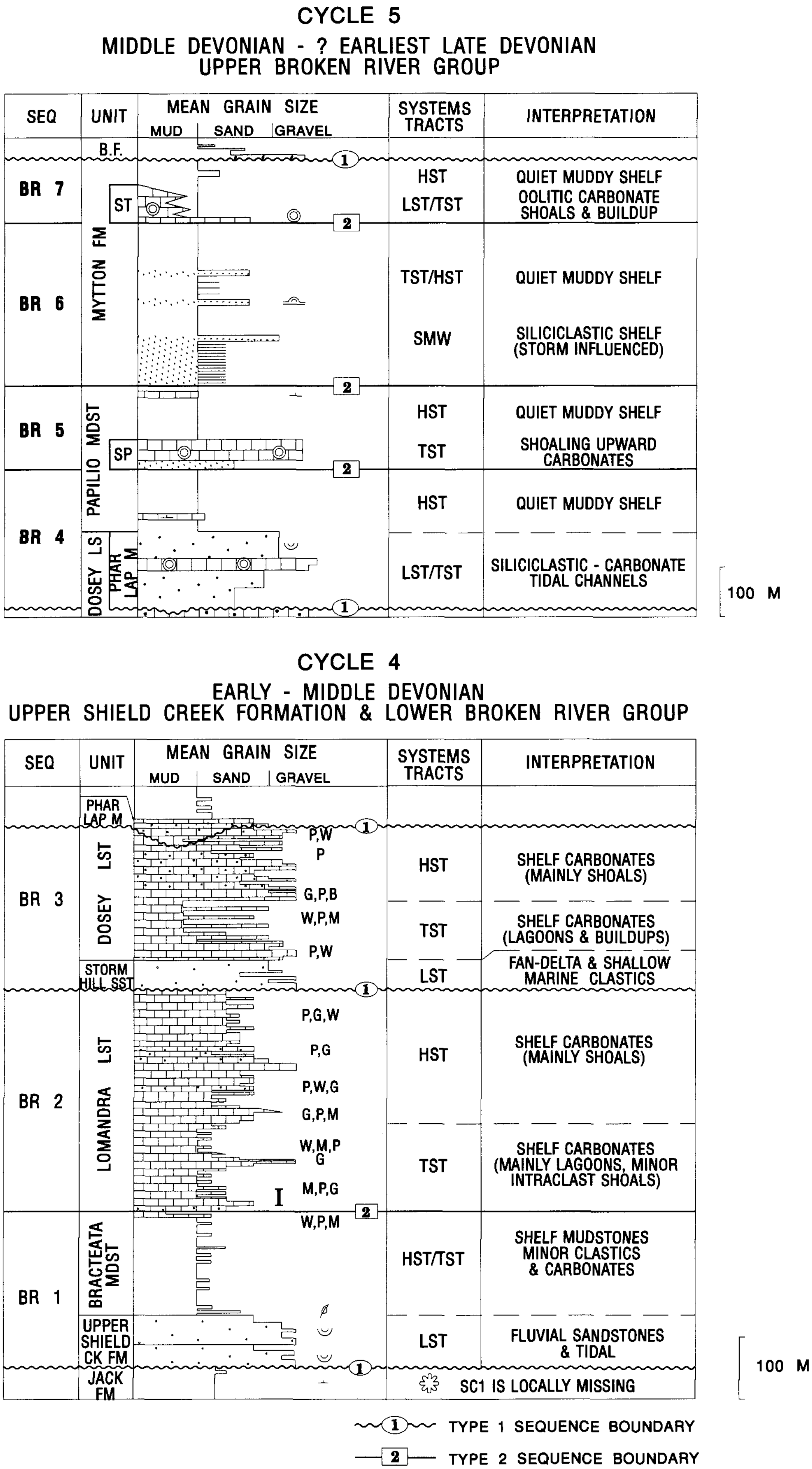


Figure 89. Sequence stratigraphy of the Broken River Group (Cycles 4 and 5).

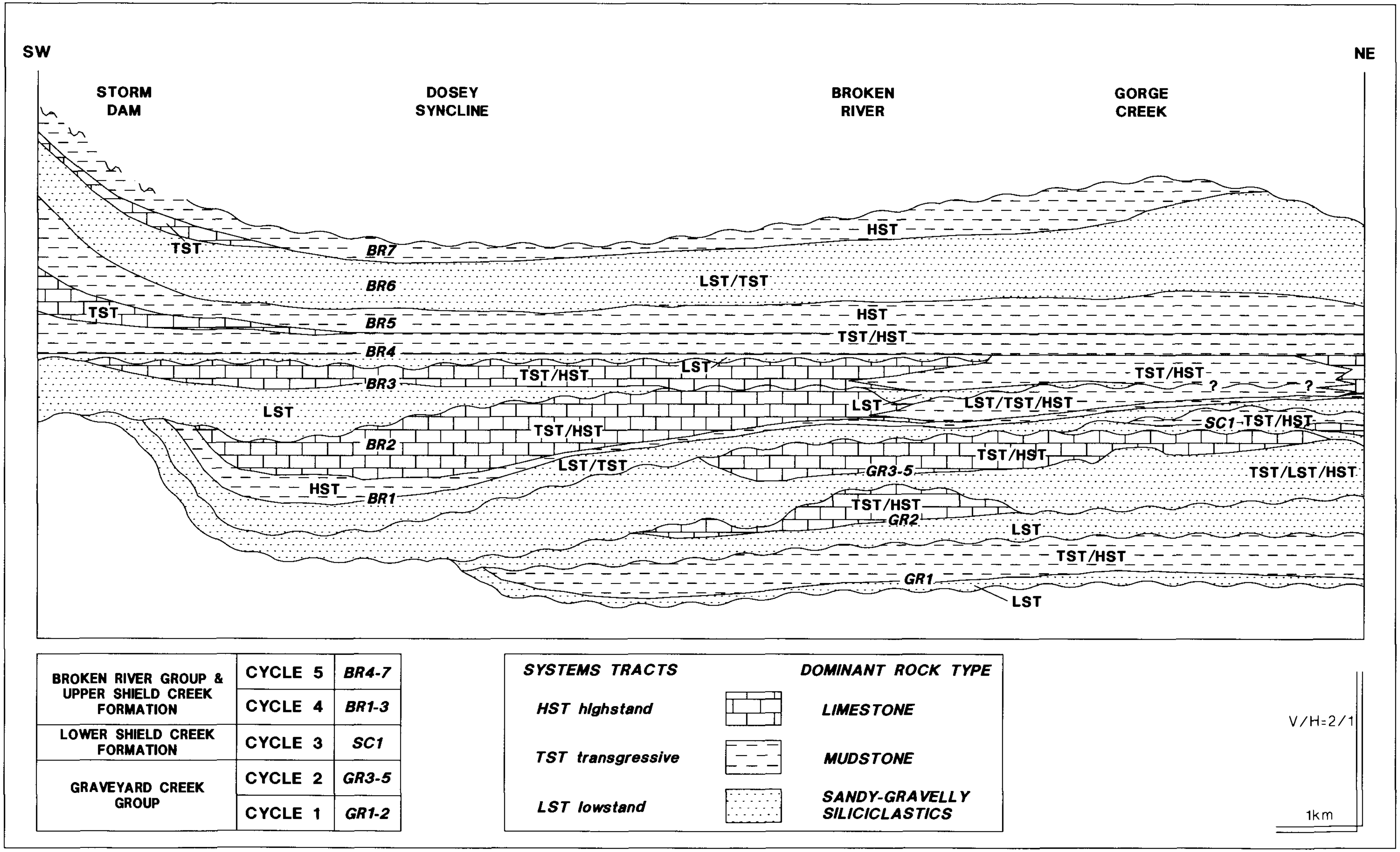


Figure 90. Unfolded section showing the sequence architecture for the Graveyard Creek Group, Shield Creek Formation and Broken River Group (Cycles 1 to 5).

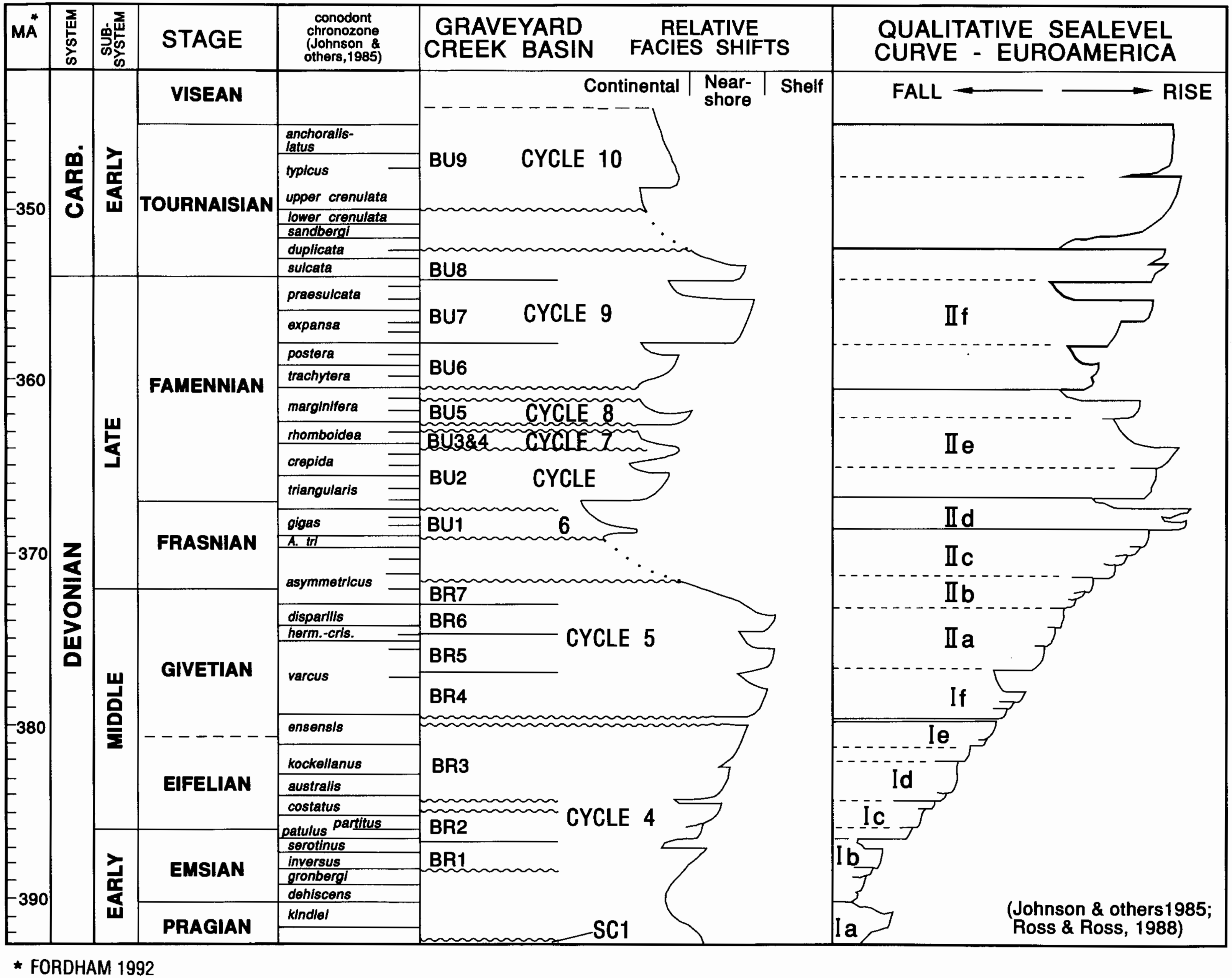


Figure 91. Relationship between the sequence stratigraphy of the Graveyard Creek Subprovince, chronostratigraphy, and published sea level curves.

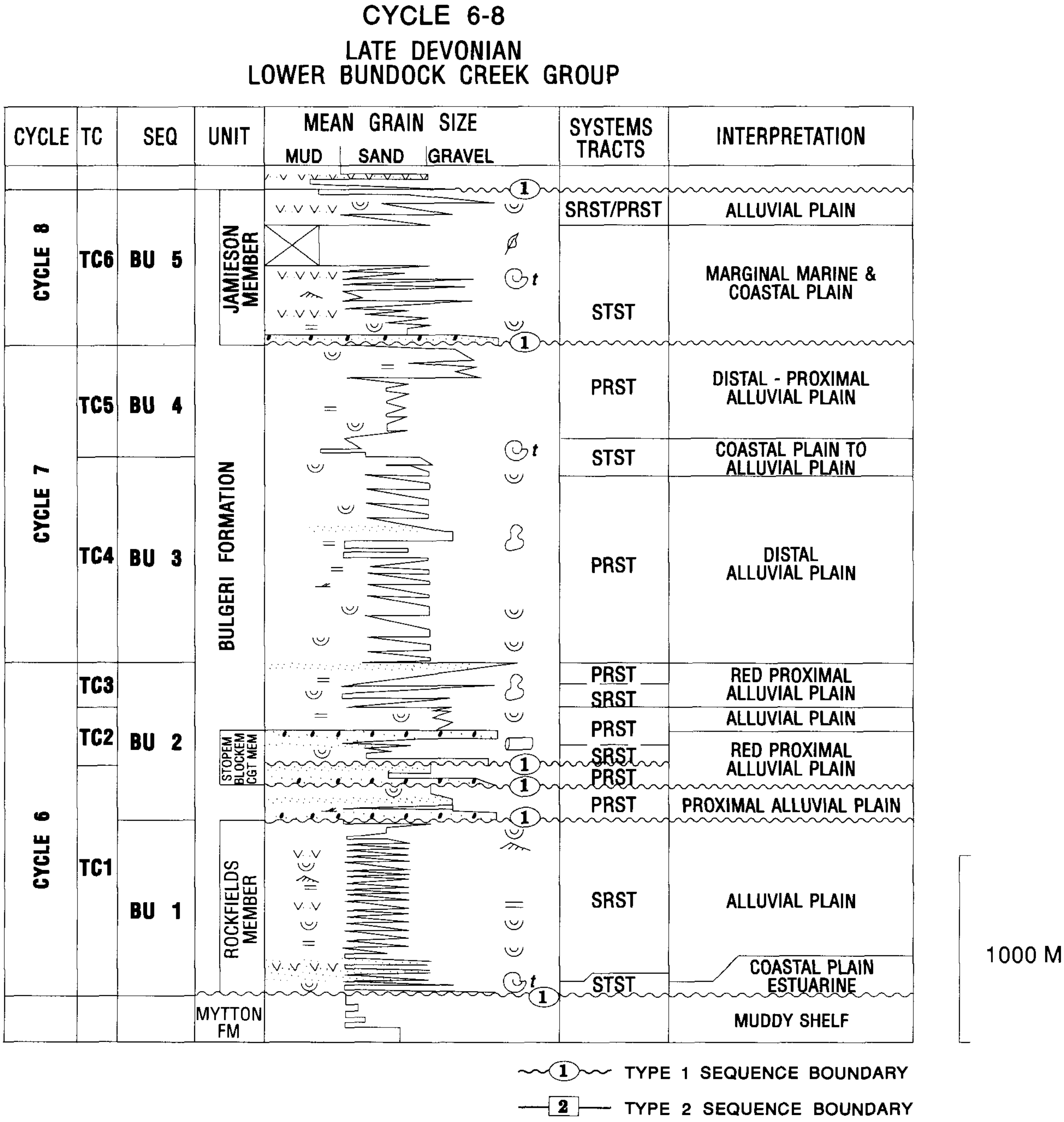


Figure 92. Sequence stratigraphy of the Bulgeri Formation (Cycles 6 to 8).

into the basin. The boundary with the Papilio Mudstone is quite sharp, although in places it appears transitional (Humphries, 1990). The boundary marks a basinward shift in facies associated with widespread deposition of siliciclastics across a muddy shelf. The lack of subaerial exposure and erosion along this boundary suggests that it may be a Type-2 sequence boundary. The lower 100 m of the Mytton Formation is predominantly sandstone, and is interpreted as storm-influenced siliciclastic shelf deposits that accumulated as a SMW during a relative lowering of sea level. The SMW is overlain by a very thick succession of predominantly muddy facies with thin interbedded sandstones in places. Some of these sandstones contain well-developed hummocky cross-stratification, and are also interpreted as storm-influenced deposits on a wide quiet muddy shelf. The uppermost part of the Mytton Formation is therefore interpreted as a HST.

Sequence **BR7** is the top of the Mytton Formation. In the Page Creek area, a limestone build-up, the Stanley Limestone Member, contains siliciclastic material at the very base associated with oolitic and oncolitic limestones. The upper part of the member comprises well-developed limestone, with reef-like coral and stromatoporoid build-ups. The Stanley Limestone Member is interpreted as a TST, and the overlying muddy facies of the Mytton Formation is interpreted as the base of a HST. The uppermost part of the

HST demonstrates a gradual shallowing, with shallow marine sedimentary rocks containing the bivalve *Leiopteria*, immediately beneath the unconformity with the Bundock Creek Group. In summary, Sequence BR7 comprises shallow marine carbonate shoals and build-ups at the base (TST), overlain by deeper muddy shelf deposits in the middle (TST/HST), shallowing upward towards the top (HST). Because there is apparently no erosional down-cutting at the base of the Stanley Limestone Member, the boundary between Sequence BR7 and underlying BR6 is interpreted as a Type-2 sequence boundary.

The age of Sequences BR4 to BR7 is well constrained by conodont data (Mawson & Talent, 1989). The Papilio Mudstone has been dated as the lower part of uppermost *ensensis* Zone through to *varcus* Zone, with the uppermost part being dated as *hermanii-cristatus* Zone. The Stanley Limestone is probably lowermost *asymmetricus* Zone. Thus Sequences BR4 to BR5 span the bulk of the Givetian to the earliest Frasnian. The overlying regional unconformity of the Bundock Creek Group developed sometime in Frasnian.

BUNDOCK CREEK GROUP

Cycle 6 - Late Devonian lower Bulgeri Formation

Cycle 6 is made up of two sequences (BU1 to BU2, the latter with four sub-sequences BU2a-d; Figure 92). Cycle 6 comprises Units A to M of the Bulgeri Formation (including the Rockfields Member and Stopem Blockem Conglomerate Member). Each sequence is bounded by an erosion surface that can be mapped across the basin, and in places truncating hundreds of metres of section (Figure 56). The main difference between the style of sequence development in the Bundock Creek Group versus the Broken River Group, is the dominant control of tectonism, reflecting a change from a stable shelf to an active foreland basin.

From a sequence stratigraphy point of view, there appears to be difficulty reconciling tectonic cyclothems with 'Vail-type' sequences (Vail & others, 1977; Miall, 1990). Theoretically, alluvial systems respond to relative sea-level lowering by fluvial down-cutting and a basinward shift in facies (Van Wagoner & others, 1988). During marine transgressions, base level is raised, and alluvial systems become sluggish and prone to estuarine and lacustrine development (Dalrymple, 1992). During relative high stands of sea-level, these estuaries and lacustrine systems fill up with sediment and thick deltaic sequences may prograde out from the coast. However, in a tectonically active basin, the effects of eustatic sea-level fluctuations can be completely masked, and identifying 'Vail-type' systems tracts is difficult.

Swift & others (1987) proposed an alternative model for sequence development in foreland basins, which contrasts markedly with the passive margin model of Vail & others (1977, 1984). In a foreland basin, tectonic loading produces maximum subsidence nearest the active fault margin. Therefore maximum accommodation space is developed in the proximal region of the basin, whereas in a passive margin it is typically developed in the distal part of the basin. This has important implications for the development of systems tracts. The great supply of sediment available to the proximal region of the basin as the uplifted region is eroded, results in a thick regressive wedge of non-marine sediments prograding out across the basin, away from the zone of maximum subsidence. Swift & others proposed that a much simpler architecture is developed in foreland basins than in passive margin sequences. Typically, only thin, relatively fine-grained, transgressive deposits are preserved at the base of the basin; the rest of the basin filled by dominantly non-marine, regressive coarsening-upward successions, during relative high stands of sea-level.

Recent studies of coarsening-upward, alluvial successions of asymmetric rift, pull-apart and foreland basins (eg. Blair & Bilodeau, 1988; Heller & others, 1988; Paola & others, 1992; Heller & Paola, 1992), have proposed that during periods of tectonic activity, gravels tend to be ponded adjacent to the active fault margin of the basin due to locally high rates of subsidence. Further out in the basin, widespread fine-grained deposits dominate, and therefore such successions (typically lacustrine or fluvio-lacustrine in nature) mark periods of tectonism. Only when subsidence rates have declined, due to concomitant reduction or cessation in uplift of the source areas, will gravelly sediments be able to prograde across the basin. These models predict that widespread coarse-grained successions are therefore post-tectonic, driven by subsidence rather than sediment supply (Paola & others, 1992; Heller & Paola, 1992).

Earlier studies (Lang, 1986a; Withnall & others, 1988b; Lang & Fielding, 1989) held the traditional view that coarse-grained successions of the Bulgeri Formation, such as the Stopem Blockem Conglomerate Member, were syntectonic in nature. In the light of these recent models, Lang (in press) has reinterpreted the lower Bulgeri Formation in terms of three tectonic 'cyclothems', each dominated by extra-basinal tectonism, and deposited in a foreland basin. Each 'cyclothem' contains a relatively fine-grained, syntectonic, lower part, and a coarse-grained, post-tectonic, upper part, although some conglomerates (eg calcirudites) were syntectonic and controlled by intra-basinal tectonism.

In this chapter, three new terms are introduced to reconcile the systems tracts terminology of Vail & others (1977, 1984) and Van Wagoner & others (1988) with the syntectonic/post-tectonic cyclothem terminology. The terms are Syntectonic Transgressive Systems Tracts (STST), Syntectonic Regressive Systems Tracts (SRST) and Post-tectonic Regressive Systems Tracts (PRST).

Sequence BU1 comprises the Rockfields Member which overlies the regional angular unconformity at the base of the Bundock Creek Group. This unconformity truncates up to 900 m of the underlying Mytton Formation and the upper part of the Dip Creek Limestone. It is associated with a major relative drop in sea-level and fluvial down-cutting, and is therefore a Type-1 unconformity. Lang (1986a) determined that the Broken River Group was tilted to the southwest at an angle of at least 4° and possibly up to 10°, below the unconformity, which therefore marks a major tectonic event. It has been taken as representing the onset of deformation of the Camel Creek Subprovince (Withnall & others, 1988b; Withnall & Lang, 1990, and this volume), with the Clarke River Fault acting as a tear or transcurrent fault.

Unit A of the Rockfields Member comprises conglomerates along the base of the unconformity, overlain by a thin, transgressive sequence of coastal plain, estuarine and shallow marine facies. This brief transgressional event is interpreted as a STST developed during rapid syntectonic subsidence that allowed the sea to briefly occupy the basin before retreating northward over the Georgetown Province. Relatively high global sea-levels during the Frasnian (Johnson & others, 1985) may have also contributed to this transgression. The STST is overlain by a thick succession of predominantly fine-grained, alluvial plain facies with extensive flood plain lakes (Units B, C and D). The succession becomes slightly coarser grained in Unit D, before being truncated by the base of the overlying sequence. Lang (in press) referred to these units as the 'Rockfields' alluvial system. They are interpreted as a SRST, representing fine-grained, syntectonic alluvial deposits accumulated during a period of rapid subsidence. Evidence of seismic-induced soft-sediment deformation in Unit B and C (Lang & Fielding, 1991) further supports a syntectonic origin. Sequence BU1 is therefore regarded as the syntectonic lower phase of a tectonic cyclothem (TC1; Figure 92).

Sequence BU2 comprises four sub-sequences (BU2a to BU2d), which relate to the informal unit subdivision of the lower Bulgeri Formation. The sequence is characterised by coarse-grained, braided stream deposits interbedded with fine-grained, alluvial plain facies. Lang (in press) recognised two compositionally distinct, coalescing axial and transverse alluvial drainage systems, referred to as the 'Bulgeri' and 'Stopem Blockem' alluvial systems, respectively.

Sub-sequence BU2a (Units E and F) consists of coarse-grained quartzose conglomerates and cross-bedded sandstones, typical of the 'Bulgeri' alluvial system. The rocks overlie an erosional surface that truncates nearly 250 m of the underlying Sequence BU1 (Rockfields Member) between the Broken River and Gorge Creek. This indicates that Sequence BU1 was tilted approximately 2° towards the southwest, prior to the accumulation of Unit E. This sub-sequence is interpreted as a PRST. It was deposited during post-tectonic progradation of coarse-grained sediments, that were transported by gravelly and sandy braided rivers. These drained along the basin axis away from the Clarke River Fault and parallel to the Gray Creek Fault.

Sub-sequence BU2b comprises Units G and H. Unit G consists of coarse-grained, reddened, lithic conglomerates, typical of the 'Stopem Blockem' alluvial system. It also overlies a prominent erosional surface that truncates over 240 m of the underlying units between the Broken River and Gorge Creek. This represents a tilting of the underlying succession of several degrees prior to deposition of Unit G. Lang (in press) interpreted this sub-sequence as representing gravelly, braided rivers, draining transverse to the basin away from the uplifted Camel Creek Subprovince to the east. Unit H consists of coarse-grained quartzose sandstones, typical of the axial 'Bulgeri' alluvial system. Like Unit F, they are interpreted as sandy, braided river deposits, which were derived from south of the Clarke River Fault. These two drainage systems merged, and ultimately flowed northward across the Georgetown Province.

Two alternative interpretations for Sub-sequence BR2b are possible. Unit G could represent a PRST or a SRST. In the case of a PRST, Unit G would represent the post-tectonic arrival of gravels of the 'Stopem Blockem' alluvial system. These merged with post-tectonic sediments of the 'Bulgeri' alluvial system, represented by Unit H. The PRST would thus be composed of two units derived from the first cycle of regional uplift, but from compositionally different sources. Alternatively, Unit G may represent a SRST, resulting from the initial syntectonic progradation of gravels derived during a separate cycle of uplift in the Camel Creek Subprovince. However, Unit H would represent a re-establishment of the 'Bulgeri' alluvial system as part of a PRST. In either case, local syntectonic limestone gravels were derived from uplifted fault blocks of Devonian limestone in the Pandanus Creek area.

In summary, Sub-sequences BU2a and BU2b represent the predominantly post-tectonic upper phase of the first tectonic cyclothem (TC1; Figure 92).

Sub-sequence BU2c comprises Units I, J and K. Unit I and J are typical of the 'Stopem Blockem' alluvial system. Unit I is a relatively fine-grained succession with thin, reddened, lithic conglomerates, sandstones and calcirudites in the lower part, and thick, interbedded sandstones and extensive, fine-grained redbeds in the upper part. At least 500 m of erosion can be demonstrated at the base of Unit I between the Broken River and GSQ Clarke River 1 (Figure 56). Furthermore, this unconformity truncates all of the underlying Bulgeri Formation and upper Broken River Group around the hinge of the Atherton Creek Anticlinorium, where it is represented by calcirudite lenses. Unit I is interpreted as mainly fine-grained, flood-plain sediments and palaeosols, with minor gravelly river deposits. These represent the lower syntectonic phase of a second tectonic cyclothem (TC2; Figure 56). These rocks accumulated during rapid subsidence, and are interpreted as a SRST. The calcirudites represent limestone gravels deposited in short-headed alluvial fans, emanating from intrabasinal uplift of Devonian limestones in the Pandanus Creek area.

Unit J is a relatively coarse-grained succession dominated by thick, reddened, lithic conglomerates interbedded with minor sandstone and fine-grained redbeds. No major erosive surface can be detected at the base of the unit, although local scouring is evident. The thick conglomerate successions of Unit J are interpreted as gravelly, braided river deposits accumulated during the post-tectonic phase of TC2. The overlying Unit K, is similar to Units F and H, but contains more fine-grained redbeds. It is interpreted as sandy, braided river deposits with minor fine-grained, flood-plain deposits. It represents the re-establishment of the 'Bulgeri' alluvial system, during the post-tectonic phase of TC2. Both units represent a PRST.

Sub-sequence BU2d comprises Units L and M and makes up yet another cyclothem. Unit L forms a distinctive sequence, dominated by fine-grained redbeds, with thin, reddened, lithic conglomerates typical of the 'Stopem Blockem' alluvial system, and quartzose to feldspathic sandstones typical of the 'Bulgeri' alluvial system. The most striking feature about Unit L is the development of calcrete glaebules in the redbeds. No regionally significant erosive surface is evident at the base Unit L, but the sequence abruptly overlies Unit K and is widespread.

The redbeds in Unit L have been interpreted as representing overbank fines deposited over laterally extensive flood plains, where calcic palaeosols developed over long periods. Thin sandstones interbedded with the redbeds are interpreted as minor channel fills or crevasse-splays. The sandstones and conglomerates represent relatively small channel-fill deposits of both the 'Bulgeri' and 'Stopem Blockem' alluvial systems, indicating that these systems were merging. The generally fine-grained nature of Unit L may reflect a new syntectonic phase of a third tectonic cyclothem (TC3; Figure 92), and represents a SRST.

Unit M is the uppermost conglomeratic wedge of the 'Stopem Blockem' alluvial system, and consists mainly of reddened, pebbly, lithic sandstone and conglomerate, and laterally discontinuous, fine-grained redbeds. Lesser quartzose to feldspathic sandstones typical of the 'Bulgeri' alluvial system occur in places. No prominent erosion surface has been identified at the base of Unit M, but it abruptly overlies Unit L, and becomes thicker towards the southwest of the basin (eg. Page Creek area). Conglomerates and sandstones of Unit M are interpreted as gravelly and sandy, braided river deposits that accumulated during the post-tectonic phase of TC3. The fine-grained redbeds represent minor overbank deposits. The whole succession is interpreted as a PRST.

The age of Cycle 6 is not well constrained. It is obviously younger than the earliest Frasnian, which occurs in the Stanley Limestone Member of the preceding cycle. Considerable erosion of the Broken River Group suggests a long period of time may be represented by the unconformity at the base of the Bundock Creek Group. Consequently, it is uncertain how much of the Cycle 6 is Frasnian in age.

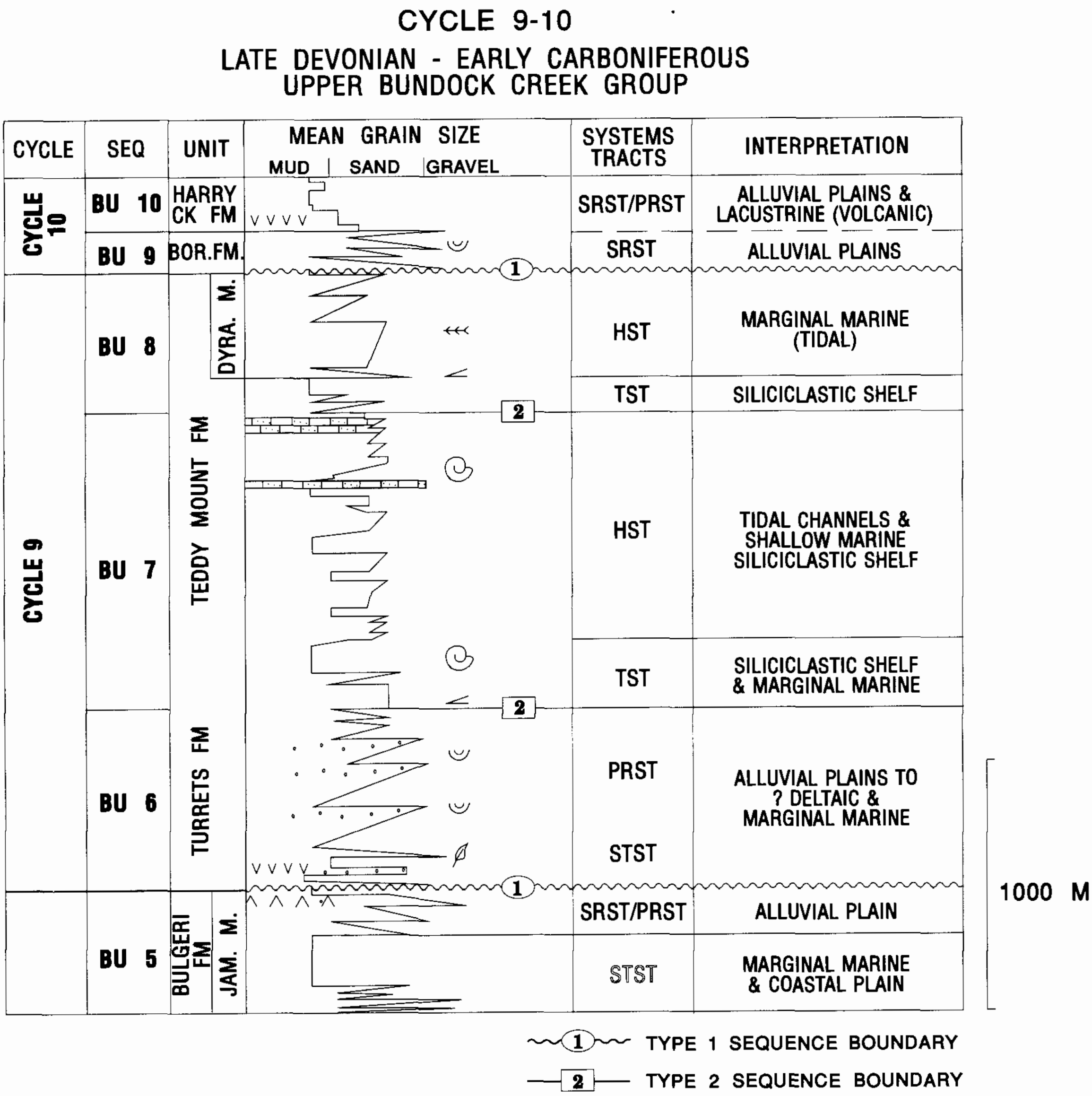


Figure 93. Sequence stratigraphy of the upper Bundock Creek Group (Cycles 9 and 10).

Sequence BU1 contains a low-diversity *Cyrtospirifer* brachiopod fauna near the base, and this is similar to the Frasnian fauna referred to by Mawson & others (1985, p11) from undifferentiated Bulgeri Formation near Teddy Mount. Talent (1989) recognised a widespread Frasnian marine incursion throughout eastern Australia, which has been dated as upper or uppermost *gigas* Zone and aligned with the global transgressive event, T-R Cycle IId of Johnson & others (1985) (Figure 91). The age of Sequence BU2 is even more uncertain as there are no marine fossils. However, it probably spans the Frasnian-Famennian boundary.

The Rockfields Member has many similarities with the Vanneck Formation, a probable Frasnian alluvial-lacustrine succession in the nearby Burdekin Basin (Lang & others, 1990b). Both formations contain a series of green reworked tuffs, indicating regional acid to intermediate volcanism, although the exact location of the source is unknown. The succession overlying the Vanneck Formation (the Julia Formation) contains non-marine redbeds and conglomerates (Lang & others, 1990a), not dissimilar to those of the upper part of Cycle 6. This Burdekin Basin succession (Figure 94) thus appears to mirror events in the Broken River area.

In summary, the lower part of Cyclothem TC1 of Cycle 6, accumulated mainly fine-grained sediments in a rapidly subsiding basin, synchronous with regional tectonism and volcanism in the mid to late Frasnian. The upper part of TC1 represents mainly post-tectonic progradation of coarse-grained sediments from both continental and orogenic sources to the south and east respectively. TC2 and TC3 represent shorter cyclothems, reflecting two more tectonic events. This tectonism correlates with the Tabberabberan Orogeny in southeastern Australia (Veevers, 1984).

Cycle 7 - Late Devonian upper Bulgeri Formation

Cycle 7 includes most of the middle part of the Bulgeri Formation, and consists of two sequences (BU3 and BU4).

Sequence BU3 corresponds to Units N, which is a very thick sequence of pebbly feldspathic sandstone and interbedded siltstone and mudstone. Fine-grained intervals are

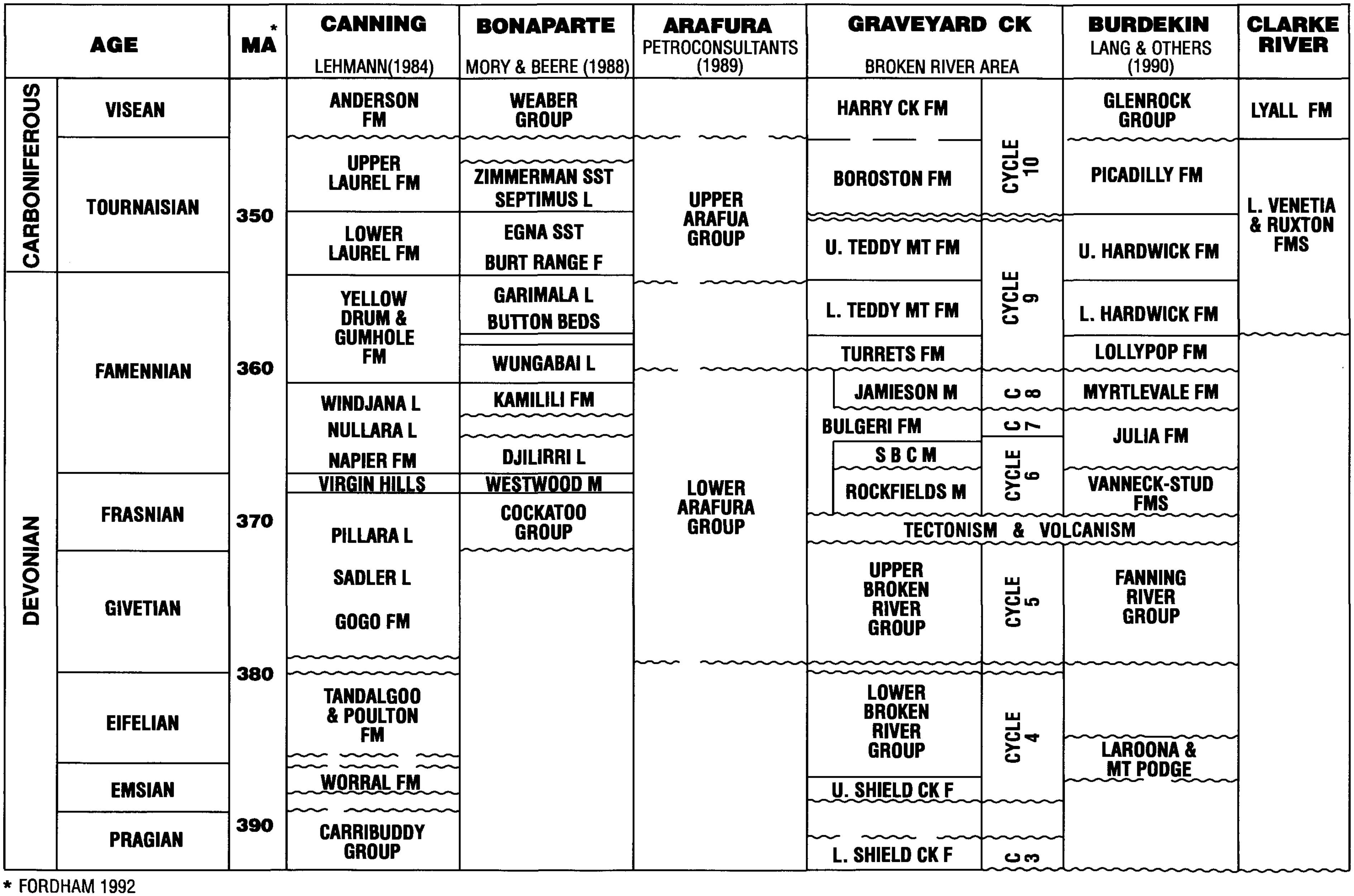


Figure 94. Correlation between the Graveyard Creek Subprovince and other basins in northern Australia.

red, variegated, or dark grey and carbonaceous, and in places contain green reworked tuffs. Unit N is poorly known, but available data suggests that it was deposited on alluvial plains more distal than the underlying successions. In general, the lower half of the sequence is finer grained than the upper half, and is interpreted as possibly representing a SRST of a fourth tectonic cyclothem (TC4). The base of the upper half contains coarser-grained sandstones than the rest of the sequence, and may represent fluvial progradation of more proximal facies, at the start of a PRST in the upper half of TC4. The composition of this sequence is more consistent with the 'Bulgeri' alluvial system described above.

Sequence BU4 comprises Units O and P, and broadly represents a coarsening-upward succession. Unit O consists of muddy sandstones and siltstones containing a poorly preserved marine fauna, and sandstones interbedded with rare redbeds. The unit has both marine and non-marine characteristics, and is therefore interpreted as a coastal plain to muddy nearshore succession. It represents a brief transgressional event, probably in the early Famennian (*crepida* to *rhomboidea* Zones?). This represents a marine transgression that has not previously been recognised in northeastern Australia, and is interpreted as possibly the result of either subsidence-induced transgression and/or a global transgression equivalent to the lower part of T-R Cycle IIe (Johnson & others, 1985). It therefore represents a STST, not unlike Unit A in basal Sequence BU1, and forms the lower part of a fifth tectonic cyclothem (TC5).

Unit P comprises sandstones, typical of the 'Bulgeri' alluvial system, with the upper part becoming conglomeratic in places. Minor fine-grained redbeds occur throughout. The sandstones and conglomerates represent channel-fill deposits, and the fine-grained intervals represent overbank deposits. The overall coarse-grained aspect of Unit P reflects a progradation of proximal alluvial plain facies over distal alluvial plain and coastal plain facies of Unit O. Therefore Unit P may represent a PRST.

Cycle 8 - Late Devonian uppermost Bulgeri Formation

Cycle 8 comprises the uppermost sequence of the Bulgeri Formation (BU5), and includes all of the Jamieson Member (Unit Q). The base is marked by a prominent erosional surface underlying conglomeratic sandstones and conglomerates, which are overlain by a thick succession of volcaniclastic sandstones and green mudstones containing thin granule conglomerates. The mudstones contain a poor marine fauna, indicating another marine transgression. The upper half of the Jamieson Member coarsens upwards, and includes a regressive sequence of pebbly conglomerates containing abundant volcanic clasts. Green tuffs are common throughout the succession, and fine-grained redbeds occur at the base and near the top of the succession. Cycle 8 may represent a sixth tectonic cyclothem (TC6), with syntectonic conglomerates at the base, overlain by a marine-influenced STST, in turn overlain by a prograding alluvial plain facies of a SRST/PRST. Volcanism in the region continued throughout this period.

The age of the transgression is poorly constrained, but is probably mid-Famennian, and may correlate with a global transgressive event in the *marginifera* Zone (Talent, 1989). This may relate to the transgression represented by the Myrtlevale Formation in the nearby Burdekin Basin (Pickett, 1981; Gunther & others, 1990), and may correlate with the upper part of T-R Cycle IIe of Johnson & others (1985) (Figure 91).

Cycle 9 - Late Devonian to Early Carboniferous Turrets and Teddy Mount Formations

Cycle 9 comprises three sequences, BU6, BU7 and BU8 (Figure 93). Cycle 9 is bounded by a disconformity at the base of the Turrets Formation, which forms the base of Sequence BU6.

Sequence BU6 comprises pebbly and cobbly conglomerate overlain by finer-grained, tuffaceous sandstones, which in turn are overlain by series of coarsening upwards successions, interpreted as delta plain or alluvial plain in origin. The sequence is interpreted as a STST at the very base, followed by a PRST. Palaeocurrent data indicate a possible change in direction of the source area during the deposition of the Turrets Formation, reflecting uplift in the Georgetown Province to the north. This is consistent with a correlation with the Lollypop Formation of the Burdekin Basin, which was also sourced from the northwest (Lang & others, 1990b).

Sequence BU7 includes the uppermost marine-influenced part of the Turrets Formation, and the lower 900 m of the Teddy Mount Formation in the type section. The uppermost part of the Turrets Formation contains calcareous sandstones, which are interpreted as marginal marine deposits, accumulated during the early stage of a transgression. No significant erosion surface separates this succession from the underlying part of the Turrets Formation. The base of the Teddy Mount Formation is sharp and overlain by fossiliferous mudstones, calcareous sandstones and phosphatic, fossiliferous limestones, interpreted as shallow marine shelf to shoreface and tidal channel deposits in a series of shallowing upward cycles. The marine mudstones represent a rapid deepening event, which probably coincides with maximum transgression that marks the top of a TST. The overlying calcareous sandstones and limestones form a thick HST. In detail, the HST comprises numerous parasequences, which reflect a series of transgressions and regressions.

Conodonts from the phosphatic limestones suggest a Late Devonian (latest Famennian) age for Sequence BU7. It may, however, range up into the Early Carboniferous in places (Lang, 1985, 1986a; Jell & others, this volume). This implies that the beginning of the transgression at the base of Sequence BU7, may correlate with T-R Cycle IIf in the *expansa* to *praesulcata* Zones of the latest Famennian (Figure 91). Sequence BU7 correlates with the basal marine of the Venetia and Ruxton Formations of the Clarke River Group (Draper & others, this volume), and the Hardwick Formation of the Burdekin Basin (Gunther & others, 1990; Lang & others, 1990b) (see Figure 94).

Sequence BU8 comprises the upper part of the Teddy Mount Formation, from about 900 m in the type section to the top of the formation (including the Dyraaba Member). No significant erosion surface separates this succession from the underlying part of the Teddy Mount Formation. The lower 130 m of the sequence is characterised by calcareous mudstones with interbedded sandstones, interpreted as shallow marine to marginal marine deposits. These were deposited in slightly deeper conditions than the upper part of Sequence BU7 and represent a TST. The remainder of Sequence BU8 (Dyraaba Member) comprises plant-rich, calcareous sandstones and interbedded mudstones, interpreted as tidal channel, shoreface and shallow marine deposits. The uppermost part of the Dyraaba Member contains a fine-grained interval before becoming coarser-grained, immediately beneath the Boroston Formation. In general, Sequence BU8 represents a TST at the base, and a HST at the top, although in detail several parasequences may be recognised.

The age of Sequence BU8 is poorly constrained, but is probably early Tournaisian (*sulcata* to *duplicata* Zones?, Figure 91), and may correlate with a shallowing eustatic sea level trend (Ross & Ross, 1988, figure 9). Sequence BU8 probably correlates with the upper part of the Hardwick Formation in the Burdekin Basin (Gunther & others, 1990; Lang & others, 1990b) (Figure 94).

Cycle 10 - Early Carboniferous Boroston and Harry Creek Formations

Cycle 10 (Figure 94) comprises two sequences, BU9 (Boroston Formation) and BU10 (Harry Creek Formation), which represent the uppermost part of the Bundock Creek Group, and a return to major tectonic and volcanic influences.

Sequence BU9 is underlain by a major erosion surface, which truncates the upper part of the Teddy Mount Formation. The sequence comprises coarse-grained, quartzose sandstones and conglomerates mainly sourced from the Georgetown Province. Minor tuffaceous mudstones and siltstones and minor primary tuffs occur in the sequence. Palaeocurrent data indicate a source area to the north during the deposition of the Boroston Formation, reflecting uplift in the Georgetown Province. The sequence is interpreted as tectonically-influenced, deposited in alluvial fans and braided rivers as a SRST.

Sequence BU10 comprises mainly volcaniclastic sandstones, siltstones and conglomerates with several tuff intervals. This sequence is finer grained in the middle part of the succession, and is interpreted as alluvial plain and lacustrine deposits within a volcanic terrain. The sequence is interpreted as a SRST at the base, and a PRST at the top.

Cycle 10 is correlated with the upper part of the Venetia Formation and Lyall Formation in the Clarke River Basin, and the Piccadilly Formation and Glenrock Group in the Burdekin Basin (Gunther & others, 1990; Hutton & others, 1990a). The dominance of coarse-grained facies and volcaniclastic sediments indicates that the basin was tectonically active at this time, and close to an active volcanic terrain.

GEOLOGICAL AND TECTONIC HISTORY

(I.W. Withnall & S.C. Lang)

INTRODUCTION

Previous tectonic models

Various tectonic models to explain the geology of the Broken River Province have been proposed. The first attempt (White, 1961, 1965) considered that the Broken River Province developed as a geosyncline in the Late Ordovician or Early Silurian as an indentation or embayment in the craton margin. The embayment propagated westwards as a rift. The supposed unconformity between the Greenvale and Kangaroo Hills Formations was due to uplift of a central tectonic welt, 'the Wairuna Tectonic Land', in the Late Silurian or Early Devonian, isolating the rift (the Graveyard Creek Foredeep) from the main geosyncline (the Kangaroo Hills Deep). By the Middle Devonian, most of the Province was emergent, marine sedimentation being restricted to the southwest, until the Early Carboniferous, when a new rift developed to the east (Clarke River Basin) on the folded Wairuna Tectonic Land.

Arnold (1975) (following Crook, 1974) interpreted the quartz-rich 'flysch' as indicating a stable cratonic source and a passive margin, whereas the quartz-intermediate 'flysch' came from a more unstable source. He suggested that the quartz-rich 'flysch' was older, based on the relationship of the quartz-rich 'Judea beds' to the quartz-intermediate 'Graveyard Creek Formation' in the Graveyard Creek Subprovince. In the Silurian, the passive margin became the site of subduction and a magmatic arc. Uplift of the craton provided a more unstable source for the quartz-intermediate 'flysch'. The large Siluro-Devonian batholiths in the eastern Georgetown Inlier and farther north (Cooper & others, 1976) were interpreted as the eroded roots of an Andean-type volcanic arc. Arnold (*in* Arnold & Fawckner, 1980) interpreted the assemblage in the Camel Creek Subprovince as an accretionary prism consisting of an imbricate stack of thrust sheets. These sheets comprised packets of both the quartz-intermediate 'flysch', derived from the arc and its cratonic basement, and quartz-rich 'flysch' from the earlier passive-margin stage.

Arnold's model was developed for the Broken River Province, but has been extended to the Hodgkinson Province by Henderson (1980) and other authors such as Powell (*in* Veevers, 1984) and Coney & others (1990).

Bell (1980) tried to rationalise the deformation and shape of the Camel Creek Subprovince in terms of a large orocline with a northeast-trending axis. The Burdekin, Gray Creek, and Clarke River Faults were considered to be a single structure folded by the orocline. The northeast-trending folds, coaxial with the proposed orocline, were thought to have formed in the Middle Carboniferous. Powell & others (1985) suggested that the orocline was an expression of a mid Carboniferous, continent-wide, north-south, mega-kinking event. The oroclinal model, although supposedly rationalising some the structural data did not attempt to explain the origin of the Province. In addition, the mid Carboniferous timing is wrong, because the Early Carboniferous rocks of the Clarke River Group, which lies on the axial plane of the orocline, is unaffected by it. The timing was based on unconformities which have since been shown to be non-existent. More importantly, the Clarke River Fault continues well to the west of the supposed oroclinal hinge as a major ductile mylonite zone (Withnall & others, 1986).

Harrington (1981) rejected Bell's orocline hypothesis, and presented a model based on a triple junction between three plates, represented by the Georgetown, Broken River, and Lolworth-Ravenswood Provinces. The Burdekin Fault was a convergent plate boundary and the Clarke River Fault was a sinistral transform fault. Southward movement of the triple junction left the Gray Creek Fault in its wake, and caused a rift to open up behind it to the west in which the contents of the Graveyard Creek Subprovince accumulated.

Henderson (1987) published a modification of Arnold's model. He rationalised the formation of the Broken River Province in terms of oblique subduction and strike-slip faulting. He still regarded the Hodgkinson Province and Camel Creek Subprovince as subduction complexes and suggested that the Graveyard Creek Subprovince was a forearc basin assemblage. The Gray Creek Fault was interpreted as a Siluro-Devonian dextral strike-slip structure. In the Late Devonian a sheet of basement with a tear fault at its southern margin was postulated to have been thrust over the forearc basin, while sinistral movement occurred on the Clarke River Fault. As a result of this thrusting event, the forearc basin was obscured by the overthrust eastern Georgetown Province except for the portion between the Clarke River Fault and the tear fault, which corresponds to the Teddy Mount Fault. Shear adjacent to the Clarke River Fault was considered to be responsible for the northeast-trending folds in the Camel Creek Subprovince. Dextral strike-slip movement on the Gray Creek-Burdekin Fault System resulted in the formation of a deep molasse basin in which the Bundock Creek Group was deposited. Farther east, shallow basins developed in response to vertical movement on the Gray Creek and Clarke River Faults.

An alternative model

Fawckner (1981, and *in* Arnold & Fawckner, 1980) put forward an alternative model for the Hodgkinson Province, suggesting that it was a marginal basin formed by rifting and crustal extension, after an initial period of magmatic activity prior to the Silurian. He emphasised the voluminous tholeiitic basalts in the western part of the Hodgkinson Province, which together with the lack of volcanic detritus throughout the sequence, is not easily accommodated in an arc-trench model.

Although volcanic detritus is present in the Silurian quartz-intermediate 'flysch' of the Broken River Province, it is not as voluminous as might be expected adjacent to an active volcanic arc. Minor tuffs and pyroclastic turbidites are present in the Graveyard Creek Subprovince, but much of the other volcanic detritus could be derived from older volcanic rocks, e.g. the Ordovician volcanic rocks in the Carriers Well Formation and Everetts Creek Volcanics, and the possible Cambro-Ordovician Balcooma Metavolcanics and Eland Metavolcanics west of Greenvale (Withnall, 1989b).

Apart from lacking good evidence for an active volcanic arc, the structure of the Camel Creek Subprovince does resemble an accretionary prism. Features consistent with such a model are the abundant melange and the imbricate thrust slices, which steepen westwards and have an internal westward younging, but overall eastward younging. However, Hammond (1986) put forward an alternative interpretation of the melange and younging relationships. According to him, a large intracratonic thrust duplex formed when the Georgetown Province was thrust eastward over the Camel Creek Subprovince in the Early Devonian. He considered that the first folding event, which produced the slaty cleavage, and the thrusting, were a single event, rather than separate events. Thrusting along overturned limbs of the folds resulted in the predominant westward younging direction. The melange zones were suggested as representing thrust faults.

Hammond's hypothesis was based on his studies in the Hodgkinson Province. The Hodgkinson Province also contains abundant melange and a predominant westward younging, and is interpreted as a stack of imbricate thrust slices (Fawckner, 1981; Bultitude & others, 1985, 1990; Hammond, 1986; Halfpenny & others, 1987; Shaw & others, 1987).

If the Hodgkinson and Broken River Provinces were once continuous, they probably had similar tectonic settings. Current workers in the Hodgkinson Province favour a model similar to Fawckner's (Bultitude & others, 1990). They suggest that the Hodgkinson Province was an intracratonic rift formed along the lines postulated for extensional basins by Lister & others (1986). An upwelling mantle diapir may have produced thinning and extension of the crust, and generation of tholeiitic basalt. The basin was bounded to the west by the Georgetown Province. The Barnard Metamorphics to the east may represent the eastern cratonic block. If there was a subducting plate margin and associated arc, the lack of volcanic detritus in the Hodgkinson Province would place it well to the east of the present coastline. As suggested by Hammond (1986), much of the melange is thought to be related to intracratonic thrusting rather than subduction. Some is probably also related to large transcurrent faults. The age of the terminal deformation is probably Late Devonian or Early Carboniferous, because of the presence of Frasnian and Famennian conodonts in the Hodgkinson Formation.

Withnall & others (1987, 1988b) and Withnall & Lang (1990) adapted this extensional model to the Broken River Province. Munson (1987) independently developed a similar extensional model for the Broken River Province, suggesting that the Graveyard Creek Subprovince was an aulacogen. However, even if the Hodgkinson and Broken River Provinces formed in similar tectonic settings, details of timing of deformation and depositional history are somewhat different. The Hodgkinson Province lacks the Ordovician calc-alkaline volcanics, although Ordovician quartz-rich 'flysch' and tholeiitic basalts (similar to the Judea and Wairuna Formations) are now known along the western edge of the Hodgkinson Province (Bultitude & others, 1990); in addition, U-Pb zircon dating of a felsic volcanic clast from the Late Ordovician Mountain Creek Conglomerate has given a Late Ordovician age (R. Bultitude and J. Domagala, personal communication, 1992), indicating a nearby volcanic source of this age. An unconformity is recognised in the Ordovician of the Hodgkinson Province, but later sedimentation continued into the Late Devonian before any other apparent major deformation. In contrast, the youngest rocks known in the Camel Creek Subprovince are Early Devonian and these were deformed at least twice before the end of the Devonian.

The extensional model forms the basis of the tectonic history outlined below, although we now suggest that periods of convergence were interspersed with the extension. The history is summarised in cartoon form in Figure 95.

CAMBRIAN TO ORDOVICIAN

A tectonic model for the Broken River Province should take into account the early Palaeozoic metavolcanic rocks in the adjacent eastern Georgetown Province (Withnall, 1989b; Withnall & Grimes, 1991; Withnall & others, 1991) and Lolworth-Ravenswood Province (Henderson, 1986), because they were the immediate precursors of the Broken River Province rocks, and may have even overlapped with them temporally. None of the earlier models have considered these metavolcanic rocks. They indicate that in the Cambrian and Ordovician, the northern part of the Tasman Orogen was apparently the site of calc-alkaline magmatism, probably subduction-related.

Murray & Kirkegaard (1978) considered the Seventy Mile Range Group in the Lolworth-Ravenswood Province to be a remnant of a volcanic island arc separated from the craton by a marginal sea of unknown extent. Henderson (1986) postulated that these rocks were deposited in a back-arc basin formed by continental extension west of an Andean volcanic arc. Withnall (1989b) suggested that the Balcooma Metavolcanics and Lucky Creek Metamorphic Group in the eastern Georgetown Province, also represented a volcanic arc on the cratonic margin. The presence of Early Ordovician graptolites in the Judea Formation, suggests that the tholeiitic basalts and altered rhyolite (quartz-keratophyre) of the Donaldsons Well Volcanic Member, which form the oldest known rocks in the Broken River Province, could have overlapped with this magmatic phase or may be slightly younger. The overlying part of the Judea Formation is a quartz-rich turbidite sequence which contains no volcaniclastic rocks, suggesting that volcanic rocks were not subaerially exposed in the region at the time of deposition. This is at variance with an Andean setting in which large mountain chains would be expected.

The Wairuna Formation is also predominantly a sequence of quartz-rich turbidites with abundant tholeiitic basalt. The geochemistry of the tholeiitic basalts is more consistent with a backarc setting than true oceanic tholeiites. The age of the Wairuna Formation is uncertain, but it could be Early Ordovician like the Judea Formation, and both units could represent a passive, extensional phase after the cessation of subduction and arc volcanism in the Late Cambrian-Early Ordovician. Alternatively, it could be Late Ordovician, because quartz-rich arenites are also associated with the Carriers Well Formation. Quartz-rich sediment was derived by recycling quartz-rich metasediments from the Georgetown Province, which may have been a denuded stable craton at this time.

The Late Ordovician Carriers Well Formation and Everetts Creek Volcanics contain calc-alkaline basaltic to rhyolitic lavas and volcaniclastic rocks, and may represent another phase of arc-type magmatism, although as preserved, they have a limited areal extent. The Late Ordovician clasts identified in the Hodgkinson Province suggest an original greater extent. Quartz-rich sediments are also present in the Carriers Well Formation, suggesting a source from the craton as well as the arc. Volcanic rocks with both calc-alkaline and ocean-floor tholeiitic geochemical affinities are present. It is possible that the Carriers Well Formation and Everetts Creek Volcanics were deposited behind, but adjacent to a volcanic arc, so that rocks characteristic of both settings are mixed. Tectonic processes could also have produced some of the juxtaposition of the different rock suites. The relative importance of original depositional and later tectonic processes requires further investigation.

This pattern of mixed provenance continues to the east in the Camel Creek Subprovince. The Greenvale Formation (dominated by lithic arenite with a significant volcanic component as well as metamorphic basement material) and the quartz-rich Pelican Range Formation appear to interfinger locally, although generally they appear to be juxtaposed as thrust packages. The age of these units is uncertain, but it could be Late Ordovician. Intercalation of quartzose and immature sediments is also a feature in

Ordovician forearc basins in southeast Australia (Powell, *in* Veevers, 1984, p 293).

If the Late Ordovician volcanics are subduction-related, it is possible that the extensive melange in these probable Ordovician rocks to the east was produced in a subduction complex rather than all being related to terminal deformation in the Devonian as suggested by Hammond (1986). Alternatively it could have been produced in a separate, earlier deformation event in the Late Ordovician or Early Silurian. This deformation may have involved thrusting of the Judea Formation onto the craton. A Late Ordovician to Early Silurian age for deformation is suggested by Rb-Sr dating of mylonite in the Halls Reward Fault, the contact between the Judea Formation and the Proterozoic Halls Reward Metamorphics (L.P. Black, unpublished data; Withnall, 1989b). Thrusting of the Proterozoic basement rocks of the Georgetown Province over the Balcooma Metavolcanics and Lucky Metamorphic Group may also have occurred at this time.

The Ordovician rocks of the Broken River Province may have been part of a continuous belt with rocks in the Thomson Fold Belt to the south. These may include the Fork Lagoons beds in the Anakie Inlier (Anderson & Palmieri, 1978) and quartzose arenites and argillites known from basement cores below the Adavale Basin (Murray, 1986, and unpublished data).

SILURIAN TO EARLY DEVONIAN

The Silurian Perry Creek Formation of the Camel Creek Subprovince is relatively quartz-rich, indicating that the most significant input was from the craton, although some volcanic detritus is still evident. The Early Devonian Kangaroo Hills Formation is more feldspathic and contains significantly less volcanic detritus (Figure 5), the main provenance being a plutonic/metamorphic terrain. The waning proportion of volcanic detritus can be explained by the Cambrian to Ordovician volcanic rocks having been largely eroded away by the Late Silurian. It is not necessary to invoke an active volcanic arc in the Silurian, although it cannot be ruled out. Tholeiitic basalts are not as common in the Perry Creek Formation as in the Ordovician units. Although they are more consistent with an extensional setting than an accretionary prism, it could be argued that, because of their small size, they represent off-scrapings of oceanic crust. However, this is a less likely origin for the much more voluminous Silurian tholeiitic basalts in the Hodgkinson Province (Bultitude & others, 1990). If an arc existed at this time, it may have migrated farther east (cf. Karig, 1972), so that the Perry Creek Formation was deposited in a back-arc setting similar to that suggested for some of the Late Ordovician rocks.

Correlatives of the Perry Creek and Kangaroo Hills Formations to the south of the Clarke River Fault are not known, and it is possible that the fault was a transform or transfer fault marking the southern limit of the extensional basin.

In the Silurian, the Graveyard Creek Subprovince was the site of a small, rapidly subsiding basin (possibly a pull-apart) along the edge of the Hodgkinson - Camel Creek extensional basin. Deposition commenced in the Early Silurian (Llandovery) with the Graveyard Creek Group, which was deposited on a basement of deformed Judea Formation. Diamictites, olistostromes, and dramatic thickness changes suggest active faulting along its northwestern margin and in a narrow zone within the basin adjacent to that margin. In the south, little or no active faulting is evident along the margin with the Lolworth-Ravenswood Province, and a relatively thin sequence of shallow marine siliciclastics and limestone was deposited there.

The Graveyard Creek Group arenites contain minor volcanic detritus like those of the Perry Creek Formation. However, the only evidence of contemporaneous volcanism in the Graveyard Creek Subprovince is a thin volcaniclastic interval in the north. This may be related to emplacement of the Dido Tonalite in the Georgetown Province in the Early Silurian at about 430 Ma (Black & McCulloch, 1990; Withnall, 1989b). The Craigie Tonalite in the northern part of the Lolworth-Ravenswood Province may also have been emplaced at this time. Recent ion-probe zircon data suggest that other extensive batholiths in the Georgetown Province were also emplaced in the Early Silurian rather than in the Early Devonian as previously thought (L.P. Black and R.J. Bultitude, personal communication, 1993). These batholiths have been suggested as the roots of a volcanic arc (Arnold, 1975; Henderson, 1980). The batholiths are commonly hydrous, peraluminous, muscovite-bearing granites (Withnall & others, 1986; Withnall, 1989b), and are variably foliated. They were probably emplaced at moderately deep levels of the crust (15 km or greater), and it is debatable whether they would have had volcanic equivalents. Melting of lower crustal rocks may have been initiated after crustal thickening due to thrusting in the eastern part of the Georgetown Province in the Late Ordovician to Early Silurian. Alternatively, underplating of the craton in the Early Silurian may have resulted in the granitoid generation and emplacement.

Thus, although there is evidence for extensive plutonism in the Georgetown Province in the Early Silurian, there is no evidence for extensive or long-lived contemporaneous volcanism in the sedimentary record of the Broken River Province, as might be expected in a fore-arc basin.

The characteristics of the rocks in the Broken River Province in the Silurian to Early Devonian are not inconsistent with a wide extensional basin, which was initiated in the Late Ordovician or Early Silurian, possibly by back-arc spreading. This contrasts with Lachlan Orogen of southeastern Australia at this time, where a series of narrow meridional horsts and grabens associated with widespread silicic volcanism and granitoid emplacement occurred (Powell *in* Veevers, 1984; Cas, 1983). The nature of the crust underlying the basin is uncertain. It is generally agreed from regional gravity data and geochemistry of the later granites that the Hodgkinson Province is underlain by continental crust (eg. Fraser & others, 1977). However the regional gravity of the Camel Creek Subprovince suggests that it could be underlain by oceanic crust, at least in part (Mathur & Shaw, 1982).

EARLY TO MIDDLE DEVONIAN

No rocks definitely younger than Early Devonian are known from the Camel Creek Subprovince. This apparent cessation of deposition has generally been interpreted as due to deformation in the Early Devonian by westward convergence which resulted in the pattern of imbricate thrust slices and some of the melange (Hammond, 1986; Withnall & others, 1987; Withnall & Lang, 1990). This is the scenario presented in Figure 96. Deformation at this time would have coincided with extensive uplift in the adjacent Georgetown Province, as indicated by isotopic cooling ages of around 400 Ma (Bain & others, in press), and also with granitoid emplacement and probable uplift in the Lolworth-Ravenswood Provinces (Hutton & others, 1990b). Early Devonian (Emsian) marine sediments unconformably overlie amphibolite grade metamorphics and Silurian two-mica granites of the Georgetown Province. This unconformity therefore represents uplift and erosion of up to 15 km of the upper crust prior the Emsian. The arkosic lower part of the Shield Creek Formation may

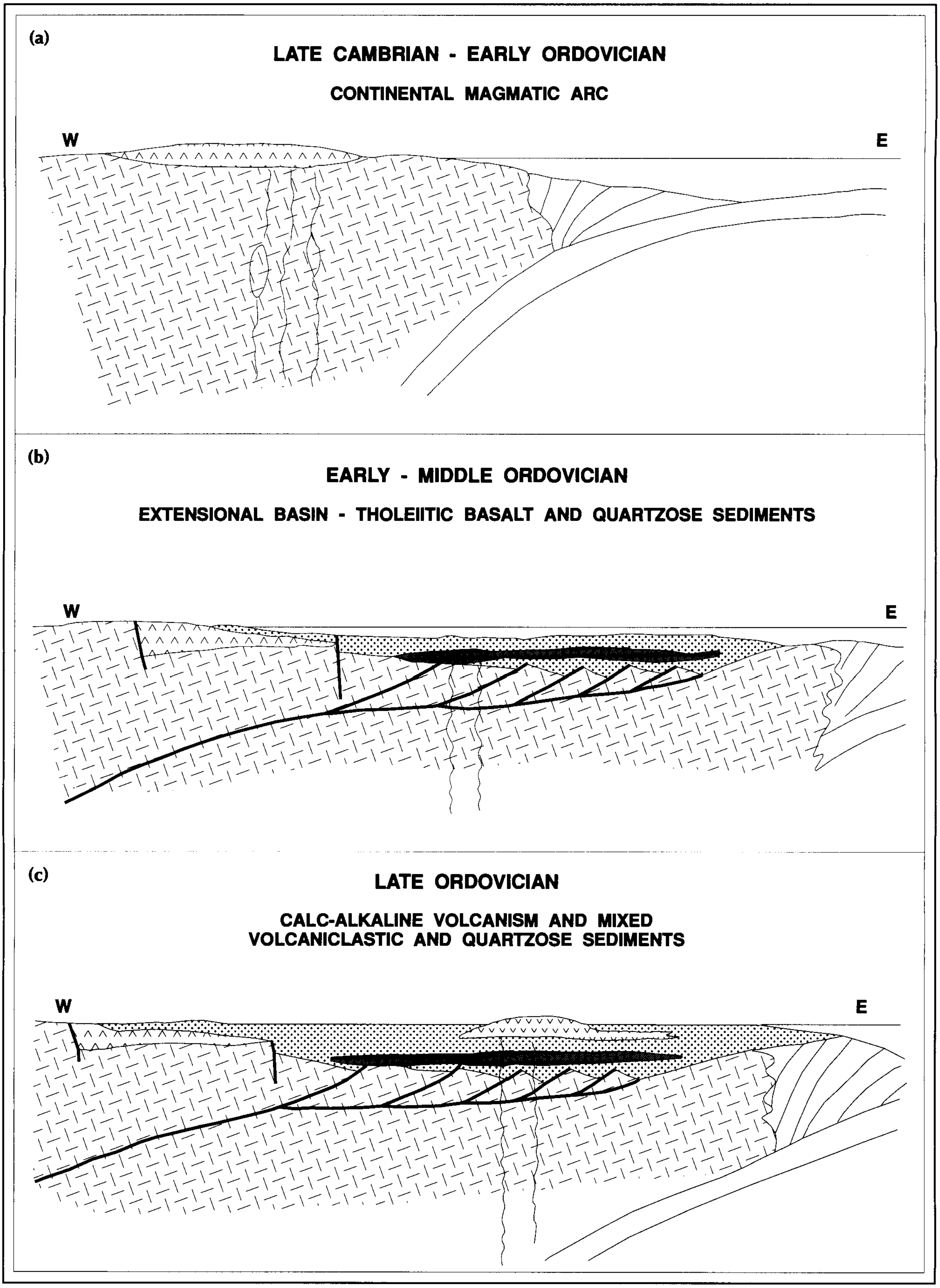


Figure 95. Tectonic model for the Broken River Province.

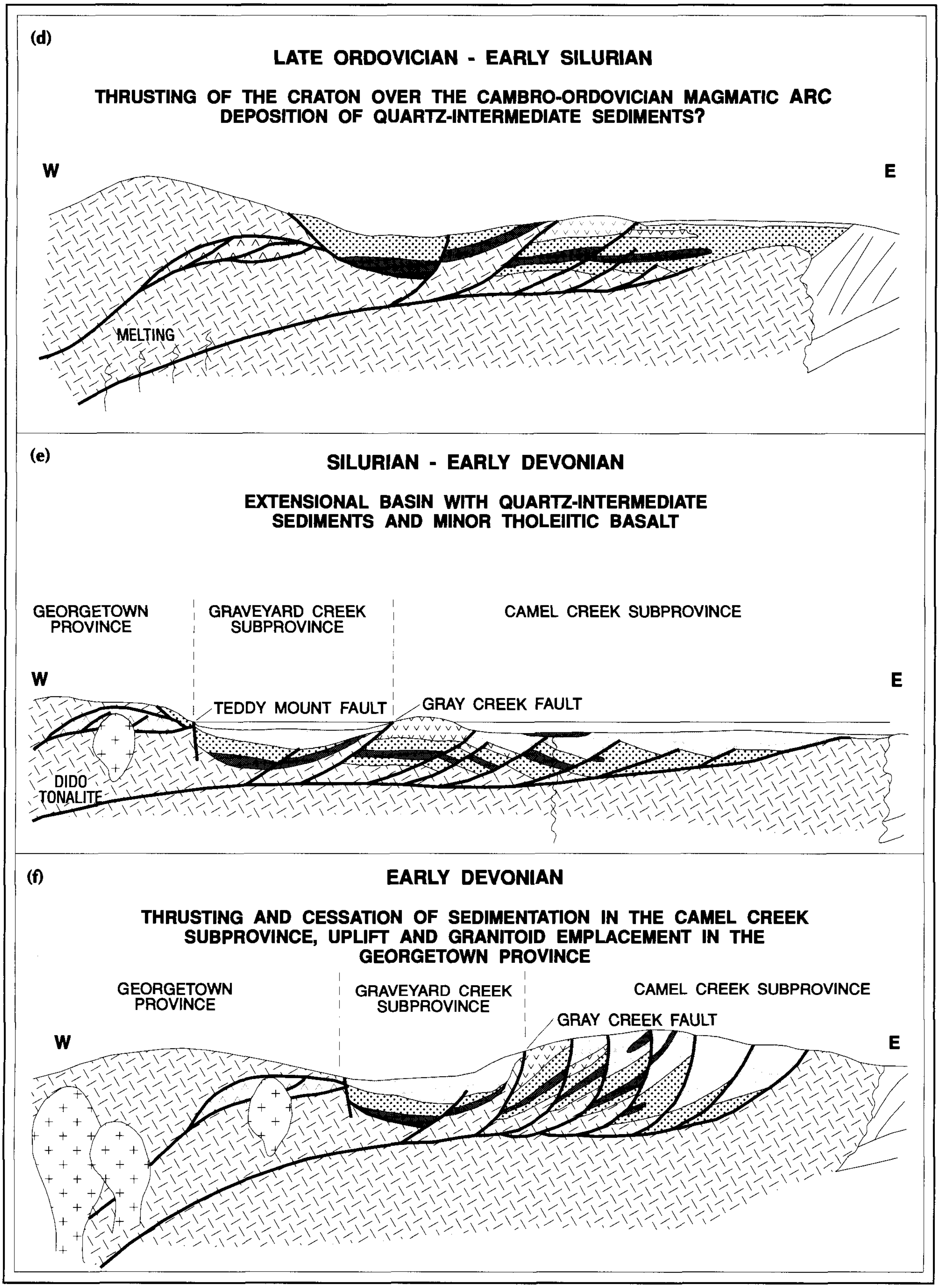


Figure 95 continued

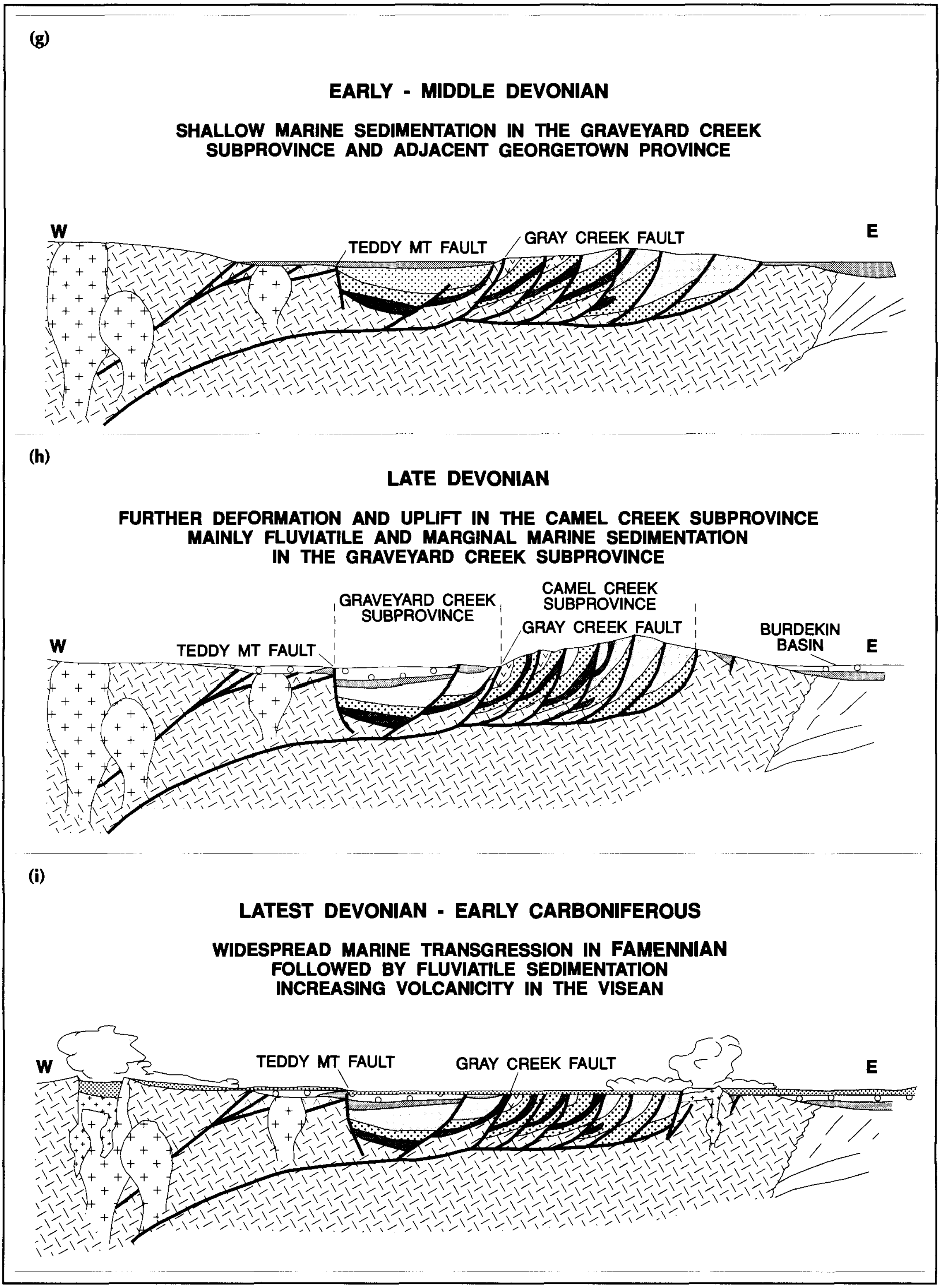
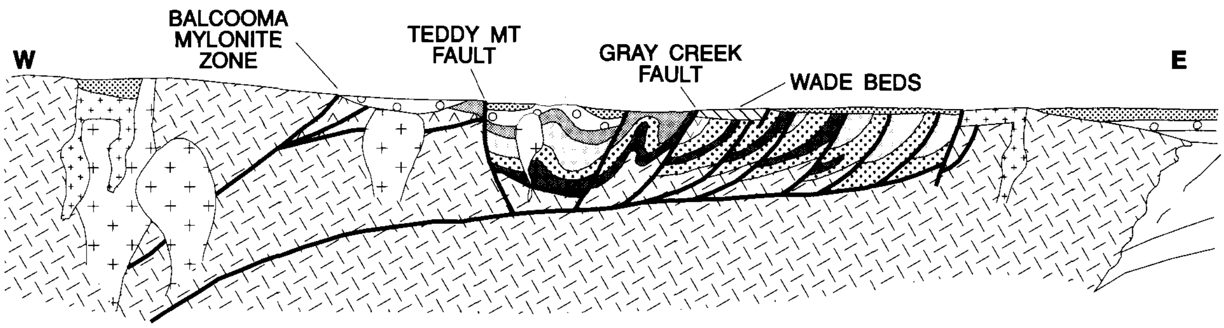


Figure 95 continued

(j)

LATE CARBONIFEROUS - EARLY PERMIAN

FOLDING AND GRANITOID EMPLACEMENT IN THE GRAVEYARD CREEK SUBPROVINCE
FLUVIATILE SEDIMENTATION LOCALLY



REFERENCE

- *BASEMENT / CONTINENTAL CRUST*
- *CAMBRO-ORDOVICIAN SUBDUCTION COMPLEX*
- *CAMBRO-ORDOVICIAN TO INTERMEDIATE CALC-ALKALINE VOLCANICS*
- *QUARTZOSE SEDIMENTS (MAINLY TURBIDITES)*
- *THOLEIITIC BASALT*
- *CALC-ALKALINE VOLCANICS AND VOLCANICLASTICS SEDIMENTS*
- *QUARTZ-INTERMEDIATE TURBIDITES*
- *GRANITOIDS*
- *SHELF SEDIMENTS*
- *MAINLY FLUVIATILE SEDIMENTS (BULGERI FORMATION AND EQUIVALENTS)*
- *SHALLOW MARINE TO FLUVIATILE SEDIMENTS (TEDDY MOUNT, VENETIA AND GILBERTON FORMATIONS)*
- *FLUVIATILE SEDIMENTS (WADE BEDS)*

Figure 95 continued

preserve some of the sediment derived from this erosion. Hammond (1986) used the evidence for uplift to suggest that the Georgetown Province was thrust over the Camel Creek Subprovince along the Burdekin and Gray Creek Faults as a large duplex structure in the Early Devonian.

In the Hodgkinson Province, deposition continued through the Devonian, and there is no evidence for Early Devonian deformation there. The Graveyard Creek Subprovince also escaped the postulated Early Devonian deformation in the Camel Creek Subprovince, except perhaps for minor folding near the Gray Creek Fault. The explanation offered by Hammond (1986), Withnall & others (1988b) and Withnall & Lang (1990) was that the subprovince was riding on the upper cratonic plate.

If there was extensive deformation in the Camel Creek Subprovince in the Early Devonian, the Clarke River Fault was probably also active. Both dextral (McLennan, 1986) and sinistral movement (Arnold, 1975; Henderson, 1980, 1987; Harrington, 1981) have been suggested for the fault. Correlations of rocks in the eastern Georgetown Province with similar units in the Lolworth-Ravenswood Province, as well as the shape of the orocline in the Camel Creek Subprovince, are more consistent with sinistral movement on the fault. The dextral movement suggested by McLennan (1986) on microstructural and macroscopic structural evidence from the Craigie area, suggests that a continuation of the Camel Creek Subprovince might have lain to the south of the Graveyard Creek Subprovince as part of the Thomson Fold Belt. If the Clarke River Fault was a tear fault marking the southern limit of the earlier extension and subsequent convergence between the Georgetown Province and the Camel Creek Subprovince, it is possible that both sinistral and dextral relative movement could have occurred on different segments, as well as at different times.

In the Graveyard Creek Subprovince, after an apparently short hiatus at the top of the Graveyard Creek Group, sedimentation continued with the deposition of mainly siliciclastic and carbonate shelf sediments of the Shield Creek Formation and Broken River Group. This deposition extended from the late Lochkovian to the Givetian. Figure 96 summarises the environments of deposition during the deposition of the Broken River Group. Remnants preserved on the Georgetown Province, such as near Conjuboy, indicate that sedimentation was not restricted to the present limits of the Graveyard Creek Subprovince, but it was probably thickest there.

As discussed in the preceding chapter on sequence stratigraphy, the sedimentary record from the Lochkovian to early Frasnian indicates that global eustatic sea level fluctuations influenced sedimentation patterns and were not obscured by tectonically driven fluctuations in relative sea level. The gross facies patterns indicate a shelf to slope transition from southwest to northeast, and this is supported by palaeocurrent directions which indicate that the main transport direction was east-northeasterly towards the present position of the Camel Creek Subprovince. The composition of the sediments within the Shield Creek Formation and Broken River Group are dominantly derived from the craton, with the exception of some mafic volcanic clasts in the Burges Formation; these clasts could have been derived from the Judea Formation which may have overlain the craton and been exposed immediately to the west (eg. west of Storm Hill area). If the Camel Creek Subprovince had been deformed in the Early Devonian, it would have formed an uplifted orogenic belt to the east. There is no evidence of any Early or Middle Devonian rocks containing westerly directed palaeoflows or large quantities of sediment sourced from the orogen. Therefore the uplifted portion of the orogen, if it existed, lay well to the east, or it may have been peneplained during the Early Devonian (Lochkovian). The hiatus between conodont dates from the upper Jack Formation (Pridoli or earliest Lochkovian) and the Martins Well Limestone Member of Shield Creek Formation (late Lochkovian to Pragian) translates to between 8 and 10 Ma using the time scales of either Harland & others (1990) or Fordham (1992). This would be ample time for peneplanation of the orogen.

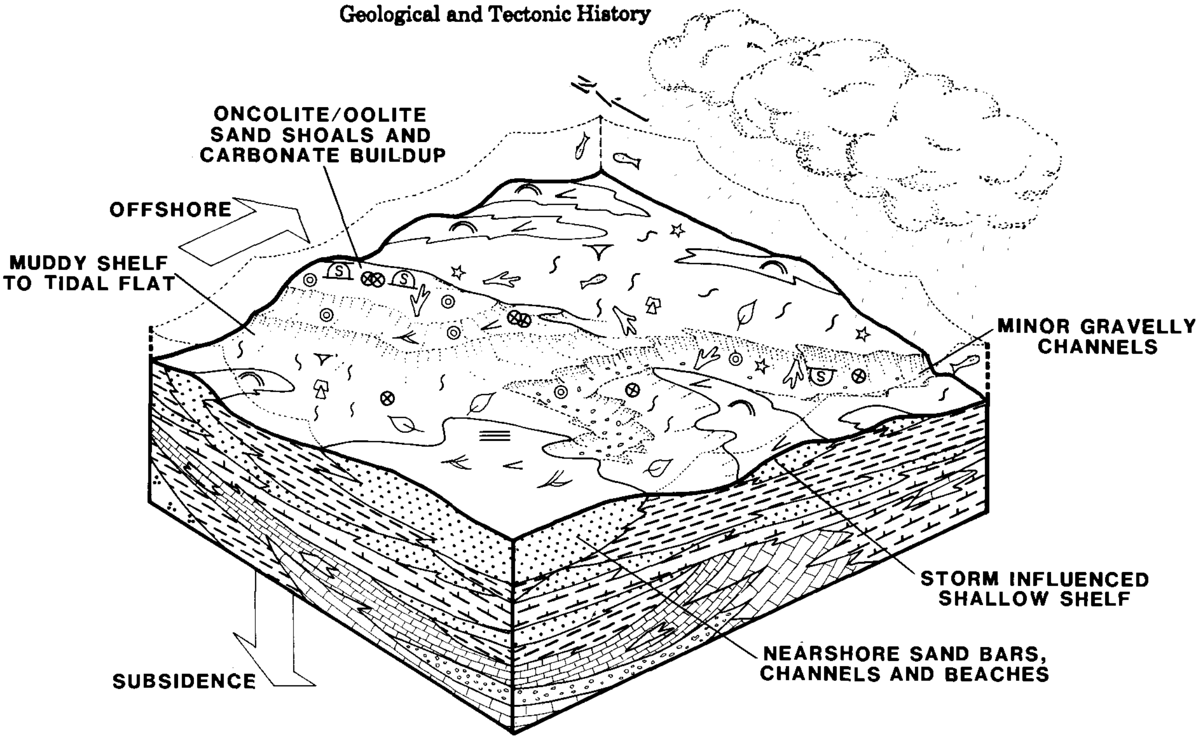
Alternatively, the Camel Creek Subprovince may not have been deformed in the Early Devonian. In this case, the Shield Creek Formation resulted from uplift in only the Georgetown and Lolworth-Ravenswood Provinces prior to widespread marine transgression in the Emsian. The difficulty with this is the lack of any definite Middle Devonian successions in the Camel Creek Subprovinces to the east. However, widespread Early to Middle Devonian marine deposits occur in the nearby Burdekin Basin which overlies the Lolworth-Ravenswood Province (Lang & others (1990b). Immediately south of the Camel Creek Subprovince, in the Ewan-Mount Podge area, Early Devonian and Middle Devonian sedimentary rocks overlie metamorphic basement, and Lang & others (1990b) suggest that these were related to a transgression from the north. Farther west, in the Blue Range area, an isolated outcrop of steeply dipping limestone is similar to the limestones in the Burdekin Formation. It has not been reliably dated, but if it does correlate with the Burdekin Formation, it would suggest that during the Early to Middle Devonian, deposition continued across the Camel Creek Subprovince, but has simply not been preserved.

In any case, the Shield Creek Formation and Broken River Group appear to have accumulated on a continental shelf on the eastern margin of the Georgetown Province, and probably extended northward to the Hodgkinson Province, and southeastward to the Burdekin Basin.

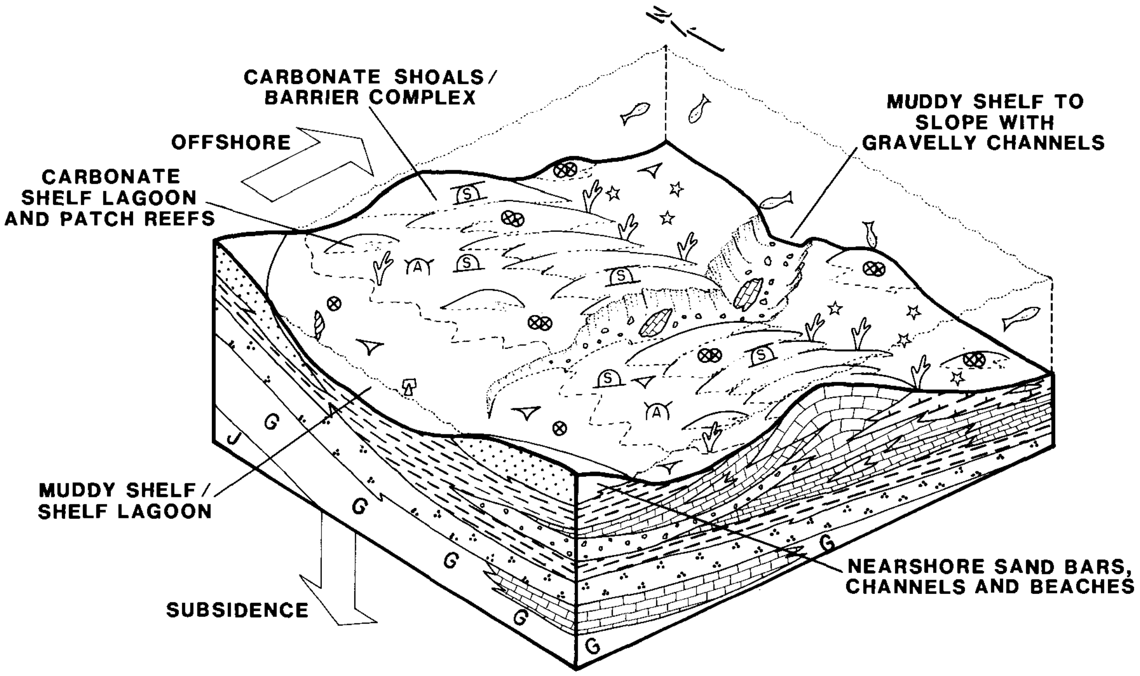
LATE DEVONIAN TO CARBONIFEROUS

Deformation of the Graveyard Creek Subprovince in the early Frasnian resulted in a slight angular unconformity at the top of the Broken River Group. It may have been associated with renewed convergence between the Georgetown Province and the Camel Creek Subprovince. The convergence possibly changed in direction from west (as in D_1) to the northwest so that major northeast-trending folds of D_1 structures were produced. The northeast-trending segment of the Palmerville Fault may have formed at this time as a tear fault, offsetting the Burdekin Fault from the north-trending part of the Palmerville Fault. Again, the deformation in the Camel Creek Subprovince appears to have been much more intense than in the Graveyard Creek Subprovince which was overlying the craton or perhaps a thick cratonic upper plate. The mild deformation of the Graveyard Creek Subprovince could have been produced by tilting of the Broken River Group above a ramp during the renewed convergence.

If the major thrusting event in the Camel Creek Subprovince did not occur in the Early Devonian, it may have coincided with the unconformity overlying the Broken River group. In other words, both D_1 and D_2 in the Camel Creek Subprovince could have been phases of a single major convergent event initiated in the early Frasnian. The main constraint on the deformation events is that they both predate the latest Devonian or Tournaisian marine sediments that unconformably overlie the Camel Creek Subprovince at the base of the Clarke River Group. Therefore sufficient time after the deformation must have elapsed for erosion and peneplanation of the Camel Creek Subprovince to sea-level by the end of the Devonian. The early Frasnian is still too early for the terminal deformation in the Hodgkinson Province, where sedimentation in the east



GIVETIAN



LATE EMSIAN-EIFELIAN

REFERENCE

HORIZONTAL STRATIFICATION	*PLANT FRAGMENTS*	*BIVALVES*
LOW ANGLE PLANAR CROSS-STRATIFICATION	*MASSIVE CORALS*	*BRACHIOPODS*
HUMMOCKY CROSS-STRATIFICATION	*SOLITARY CORALS*	*MASSIVE AND LAMELLAR STROMATOPOROIDS*
TROUGH CROSS-STRATIFICATION	*BRANCHING CORALS*	*HEMISPHERICAL AND GLOBULAR STROMATOPOROIDS*
OOLITES AND ONCOLITES	*CRINOIDS*	*BRANCHING STOMATOPOROIDS "AMPHIPORA"*
BURROWS	*GASTROPODS*	*FISH*

Figure 96. Early to Middle Devonian depositional models for the Broken River Group.

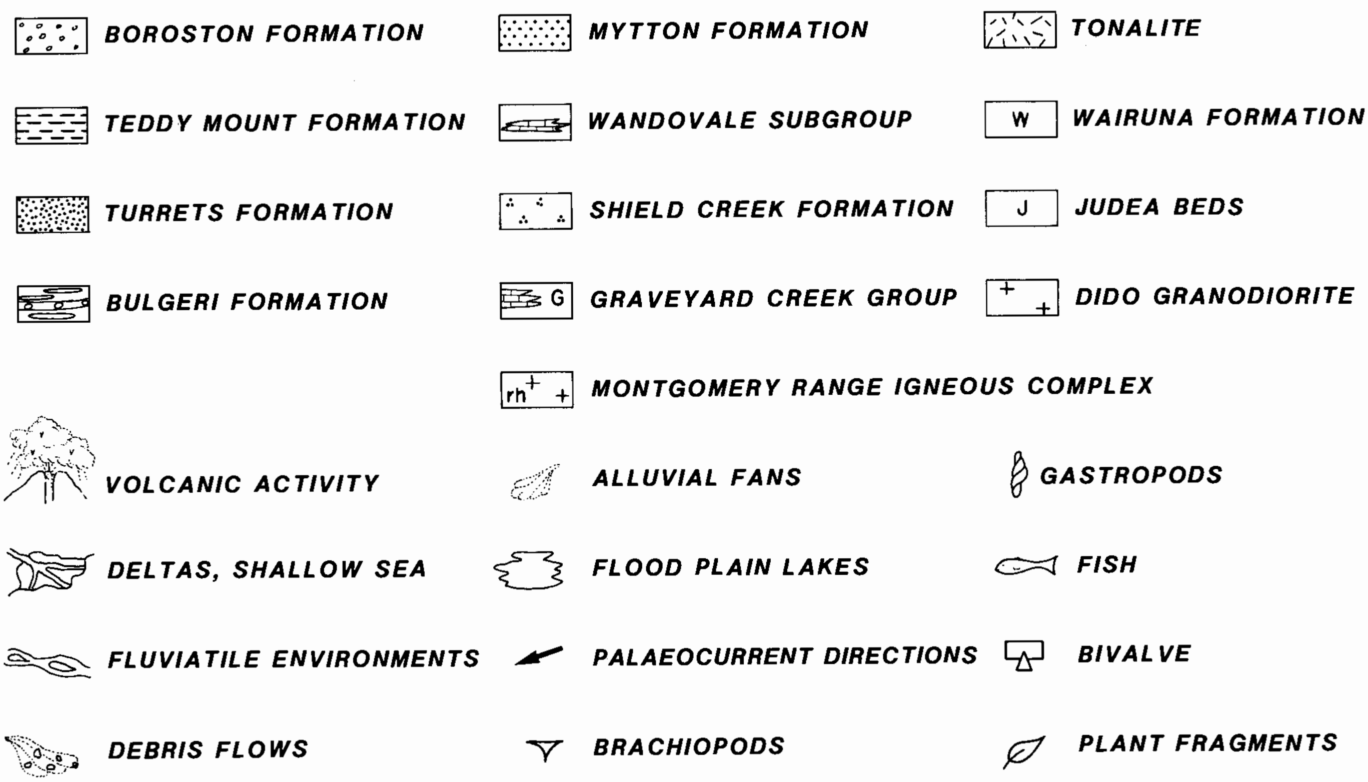


Figure 97. Reference for Figure 98.

is known to extend into the Famennian (B.G. Fordham, personal communication, 1989).

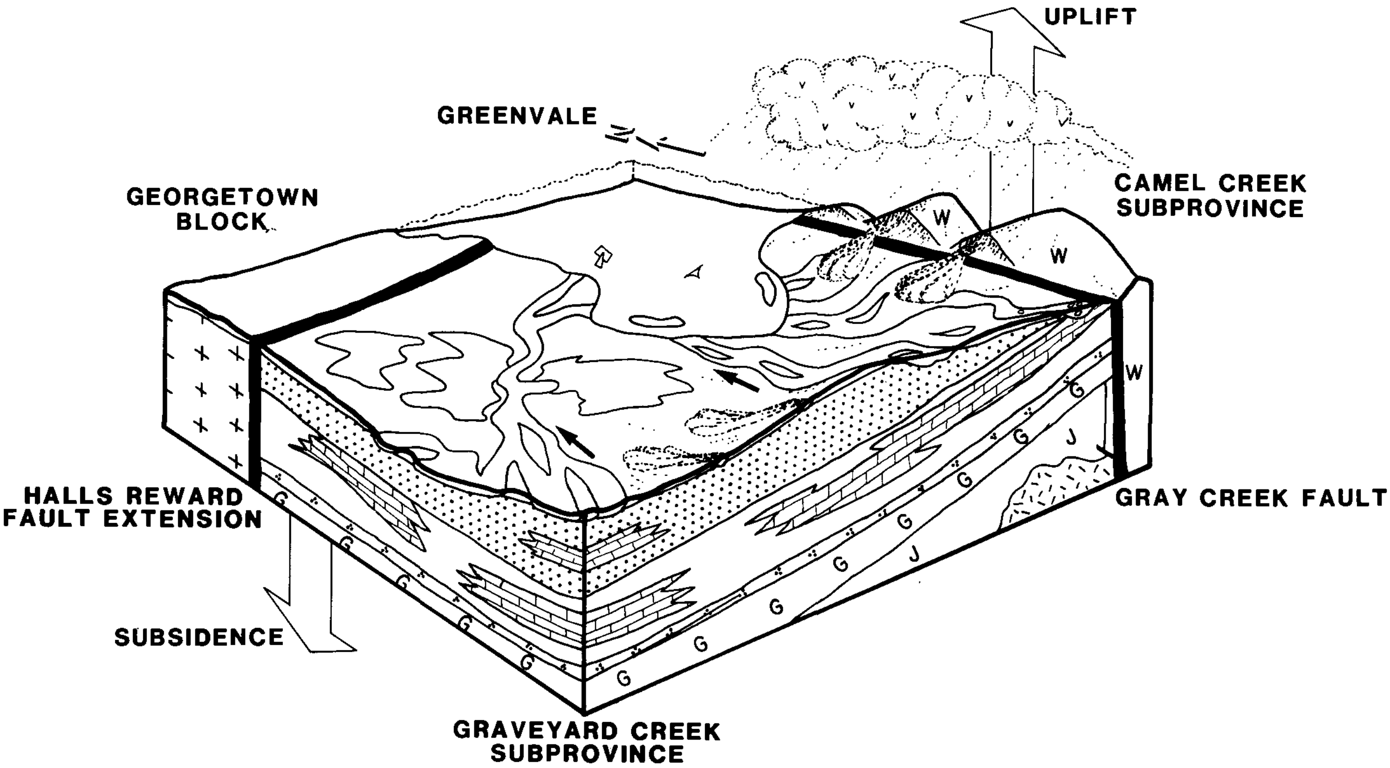
After a short hiatus, deposition of the Bundock Creek Group commenced in the late? Frasnian with the deposition of the Bulgeri Formation. The Graveyard Creek Subprovince developed into a small, rapidly subsiding foreland basin in the hinterland of the orogen, west of the Gray Creek Fault, and north of the Clarke River Fault. The foreland basin developed in response to crustal loading associated with deformation (at least D_2) in the Camel Creek Subprovince, east of the Gray Creek Fault, and oblique-slip movement along the Clarke River Fault, which acted as a tear fault along a pre-existing crustal weakness. The relative movement along the Clarke River Fault east of the intersection with the Gray Creek Fault was probably sinistral, but the relative movement to the west could have been dextral, consistent with the data of McLennan (1986).

Previously, the basin was considered to be a pull-apart basin, because of its proximity to these major faults. Withnall & Lang (1990) suggested that a north-south dextral shear couple, such as proposed by Evans & Roberts (1980) to explain the late Palaeozoic evolution of the central part of the Tasman Orogen, could have promoted extension and subsidence in the basin. The pre-existing northeast trend of the Clarke River Fault would be favourable to reactivation as a normal fault by such a couple. Alternatively, they suggested that the required extension could have resulted from an east-west sinistral shear couple, that may have also produced sinistral movement on the Clarke River Fault.

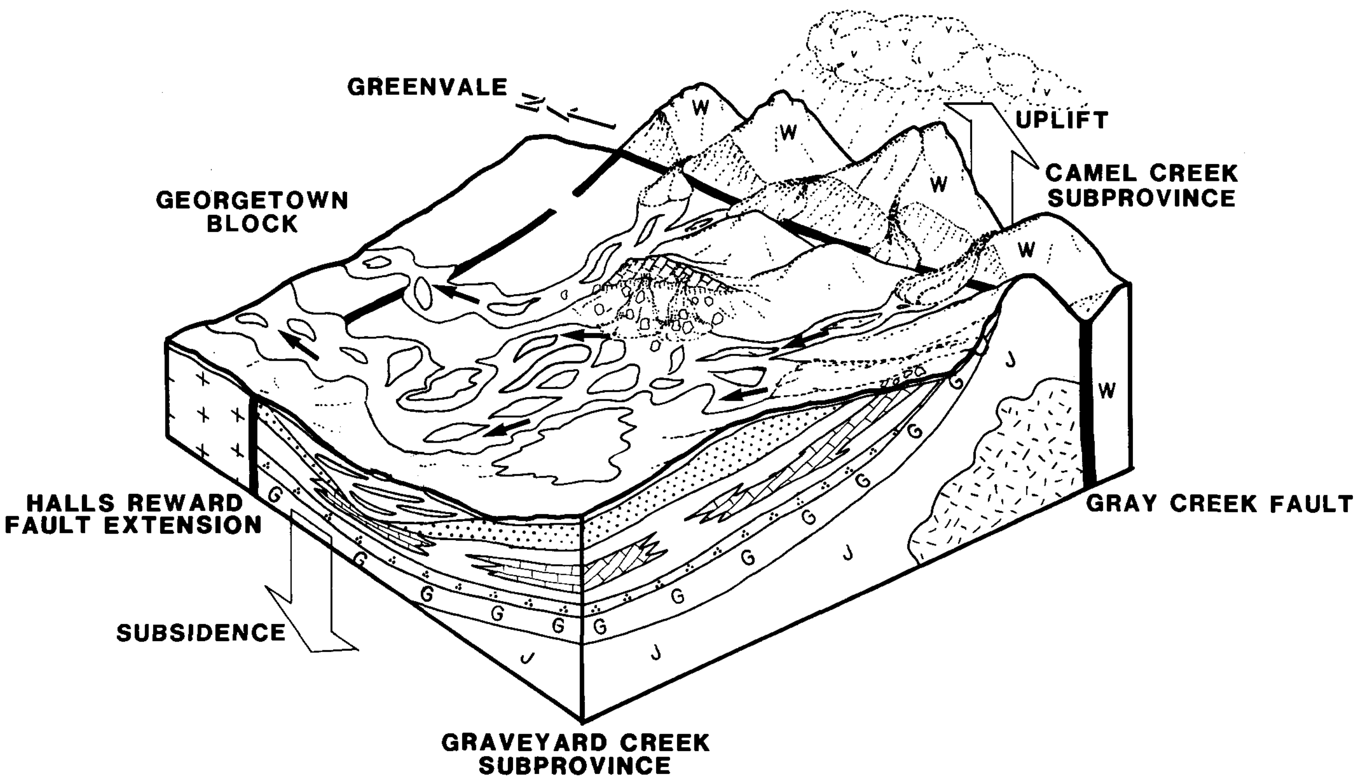
The Bulgeri Formation of the Bundock Creek Group accumulated over the Georgetown Province, and in two sub-basins within the Graveyard Creek Subprovince (Figure 36). The greatest subsidence was in the Red Range sub-basin in the south, adjacent to the Clarke River Fault. It accumulated up to 4 000 m of Bulgeri Formation, whereas the Teddy Mount sub-basin in the north accumulated only 2 000 m. The sub-basins are separated by a central ridge (the Pandanus-Gregory Springs Ridge) which Lang (1986a) interpreted as an active basement fault structure that influenced deposition of most of the Bundock Creek Group. The Teddy Mount Fault, which forms the northern edge of the Graveyard Creek Subprovince as now preserved, was not a basin margin, and appears to be a later truncational structure.

The foreland basin model is based on analysis of alluvial systems in the Bulgeri Formation. Lang (in press and this volume) recognised several, subsidence-driven, tectonic cyclothems in the lower 1 500 m of the Bulgeri Formation. Each cyclothem consists of a thick, relatively fine-grained lower part, interpreted as syn-tectonic alluvial facies, and a thick relatively coarse-grained, upper part, interpreted as post-tectonic alluvial facies. Facies analysis and mapping of alluvial stratigraphy has resulted in the recognition of compositionally distinct, coalescing, axial and transverse alluvial drainage systems as depicted in Figure 97.

The axial drainage system flowed to the northeast, approximately parallel to the Gray Creek Fault and away from the Clarke River Fault. The system drained the cratonic basement to the south and west, and accumulated mainly feldspathic and quartzose sedimentary rocks. A lower, fine-grained succession, and an upper coarse-grained succession are recognised. The lower succession ('Rockfields' alluvial system), was deposited in broad, sandy, low-sinuosity channels and semi-permanent flood-plain lakes. These rivers drained ultimately northward into a retreating coastal plain and shallow sea that lay over the Georgetown Province. The upper succession ('Bulgeri'

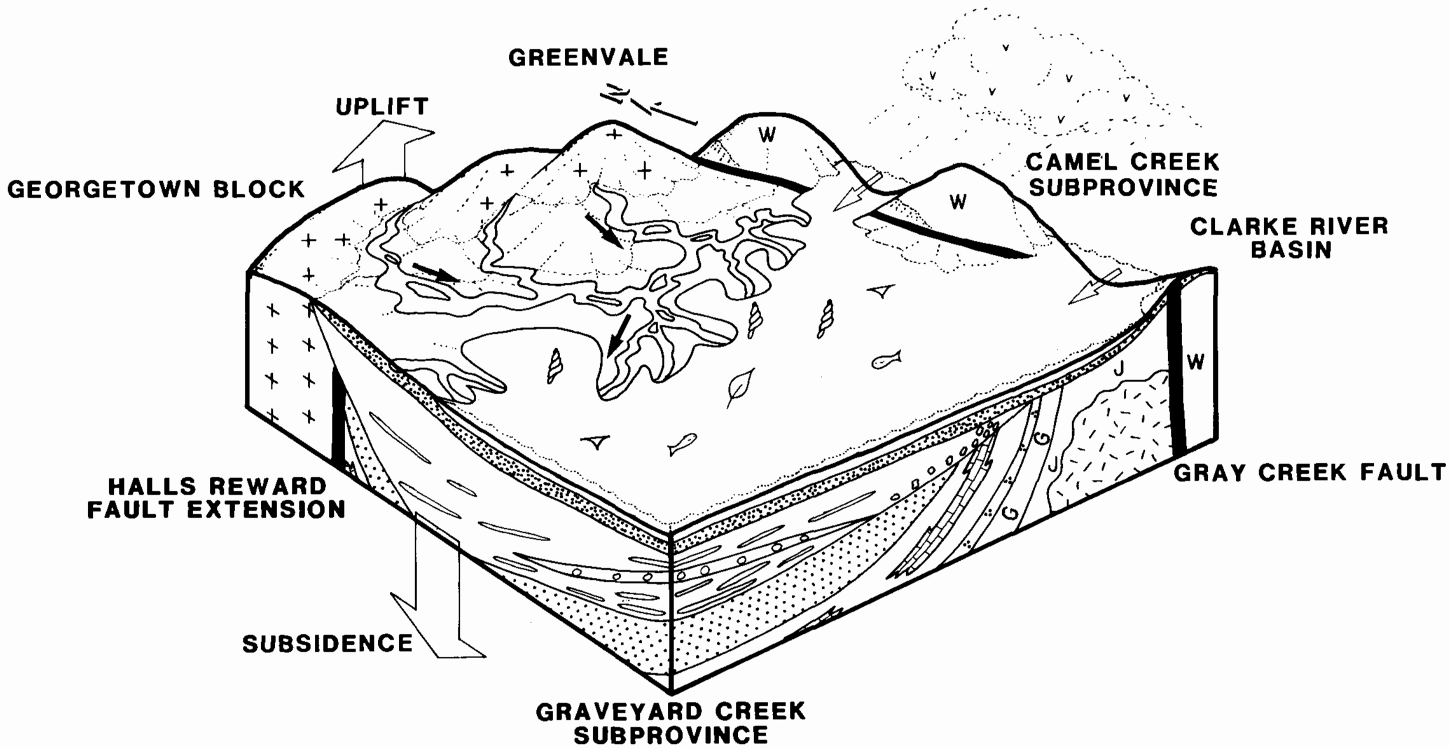


?FRASNIAN–FAMENNIAN LANDSCAPE

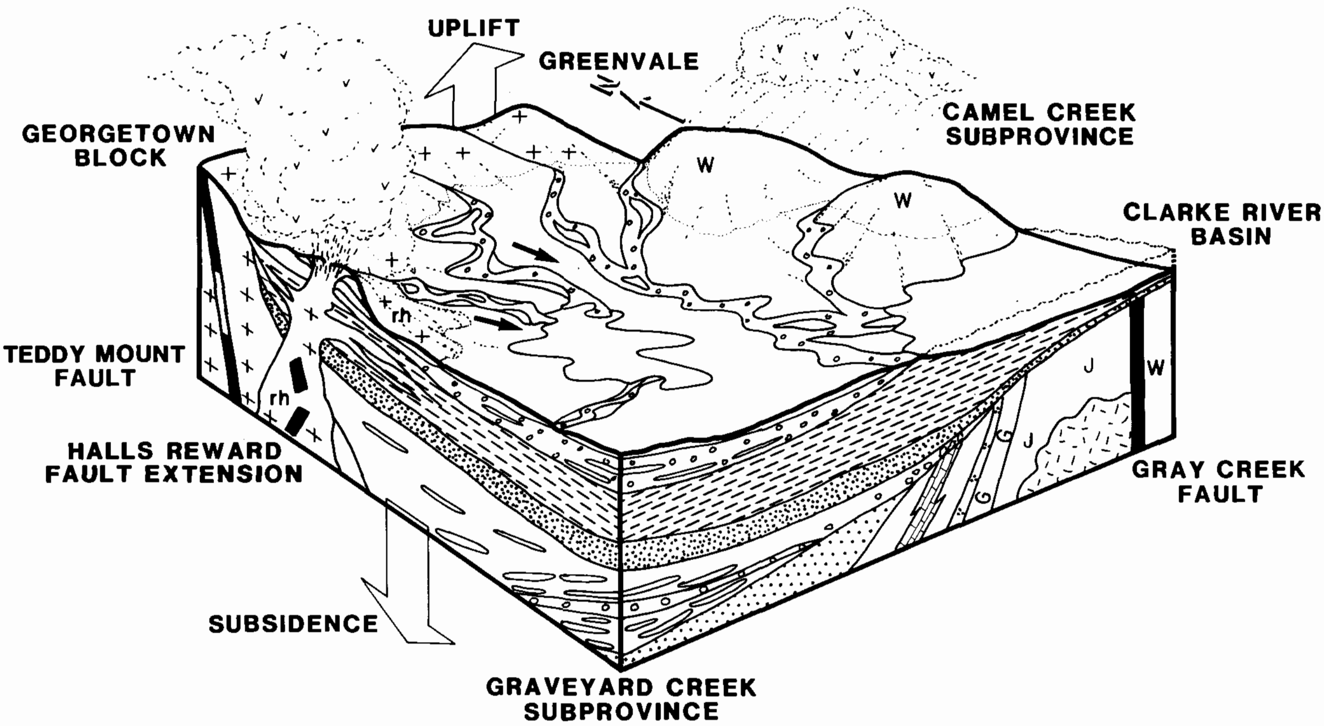


FAMENNIAN LANDSCAPE

Figure 98. Late Devonian to Visean landscapes during the deposition of the Bundock Creek Group.



LATEST FAMENNIAN TO EARLY TOURNASIAN LANDSCAPE



EARLY TO ?MIDDLE CARBONIFEROUS LANDSCAPE

Figure 98 continued

alluvial system) was deposited in gravelly and sandy braided rivers emanating from south of the Clarke River Fault.

The transverse distributary system ('Stopem Blockem' alluvial system) deposited mainly lithic, coarse-grained sedimentary rocks in gravelly braided rivers sourced from the uplifted orogenic belt to the east. These rivers flowed towards the northwest before coalescing with the axial drainage system where they changed to a northerly orientation. Uplifted fault blocks of Devonian limestone within the basin locally contributed limestone gravel to these rivers. Between the coalescing axial and transverse river systems lay extensive floodplains, which received a slow, but compositionally mixed supply of mainly fine-grained sediments. Long periods of weathering resulted in the development of reddened palaeosols, with well developed calcrete horizons.

The north to northeast flowing trunk streams flowed towards the Hodgkinson Province, across the Georgetown Province, where remnants of the fluviatile rocks are preserved. The system was probably joined by streams draining eastwards from the central part of the Georgetown Province. The palaeogeography and fluvial style of the lower Bulgeri Formation is analogous to the low sinuosity rivers of the broad alluvial plains and fans adjoining the Gulf of Carpentaria in northeastern Australia today.

Reworked tuff beds are common in the succession. Their exact source is unknown, but volcanogenic sediments are also common in the Burdekin Basin to the east at this time. The nearest primary volcanics of this age occur in the northern Drummond Basin, but the large angular volcanic clasts and accretionary lapilli suggest a much closer source yet to be recognised in the Georgetown or Lolworth-Ravenswood Provinces.

In the upper part of the Bulgeri Formation and Turrets Formation in the Famennian, non-marine conditions prevailed, but several minor marine transgressions are recorded. A major transgression is represented by the succeeding Teddy Mount Formation, and reached a peak in the latest Famennian to earliest Tournaisian. At this time, a change in the direction of sediment transport from northerly to southeasterly occurred, possibly in response to uplift of the Georgetown Province and deformation of the Hodgkinson Province to the north (Figure 98). Tuffaceous sediments continued to be supplied to the basin. Also in the latest Famennian or earliest Tournaisian, deposition commenced in the Clarke River Basin, with the Venetia and Ruxton Formations. These unconformably overlie the Camel Creek Subprovince, and comprise mainly fluviatile sediments sourced from the south, and marine sediments deposited during the same regional transgression as in the Teddy Mount Formation to the west.

A major regressive phase followed later in the Tournaisian, in response to fault movements and uplift of the Georgetown Province to the north (Figure 98). Braided rivers, dominantly from a cratonic source, deposited a thick clastic wedge represented by the Boroston Formation in the Graveyard Creek Subprovince. In the Clarke River Basin, the upper part of the Venetia Formation was probably still sourced from the Lolworth-Ravenswood Province to south, but the Ruxton Formation was sourced from the northwest.

In the Visean, increasing volcanic activity throughout north Queensland is reflected in the Harry Creek Formation in the Bundock Creek Group and the Lyall Formation in the Clarke River Group. These units comprise tuff, ignimbrite, and volcaniclastic arenite, siltstone, and mudstone, deposited in fluvial to lacustrine environments. Rhyolitic sills and dykes were probably also emplaced at this time.

In the mid-Carboniferous, a major northeast-southwest folding event deformed the Graveyard Creek Subprovince. The Camel Creek Subprovince was not greatly affected by this event, although the western part of the Clarke River Basin has open folds. The orientation of the folds is consistent with a dextral shear couple and consequent dextral movement on the Clarke River Fault. Granitoids were subsequently emplaced into the Graveyard Creek Subprovince. Although they are still part of the overall Carboniferous to Permian plutonic and volcanic cycle in north Queensland, there appears to be some local structural control. They are restricted to the area between the Teddy Mount Fault and the Pandanus-Gregory Springs Ridge.

In the Late Carboniferous to Early Permian, fluviatile sediments (the Wade beds) were deposited unconformably on the Clarke River Group. Their original extent is not known, but rocks of equivalent age are now known from palynological study of samples from the Marsh Creek beds in the Sybil Graben (Gunther & Withnall, 1992; J. Draper and J. McKellar, unpublished data). The Wade beds may be outliers of the basal part of the Galilee Basin succession to the south.

MESOZOIC AND CAINOZOIC

Fluvial Mesozoic deposition occurred in the western part of the region but the eastern part of the area may have been largely erosional during the Mesozoic. Some marine influence is indicated by the appearance of trace fossils in the uppermost beds of the Mesozoic sequence.

In the Tertiary, erosion with some local deposition resulted in the formation of an undulating surface, the Featherby Surface, which by mid Tertiary was stable enough for extensive deep weathering to occur beneath it. Ferruginous weathering profiles formed on most of the surface, but silcretes formed along some valleys.

Episodic basaltic volcanism occurred in the area from at least the late Miocene onwards. Flows were erupted in the Lake Lucy area and flowed down a north-flowing drainage system (opposite to the modern drainage) in the late Oligocene (27 Ma) and early Miocene (19 Ma). In the southern part of the region the oldest basalts are the dissected mesas on both sides of the Clarke River, which are dated at about 9 Ma. Other flows preserved as remnants, such as the nephelinite dated at 11 Ma near Greenvale, may represent once more extensive lava fields. The most extensive volcanics occurred in the McBride, Chudleigh and Nulla Provinces where basalts were erupted sporadically from the late Miocene (8 Ma) throughout the Pliocene and Pleistocene, and possibly to almost Recent times. The younger flows follow valleys cut deeply into the older flows. Stream and lake sediments are interbedded with the basalt flows in places. Some of the older flows have been deeply weathered.

Erosion in the latter part of the Tertiary dissected the Featherby Surface and fluvial sediments were deposited locally in valleys and small basins. The most extensive deposits are in the Lake Lucy Tableland. These were also deeply weathered, but not as extensively as the rocks beneath the Featherby Surface. A nodular ferricrete formed on the late Tertiary sediments and also on the flatter parts of the older Featherby Surface.

Continuing erosion in the Quaternary dissected the weathered rocks, and fluvial deposition occurred at several levels in the modern valleys.

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Appendix 1: Modal analyses of arenites from the Broken River Province.

Qm = monocrystalline quartz and composite quartz grains (individual subgrains > 0.06 mm)
Qp = polycrystalline quartz (individual subgrains <0.06 mm) - mostly showing a tectonic fabric
Qch = chert
F = feldspar
M = detrital mica, chlorite
Lv = volcanic lithics
Lm = metamorphic lithics (phyllite, schist, impure quartzite)
Ls = sedimentary lithics (mainly shale, some fine-grained arenite and siltstone)
D = heavy detrital grains (opaque oxides, epidote, hornblende, zircon etc.)
B = bioclastic carbonate
Cmt = chemical cement (mainly carbonate)
Mtx = matrix (grains smaller than 0.06mm - includes phyllosilicates, some of which could be diagenetic)

Percentages of framework grains recalculated to 100%. At least 300 framework grains counted per sample. Samples point-counted using the Gazzi-Dickinson method (Ingersoll & others, 1984).
Sample numbers refer to the Queensland Department of Resource Industries Rock and Microslide catalogue, except those prefixed by UQ which are housed in the Department of Earth Sciences, University of Queensland.

Sample number	1:100 000	Grid Reference	Qm	Qp	Qch	F	M	Lv	Lm	Ls	D	B	Mtx	Cmt
Wairuna Formation														
13581	7859	820764	82.6	9.9	1.7	4.7	0.6	-	-	0.6	-	-	14.0	-
18360	7959	926791	82.4	3.2	1.4	4.0	2.5	2.2	-	4.0	-	-	44.4	-
Carriers Well Formation														
13591	7859	871949	70.3	2.8	1.7	18.2	4.5	0.3	-	1.7	0.3	-	42.8	-
13594	7859	837878	0.8	-	-	15.1	-	83.3	-	-	0.8	-	38.8	-
Pelican Range Formation														
12457	7960	079198	86.5	-	5.1	2.6	2.6	-	0.7	2.6	-	-	31.8	-
13483	7959	336652	84.2	1.4	6.8	2.7	2.0	-	0.7	2.4	-	-	26.0	-
18363	7959	118860	86.3	0.9	2.4	4.9	2.4	0.3	-	2.4	0.3	-	34.6	-
18369	7959	086895	88.2	1.7	4.3	1.7	1.1	0.3	0.9	1.4	0.3	-	13.0	-
18371	7959	044897	79.9	2.1	2.4	10.8	1.7	0.3	-	2.1	0.7	-	42.4	-
Tribute Hills Arenite														
13475	7959	380701	90.1	2.1	1.8	1.8	-	-	-	3.6	0.6	-	33.4	-
13477	7959	333652	88.7	1.6	1.6	3.9	1.3	-	-	2.6	0.3	-	38.0	-
13478	7959	320653	91.5	1.8	2.5	3.2	0.4	-	-	0.4	0.4	-	43.6	-
18384	7959	401711	89.3	0.7	2.7	1.7	1.0	0.7	-	4.0	-	-	40.2	-
Greenvale Formation														
13473	8059	442671	34.4	3.2	0.3	9.5	3.2	10.1	33.8	4.0	1.4	-	13.0	0.5
18361	7959	144869	53.7	2.0	0.6	23.3	4.5	5.1	7.1	3.4	0.9	-	11.8	0.3
18365	7959	029904	41.3	3.1	1.5	11.3	4.6	16.2	16.8	3.1	2.1	-	18.3	-
18366	7959	194867	54.2	0.8	0.3	24.0	2.8	11.0	3.4	1.7	1.7	-	11.0	0.5
18379	7959	019763	39.2	3.8	0.6	13.4	3.5	17.2	21.7	0.6	-	-	21.5	-
18387	7960	015044	42.7	2.0	0.6	23.7	6.5	9.3	10.2	1.1	4.0	-	10.3	1.3
Perry Creek Formation														
12461	7960	192118	58.4	1.9	0.8	22.6	1.9	2.2	10.3	1.6	0.3	-	8.0	-
12462	7960	087211	79.3	3.1	0.7	5.4	0.3	7.1	3.1	0.3	0.7	-	26.3	-
12474	8059	457754	69.1	2.4	4.7	8.8	4.4	1.5	4.1	2.4	0.3	-	32.0	-
12503	7959	231900	60.4	1.5	1.2	21.3	4.5	4.2	1.8	4.5	0.6	-	16.8	-
13481	7959	265703	49.4	1.4	-	29.3	8.9	1.4	7.5	0.6	1.4	-	13.0	-
13482	7959	245710	46.2	4.6	0.5	24.9	1.1	9.2	10.5	2.7	0.3	-	7.5	-
13554	8059	519743	52.3	2.6	1.4	12.4	6.3	3.7	10.3	4.3	-	-	13.0	-
13555	8059	510765	74.0	-	6.4	13.0	4.2	-	-	0.6	0.6	-	34.0	-
18331	8059	733891	68.6	1.0	3.2	19.7	2.5	3.2	0.3	0.3	1.3	-	37.0	-
18368	7959	210868	53.9	0.6	0.8	34.3	1.1	5.3	1.4	2.8	-	-	9.5	-
18375	7959	281745	79.8	1.1	6.4	7.5	0.6	1.9	0.8	1.4	0.6	-	9.8	-
18388	7960	238996	66.1	2.7	3.9	18.8	0.6	5.2	0.6	0.9	1.2	-	17.5	-
Kangaroo Hills Formation														
12469	7960	230164	53.6	2.0	-	29.0	7.0	1.2	5.5	1.4	0.3	-	13.8	-
12470	7960	233155	50.0	1.8	4.1	25.4	2.7	1.8	3.3	8.6	0.3	2.1	15.5	-
12471	8059	442764	42.2	0.9	-	43.1	4.6	1.4	1.1	0.3	0.6	5.7	13.0	-
12473	8059	442764	58.1	0.9	0.6	33.8	3.9	0.6	0.3	-	1.8	-	16.5	-
12488	7960	406195	52.0	0.3	-	30.9	7.7	2.3	1.1	2.6	0.9	2.3	12.5	-
12494	7960	256997	44.4	0.7	0.7	39.7	5.7	0.3	0.3	0.7	-	7.4	25.8	-
12505	7959	241903	46.2	0.3	0.9	36.1	6.5	0.6	0.3	0.3	3.0	5.9	15.5	-
13470	7959	385848	40.2	0.6	-	41.5	14.9	0.9	0.9	-	0.6	0.3	19.3	-
18377	7959	340740	50.5	0.5	0.3	30.1	4.1	1.9	6.6	2.2	1.6	3.6	8.5	-
18386	7960	245998	61.7	0.8	-	27.7	1.6	1.9	3.0	0.8	2.4	-	8.0	-

Appendix 1 (continued)

Sample number	1:100 000	Grid Reference	Qm	Qp	Qch	F	M	Lv	Lm	Ls	D	B	Mtx	Cmt
Judea Formation														
11012	7859	753820	93.9	0.8	0.4	3.7	-	0.4	-	0.4	0.4	-	38.5	-
11013	7859	787756	80.2	-	2.4	11.1	2.7	1.7	-	0.3	1.7	-	40.6	-
11014	7859	702481	61.3	0.7	1.4	7.0	1.1	4.9	7.0	16.6	-	-	43.2	-
11015	7859	680441	86.3	1.1	1.8	2.8	0.4	1.1	-	4.9	1.8	-	28.8	-
UQ45935	7859	696486	80.5	1.0	3.2	7.1	1.9	1.6	1.6	1.6	1.3	-	38.4	-
UQ45936	7859	696486	79.9	6.6	-	1.2	3.9	-	6.9	-	1.5	-	16.8	-
Crooked Creek Conglomerate														
11039	7859	770867	41.4	9.6	-	6.4	7.1	1.9	25.6	8.0	-	-	22.0	-
Quinton Formation														
11045	7859	663692	45.8	5.7	0.5	32.2	8.7	1.1	4.4	-	1.6	-	7.5	0.8
11046	7859	685690	45.9	2.6	0.3	39.1	5.0	2.4	3.4	0.3	1.1	-	4.0	1.3
11047	7859	621696	46.9	1.5	0.9	36.7	4.1	4.7	3.2	1.5	0.6	-	11.5	3.3
11066	7859	612696	60.0	2.3	-	28.2	3.1	3.7	1.1	1.1	0.6	-	10.8	0.5
Poley Cow Formation														
11040	7859	743473	61.6	1.4	0.3	13.5	14.1	0.3	8.8	-	-	-	7.8	1.8
11041	7859	661448	28.5	1.8	0.9	39.5	15.8	53.5	0.9	2.2	0.9	-	42.0	1.0
UQ45940	7859	660450	46.3	3.4	0.3	18.0	8.8	3.7	14.6	4.1	2.0	-	36.8	4.4
UQ45942	7859	713503	74.4	-	-	14.0	3.2	1.6	1.6	4.2	1.0	-	38.4	-
UQ45943	7859	716495	78.8	-	-	10.3	2.4	2.1	5.8	0.6	-	-	45.0	-
Jack Formation														
20577	7859	657454	77.5	0.3	1.0	8.9	3.8	4.4	1.6	3.5	-	-	21.0	0.3
UQ45949	7859	753512	79.0	2.2	0.5	10.6	2.5	-	3.5	2.7	0.3	-	8.3	-
UQ45951	7859	665465	77.3	0.3	-	2.5	10.9	-	9.0	-	-	-	28.6	-
UQ45952	7859	665465	68.2	4.1	3.0	2.4	3.2	-	7.1	11.8	0.3	-	15.3	-
UQ47516	7858	617406	64.7	0.6	-	-	29.7	-	1.8	1.5	1.8	-	15.8	-
Shield Creek Formation														
11064	7859	685688	57.8	3.3	-	29.8	6.6	0.6	1.9	-	0.6	-	9.5	-
11067	7859	728651	58.5	3.1	0.5	32.7	3.1	0.8	1.0	-	0.3	-	3.8	-
11068	7859	727529	58.8	1.3	-	35.8	3.5	-	0.5	-	-	-	6.5	-
11069	7859	653455	68.6	1.6	-	25.0	4.3	-	-	0.3	0.3	-	7.0	-
13737			48.7	-	-	47.7	3.1	-	0.3	-	-	-	3.5	-
13738			49.1	-	-	46.1	4.1	-	0.8	-	-	-	8.3	-
Tank Creek Sandstone														
18187	7859	606649	94.6	4.1	0.5	0.5	-	-	-	-	0.3	-	7.5	-
18188	7859	606649	95.9	3.3	0.5	0.3	-	-	-	-	-	-	2.8	-
Burges Formation														
13225	7859	559424	68.6	4.9	1.4	8.3	2.9	1.1	1.1	1.4	10.3	-	28.6	1.4
UQ47463	7859	591435	79.7	1.2	-	1.2	13.9	0.6	0.3	0.9	2.2	-	18.8	16.2
UQ47525	7859	605429	55.7	0.3	0.3	4.0	18.4	1.5	0.6	-	19.3	-	14.0	4.3
AKDb2	7859		55.6	5.1	0.6	17.8	4.8	3.9	2.7	2.1	7.3	-	14.3	3.0
BR121	7859		71.2	2.8	0.3	2.8	0.6	3.3	3.0	1.4	14.7	-	22.0	5.8
Phar Lap Member														
11232	7859	669500	93.6	1.5	-	0.5	1.3	-	2.5	-	0.5	-	1.8	-
UQ47472	7859	592437	65.4	7.3	3.7	5.7	4.7	4.3	1.0	3.3	0.7	4.0	3.0	22.0
AKQB1	7859		86.1	2.6	-	10.5	0.5	-	0.3	-	-	-	4.5	-
BR118	7859		91.6	0.9	-	5.7	1.2	-	-	0.3	0.3	-	0.5	16.3
Storm Hill Formation														
13826			89.2	8.8	-	0.3	0.3	-	1.3	-	0.3	-	3.0	-
UQ47495	7858	602404	88.9	10.8	-	-	0.3	-	-	-	-	-	0.8	-
BR66B			86.0	6.2	2.1	-	2.3	-	3.4	-	-	-	3.8	-
Unassigned Wando Vale Subgroup														
13289	7758	320245	64.2	1.4	1.4	15.8	2.3	-	12.1	1.7	1.1	-	11.3	-

Appendix 1 (continued)

Sample number	1:100 000	Grid Reference	Qm	Qp	Qch	F	M	Lv	Lm	Ls	D	B	Mtx	Cmt
Mytton Formation														
11214	7859	634519	67.4	-	0.6	1.6	18.3	-	7.5	4.7	-	-	19.5	-
11275	7858	541415	69.0	-	0.3	7.0	10.0	-	0.3	5.3	8.0	-	1.2	48.8
11282	7859	621499	71.4	0.6	0.6	9.0	5.9	-	4.5	4.2	3.9	-	8.3	2.5
13239			80.5	0.3	2.1	-	4.2	-	11.1	1.8	-	-	5.0	-
13618	7858	561352	70.3	-	0.9	8.7	12.1	-	6.6	1.4	-	-	2.2	0.2
13898			73.4	0.9	0.9	12.6	2.0	-	8.8	0.9	0.6	-	7.8	6.8
14650	7859	589449	83.7	0.3	0.6	4.4	3.9	-	6.4	0.8	-	-	2.0	7.5
14651	7859	588449	68.3	1.9	0.5	9.2	8.9	-	4.6	3.8	2.7	-	6.0	1.8
14653	7859	587449	79.5	0.7	-	3.4	2.0	-	11.4	2.7	0.3	-	3.5	18.0
14654	7859	587449	84.8	1.0	1.0	1.7	1.3	-	8.6	1.3	0.3	-	5.0	19,5
14662	7859	586449	78.2	0.3	0.6	5.9	3.2	-	8.6	2.9	0.3	-	7.8	7.5
14663	7859	586449	82.3	0.9	0.3	0.9	8.2	-	3.5	2.5	1.3	-	3.6	1.3
UQ47485	7859	572438	85.5	0.6	0.9	4.4	4.1	-	2.9	1.5	0.3	-	14.0	-
UQ47487	7859	571439	90.9	0.9	1.6	2.2	0.3	-	1.9	1.9	0.3	-	4.5	16.0
UQ47488	7859	571439	86.3	1.0	1.0	1.0	0.6	-	8.9	1.0	0.3	-	21.8	-
UQ47489	7859	570440	78.1	0.3	0.8	0.8	14.3	-	4.8	0.6	0.3	-	6.8	2.2
UQ47490	7859	569441	82.2	0.3	0.6	-	5.6	-	4.1	5.0	2.1	-	7.0	8.5
UQ47494	7859	600416	73.3	0.6	1.7	14.7	2.0	-	6.0	1.7	-	-	8.5	4.5
Bulgeri Formation														
11266	7859	529460	52.0	1.4	17.9	11.6	0.3	13.0	3.5	0.3	-	-	0.5	13.0
11269	7859	530460	62.7	4.2	5.8	16.9	2.3	4.9	3.2	-	-	-	1.3	21.8
11335	7859	557451	84.2	3.7	2.3	0.3	0.3	-	6.2	2.8	0.3	-	11.3	-
11344	7859	578447	73.1	5.2	0.5	13.1	1.3	-	6.8	-	-	-	3.0	1.3
11345	7859	562445	82.7	2.0	-	7.5	1.7	-	3.9	0.8	1.4	-	5.3	5.3
11360	7859	561446	79.0	3.8	-	13.7	1.5	-	1.5	0.3	0.3	-	8.0	6.3
13251			69.6	3.9	2.9	8.5	1.0	8.8	4.2	0.7	0.3	-	15.0	8.5
13258			62.6	3.6	1.8	21.0	3.0	6.0	2.1	-	-	-	3.8	12.8
20568			75.9	2.3	-	17.4	0.5	1.0	1.8	1.0	-	-	3.8	-
20569			67.0	1.9	2.4	13.6	2.4	4.8	6.1	1.9	-	-	6.0	-
Rockfields Member														
11309	7859	577447	84.2	0.8	-	8.8	0.5	-	4.7	0.5	0.5	-	3.8	-
11321	7859	567447	81.5	1.4	-	4.8	5.4	-	2.3	0.9	3.7	-	12.0	-
11330	7859	564446	82.3	4.1	-	3.3	2.7	-	6.5	-	1.1	-	3.0	5.0
18164	7859	573448	68.4	3.3	-	24.8	0.5	-	1.1	1.9	0.3	-	1.3	7.0
18165	7859	573448	72.6	1.1	-	13.3	4.7	-	1.7	0.8	-	-	9.8	-
18166	7859	573448	79.9	0.9	-	9.4	6.3	-	1.3	1.9	0.3	-	15.3	5.3
18170	7859	573448	74.0	1.1	-	15.8	6.1	0.3	1.4	1.1	0.3	-	5.3	4.5
Stopem Blockem Conglomerate Member														
11323	7859	560447	81.7	3.5	-	10.2	0.9	-	2.0	0.9	0.9	-	4.3	9.8
11377	7859	558447	69.3	3.4	3.8	0.3	-	-	5.6	16.9	0.6	-	17.0	3.3
11387	7859	558446	67.5	8.5	5.5	-	0.3	-	6.3	10.9	1.1	-	8.5	-
Turrets Formation														
11252	7859	526462	46.0	3.7	1.9	20.8	2.2	23.9	1.2	0.3	-	-	1.0	18.5
11401			90.0	3.0	0.8	0.3	-	0.3	5.4	0.3	-	-	8.0	-
11409			71.3	2.9	0.5	19.2	0.3	3.4	1.8	-	0.5	-	5.0	-
13261			82.0	1.0	-	11.8	2.6	0.8	0.8	-	1.0	-	2.8	-
Teddy Mount Formation														
11425			74.8	1.9	-	16.7	4.7	-	1.9	-	-	-	14.5	6.0
SLID2			77.8	0.6	-	9.6	5.5	1.0	2.6	1.3	1.0	0.6	2.3	20.0
Dyraaba Member														
11209	7859	498462	82.0	0.3	-	3.6	5.6	0.3	3.9	3.0	1.3	-	12.8	11.0
Boroston Formation														
11203	7859	470464	88.4	3.0	-	-	0.8	-	2.3	-	-	-	0.8	-
Harry Creek Formation														
13676			22.8	0.9	8.3	13.6	0.9	52.2	0.3	-	0.9	-	1.8	17.3
Venetia Formation														
10836	7959	026733	56.5	16.1	2.5	9.0	1.4	7.3	5.9	1.1	-	-	11.5	-
10837	7959	026733	49.5	12.1	8.0	3.3	1.4	5.5	16.5	3.8	-	-	9.0	-
Furry Hoop Member														
10870	7959	954516	44.6	2.9	7.0	2.3	-	35.3	4.4	2.6	0.9	-	0.5	13.8
Lyall Formation (upper)														
10861	7959	926556	51.2	5.6	4.3	9.6	1.3	18.6	5.6	3.3	0.3	-	1.3	23.5

Appendix 2. Chemical analyses of Ordovician to Devonian volcanic and dyke rocks from the Broken River Province. Sample numbers refer to the Queensland Department of Resource Industries Rock and Microslide catalogue, except those prefixed by JCU, which are housed in the Department of Geology, James Cook University of North Queensland.
Analyst - Queensland Government Chemical Laboratory except for samples prefixed by JCU which are from Arnold (1975). C.I.P.W. normative mineralogy is calculated on a volatile-free basis using the method of Kelsey (1965).

Sample	11016	11017	11021	11023	11024	11025	11027	11062	JCU1171	JCU11777
Unit	Judea Formation	Judea Formation	Judea Formation	Judea Formation	Judea Formation	Judea Formation	Judea Formation	Judea Formation	Judea Formation	Judea Formation
Rock type	Altered basalt	Altered basalt	Altered andesite	Dacite	Altered basal	Dacite	Altered basalt	Altered andesite	Altered andesite	Basalt?
1:100 000	7859	7859	7859	7859	7859	7859	7859	7859	7859	7859
Grid ref	762820	766788	794705	672443	672443	670442	728551	690466		
Field No	B4/06/21	B5/26/6A	B7/32/15	B13/40/2	B13/40/9B	B13/40/9B	J130F	B13/40/17		
Analysis	RGMP02/85	RGMP01/85	RGMP03/85	GS33/82	RGMP04/85	RGMP05/85	RGMP06/85	RGMP07/85		
SiO_2	47.60	48.65	59.70	70.60	51.70	70.00	50.10	57.70	56.71	-
TiO_2	1.50	1.40	0.60	0.55	1.40	0.56	0.60	0.97	0.50	1.77
Al_2O_3	14.10	14.20	14.40	13.20	12.50	13.80	15.70	14.90	11.45	-
Fe_2O_3	3.40	2.55	2.40	0.50	1.90	1.80	1.90	2.70	-	-
FeO	8.90	9.30	4.00	4.00	7.10	3.00	6.50	5.30	8.05	-
MnO	0.23	0.21	0.13	<.10	0.18	0.08	0.14	0.17	0.13	-
MgO	7.00	8.00	2.70	1.40	9.00	1.20	9.40	3.50	5.60	-
CaO	12.50	12.00	4.40	1.40	8.90	1.50	10.50	5.00	5.23	-
Na_2O	2.20	1.85	5.40	5.40	2.90	5.70	2.30	4.10	1.08	-
K_2O	0.20	0.17	0.21	0.50	0.46	0.65	0.58	0.89	0.09	-
P_2O_5	0.14	0.16	0.24	0.18	0.18	0.13	0.03	0.22	0.08	-
H_2O+	1.50	1.40	2.80	1.60	3.00	1.50	2.50	3.20	-	-
H_2O-	-	-	-	0.10	-	-	-	-	-	-
CO_2	0.60	<.10	3.10	0.50	0.90	0.10	<.10	1.60	-	-
LOI	-	-	-	-	-	-	-	-	8.56	-
Rest	0.17	0.23	0.11	0.07	0.23	0.11	0.24	0.15	0.07	-
Total	100.04	100.12	100.19	100.00	100.35	100.13	100.49	100.40	97.55	-
Trace elements (ppm)										
Ba	<5	5	25	80	60	130	90	165	-	-
Rb	2	2	5	<5	7	6	21	6	<2	<2
Sr	199	139	168	135	183	207	117	272	175	84
Pb	<2	5	2	<5	<2	2	4	6	-	-
Th	<2	4	<2	5	<2	<2	<2	<2	-	-
U	-	-	-	<10	-	-	-	-	-	-
Zr	82	73	100	130	84	110	25	102	66	62
Nb	<2	6	<2	15	8	5	2	10	<2	4
Y	28	24	29	20	24	16	16	21	5	34
La	<2	2	15	14	11	6	<2	11	-	-
Ce	3	5	22	23	9	20	<2	25	-	-
Nd	-	-	-	-	-	-	-	-	-	-
V	268	276	124	65	217	55	169	198	-	-
Cr	340	720	180	<10	740	240	980	140	260	51
Co	-	-	-	20	-	-	-	-	-	-
Ni	60	120	<20	<10	180	<20	160	<20	48	-
Cu	158	115	80	<5	60	20	72	94	-	-
Zn	77	74	84	60	63	55	57	73	-	-
Ga	-	-	-	-	-	-	-	-	-	-
C.I.P.W. normative mineralogy (weight %)										
Q	-	-	13.11	30.92	1.40	27.55	-	12.09	28.98	-
C	-	-	-	1.70	-	1.33	-	-	.29	-
Or	1.21	1.02	1.32	3.02	2.82	3.91	3.50	5.52	.60	-
Ab	19.06	15.89	48.57	46.74	25.49	49.04	19.89	36.39	10.26	-
An	28.67	30.39	15.34	5.90	20.49	6.70	31.48	20.59	28.54	-
Ne	-	-	-	-	-	-	-	-	-	-
Di	27.88	23.72	5.16	-	19.51	-	17.42	3.26	-	-
Hy	10.02	21.86	13.08	9.12	24.72	8.90	18.08	17.69	27.82	-
Ol	6.88	1.05	-	-	-	-	6.15	-	-	-
Mt	2.96	2.84	1.58	1.10	2.21	1.14	2.03	1.96	2.18	-
Cm	.07	.16	.04	-	.17	.05	.22	.03	.06	-
Il	2.92	2.70	1.21	1.07	2.76	1.08	1.16	1.93	1.07	-
Ap	.34	.38	.60	.44	.44	.31	.07	.55	.21	-
Diff. Index	20.27	16.91	63.00	80.69	29.71	80.49	23.39	54.00	39.83	-
Colour Index	50.73	52.33	21.07	11.28	49.37	11.17	45.05	24.88	31.13	-
Norm Plag Comp	60.07	65.67	24.00	11.21	44.57	12.02	61.28	36.13	73.56	-
mg	55.10	59.12	47.89	39.74	68.17	35.26	70.59	48.70	59.32	-

Appendix 2 (continued).

Sample	JCU11754	JCU11755	JCU11756	18357	18370	JCU11926	JCU11927	JCU11931	JCU11932	JCU11933
Unit	Saddington Tonalite	Saddington Tonalite	Saddington Tonalite	Wairuna Formation	Wairuna Formation	Wairuna Formation	Wairuna Formation	Wairuna Formation	Wairuna Formation	Wairuna Formation
Rock type	Basalt dyke	Basalt dyke	Basalt dyke	Altered basalt	Altered basalt	Altered basalt?	Altered basalt?	Altered basalt	Altered basalt?	Altered basalt?
1:100 000	7859	7859	7859	7959	7959	7959	7959	7959	7959	7959
Grid ref				938963	999871					
Field No				CR1/16/17	CR3/08/6					
Analysis				RGMP19/85	RGMP18/85					
SiO_2	49.83	47.97	-	43.20	48.00	-	-	49.95	-	-
TiO_2	1.48	1.19	1.58	1.40	1.90	1.65	2.33	1.37	0.91	1.37
Al_2O_3	14.95	13.73	-	12.80	12.90	-	-	13.13	-	-
Fe_2O_3	-	-	-	1.40	2.50	-	-	-	-	-
FeO	10.34	12.01	-	9.30	9.50	-	-	10.89	-	-
MnO	0.15	0.19	-	0.13	0.23	-	-	0.19	-	-
MgO	7.24	6.56	-	7.00	7.20	-	-	8.18	-	-
CaO	9.99	8.66	-	10.00	9.70	-	-	11.08	-	-
Na_2O	2.64	3.24	-	0.60	2.20	-	-	2.36	-	-
K_2O	0.53	0.45	-	1.20	0.08	-	-	1.13	-	-
P_2O_5	0.14	0.13	-	0.07	0.16	-	-	0.14	-	-
H_2O+	<.10	<.10	-	4.90	3.30	-	-	-	-	-
H_2O-	-	-	-	-	-	-	-	-	-	-
CO_2	<.10	<.10	-	7.80	2.00	-	-	-	-	-
LOI	2.96	3.55	-	-	-	-	-	2.69	-	-
Rest	0.09	0.07	-	0.15	0.16	-	-	0.09		
Total	100.34	97.75	-	99.95	99.83	-	-	101.20		

Trace elements (ppm)

Ba	-	-	-	175	<5	-	-	-	-	-
Rb	9	5	<2	13	4	7	<2	31	<2	<2
Sr	218	172	153	249	143	257	187	241	33	329
Pb	-	-	-	3	3	-	-	-	-	-
Th	-	-	-	<2	<2	-	-	-	-	-
U	-	-	-	-	-	-	-	-	-	-
Zr	112	88	94	67	104	109	133	98	39	100
Nb	2	5	5	2	<2	11	16	6	4	5
Y	24	22	36	33	50	31	34	10	28	33
La	-	-	-	4	<2	-	-	-	-	-
Ce	-	-	-	11	<2	-	-	-	-	-
Nd	-	-	-	-	-	-	-	-	-	-
V	-	-	-	111	354	-	-	-	-	-
Cr	263	164	327	380	240	187	176	204	663	560
Co	-	-	-	-	-	-	-	-	-	-
Ni	73	69	-	<20	40	-	-	85	-	-
Cu	-	-	-	14	64	-	-	-	-	-
Zn	-	-	-	52	83	-	-	-	-	-
Ga	-	-	-	-	-	-	-	-	-	-

C.I.P.W. normative mineralogy (weight %)

Q	-	-	-	2.29	2.35	-	-	-	-	-
C	-	-	-	-	-	-	-	-	-	-
Or	3.21	2.82	-	8.13	.50	-	-	6.77	-	-
Ab	22.91	29.06	-	5.82	19.73	-	-	20.25	-	-
An	28.08	22.88	-	32.90	26.59	-	-	22.20	-	-
Ne	-	-	-	-	-	-	-	-	-	-
Di	17.83	17.96	-	19.23	19.12	-	-	26.62	-	-
Hy	20.84	12.10	-	25.37	24.43	-	-	10.63	-	-
Ol	1.29	9.36	-	-	-	-	-	7.85	-	-
Mt	2.56	3.08	-	2.93	3.01	-	-	2.67	-	-
Cm	.06	.04	-	.09	.05	-	-	.04	-	-
Il	2.88	2.40	-	3.05	3.82	-	-	2.64	-	-
Ap	.34	.33	-	.19	.40	-	-	.34	-	-
Diff. Index	26.12	31.87	-	16.24	22.58	-	-	27.02	-	-
Colour Index	45.47	44.92	-	50.67	50.44	-	-	50.46	-	-
Norm Plag Comp	55.07	44.06	-	84.96	57.40	-	-	52.30	-	-
mg	59.48	53.38	-	58.15	56.23	-	-	61.16	-	-

Appendix 2 (continued).

Sample	JCU11934	13509	13584	13585	13586	JCU11917	JCU11920	JCU11921	13587	13588
Unit	Wairuna Formation	Everetts Ck Volcs	Everetts Ck Volcs	Everetts Ck Volcs	Everetts Ck Volcs	Everetts Ck Volcs	Everetts Ck Volcs	Everetts Ck Volcs	Carriers Well Fm	Carriers Well Fm
Rock type	Altered basalt?	Altered basalt	Altered andesite	Altered basalt?	Porph. dacite	Altered andesite?	Altered basalt?	Altered basalt?	Altered basalt	Dacite
1:100 000	7959	7859	7859	7859	7859	7859	7859	7859	7959	7959
Grid ref		840878	881953	846886	842885				849971	846791
Field No		IWB006	B1/96/7B	B3/62/12	B3/62/11				B5/22/4	B5/22/5
Analysis No		RGMP95/86	RGMP14/85	RGMP13/85	RGMP12/85				RGMP15/85	RGMP16/85
SiO_2	-	52.30	57.00	52.50	70.60	55.29	-	54.40	45.70	70.30
TiO_2	0.82	0.83	0.55	1.50	0.53	0.84	1.33	0.91	1.50	0.54
Al_2O_3	-	15.70	18.00	14.00	13.20	17.60	-	15.16	14.80	11.90
Fe_2O_3	-	3.60	1.00	4.10	2.80	-	-	-	2.50	1.80
FeO	-	7.10	4.10	8.80	1.40	5.20	-	8.89	6.30	1.90
MnO	-	0.13	0.11	0.18	0.07	0.08	-	0.15	0.20	0.09
MgO	-	4.30	4.10	5.60	0.40	1.52	-	3.62	8.10	1.00
CaO	-	4.20	2.50	4.40	2.30	7.03	-	4.42	7.10	3.40
Na_2O	-	4.00	8.10	4.90	6.00	5.94	-	4.23	3.90	5.60
K_2O	-	1.80	0.03	0.05	0.62	0.17	-	1.81	0.19	0.05
P_2O_5	-	0.36	0.03	0.20	0.21	0.31	-	0.58	0.17	0.12
H_2O+	-	2.89	2.80	3.40	1.20	-	-	-	5.70	1.10
H_2O-	-	0.12	-	-	-	-	-	-	-	-
CO_2	-	2.20	1.60	0.30	0.80	-	-	-	3.50	2.20
LOI	-	-	-	-	-	4.09	-	4.12	-	-
Rest	-	0.21	0.09	0.15	0.14	0.05	-	0.10	0.30	0.07
Total	-	99.74	100.01	100.08	100.27	98.12	-	98.39	99.96	100.07

Trace elements (ppm)

Ba	-	180	40	<5	100	-	-	-	820	25
Rb	13	23	2	3	9	-	11	21	4	<2
Sr	130	535	114	230	271	213	95	507	321	138
Pb	-	2	6	<2	9	-	-	-	6	<2
Th	-	6	4	3	2	-	-	-	<2	<2
U	-	4	-	-	-	-	-	-	-	-
Zr	64	115	77	85	148	161	76	191	65	100
Nb	<2	3	<2	4	5	5	7	1	7	7
Y	24	19	13	29	26	22	30	19	21	14
La	-	23	<2	10	30	-	-	-	69	13
Ce	-	46	<2	9	59	-	-	-	11	13
Nd	-	-	-	-	-	-	-	-	-	-
V	-	355	100	382	73	-	-	-	250	46
Cr	281	<10	140	100	240	26	32	52	520	160
Co	-	40	-	-	-	-	-	-	-	-
Ni	-	<10	40	<20	<20	4	-	44	80	<20
Cu	-	115	38	100	12	-	-	-	66	<10
Zn	-	105	48	87	69	-	-	-	62	20
Ga	-	17	-	-	-	-	-	-	-	-

C.I.P.W. normative mineralogy (weight %)

Q	-	1.66	-	.47	27.37	3.63	-	4.96	-	30.10
C	-	.42	.18	-	-	-	-	-	-	-
Or	-	11.30	.19	.31	3.74	1.07	-	11.34	1.24	.31
Ab	-	35.96	71.72	43.17	51.83	53.43	-	37.95	36.49	49.05
An	-	19.64	12.78	16.72	7.41	22.17	-	18.06	24.68	7.44
Ne	-	-	.02	-	-	-	-	-	-	-
Di	-	-	-	3.86	2.47	10.72	-	.98	10.56	7.76
Hy	-	25.81	-	28.86	4.64	5.17	-	21.18	2.07	3.08
Ol	-	-	12.66	-	-	-	-	-	18.97	-
Mt	-	2.65	1.26	3.14	.97	1.34	-	2.28	2.28	.88
Cm	-	-	.03	.02	.05	.01	-	.01	.12	.04
Il	-	1.67	1.09	2.97	1.03	1.70	-	1.83	3.15	1.06
Ap	-	.91	.07	.49	.51	.78	-	1.46	.45	.29
Diff. Index	-	48.92	71.91	43.94	82.94	58.13	-	54.24	37.74	79.46
Colour Index	-	30.14	15.05	38.85	9.15	18.93	-	26.28	37.15	12.82
Norm Plag Comp	-	35.32	15.12	27.92	12.50	29.33	-	32.24	40.34	13.17
mg	-	46.58	63.22	48.45	17.62	38.00	-	46.05	66.51	37.33

Appendix 2 (continued).

Sample	18385	13487	13489	13551	13552	13553	12463	13485	13556
Unit	Pelican Range Fm	Greenvale Formation	Greenvale Formation	Greenvale Formation	Greenvale Formation	Greenvale Formation	Perry Ck Formation	Perry Ck Formation	Perry Ck Formation
Rock type	Altered basalt	Volcanic arenite	Altered basalt	Basalt	Basalt	Basalt	Altered basalt	Altered basalt	Basalt
1:100 000	7960	7959	7959	8059	8059	8059	7960	7959	8059
Grid ref	061089	358538	366530	523701	521708	531709	146927	222876	547760
Field No	VL12/56/8	IWCR280	IWCR281	IWT103	IWT112	IWT114	VL7/68/5	IWCR013	IWT074
Analysis No	RGMP17/85	RGMP90/86	RGMP97/86	RGMP483/87	RGMP484/87	RGMP485/87	RGMP94/86	RGMP96/86	RGMP482/87
SiO_2	47.80	66.00	50.70	48.90	49.20	48.90	48.80	46.40	45.20
TiO_2	1.70	0.64	0.30	1.58	1.49	0.85	1.71	1.81	1.91
Al_2O_3	13.60	14.70	14.20	14.10	14.30	15.20	13.40	15.00	17.00
Fe_2O_3	2.90	1.30	2.10	2.10	1.90	1.60	2.90	5.60	3.00
FeO	9.40	4.60	8.20	9.50	9.40	8.40	9.60	6.70	7.30
MnO	0.23	0.16	0.25	0.37	0.29	0.49	0.19	0.23	0.15
MgO	7.50	1.60	8.70	7.30	7.00	7.70	8.00	7.80	6.00
CaO	10.20	4.70	11.60	10.30	11.30	12.40	8.30	8.70	7.20
Na_2O	2.50	2.90	2.00	3.00	2.70	1.80	3.10	2.80	4.30
K_2O	0.24	0.90	0.30	0.20	0.09	0.22	0.10	0.20	0.49
P_2O_5	0.14	0.17	0.02	0.13	0.12	0.08	0.14	0.16	0.32
H_2O+	2.60	1.62	1.14	0.80	0.60	0.80	3.00	3.09	3.70
H_2O-	-	0.23	0.13	0.16	0.10	0.11	0.24	0.10	0.12
CO_2	0.60	<.10	<.10	<.10	<.10	<.10	0.10	1.20	1.90
LOI	-	-	-	-	-	-	-	-	-
Rest	0.21	0.14	0.20	0.19	0.18	0.19	0.17	0.25	0.17
Total	99.62	99.66	99.84	98.63	98.67	98.74	99.75	100.04	98.76

Trace elements (ppm)

Ba	10	170	80	85	55	65	44	115	70
Rb	5	17	5	10	5	10	1	4	12
Sr	209	390	320	220	225	205	95	390	245
Pb	2	8	12	13	8	8	<1	1	<1
Th	<2	5	3	1	1	<1	3	4	<1
U	-	<1	1	1	2	3	<1	2	3
Zr	90	185	13	90	85	45	110	125	160
Nb	3	8	<1	1	1	1	8	11	12
Y	27	37	17	36	36	20	34	34	35
La	<2	15	6	3	5	2	11	11	12
Ce	8	35	<1	9	16	6	20	21	32
Nd	-	-	-	-	-	-	-	-	-
V	296	95	255	405	385	265	355	355	210
Cr	500	-	390	200	200	470	110	230	170
Co	-	20	70	40	50	30	60	60	40
Ni	80	<10	80	50	50	80	50	80	80
Cu	152	65	90	19	13	1	165	265	65
Zn	75	78	105	140	135	135	90	94	90
Ga	-	15	10	-	-	-	17	20	-

C.I.P.W. normative mineralogy (weight %)

Q	-	31.05	-	-	-	-	-	-	-
C	-	.84	-	-	-	-	-	-	-
Or	1.47	5.45	1.80	1.21	.54	1.33	.61	1.24	3.12
Ab	21.99	25.13	17.20	26.04	23.36	15.59	27.28	24.92	33.58
An	26.17	22.74	29.36	25.04	27.23	33.51	23.24	29.21	27.64
Ne	-	-	-	-	-	-	-	-	3.06
Di	20.91	-	23.67	21.75	24.04	23.64	15.26	12.35	7.06
Hy	17.85	11.71	24.26	11.80	15.26	20.83	21.58	14.38	-
Ol	4.77	-	.52	7.90	3.60	.72	5.22	10.85	18.19
Mt	3.02	1.43	2.48	2.82	2.74	2.43	3.07	2.98	2.61
Cm	.11	-	.09	.04	.04	.10	.02	.05	.04
Il	3.36	1.24	.58	3.08	2.89	1.65	3.38	3.62	3.91
Ap	.34	.41	.05	.32	.29	.19	.34	.40	.82
Diff. Index	23.47	61.63	19.00	27.25	23.90	16.92	27.89	26.16	36.70
Colour Index	50.02	14.38	51.59	47.40	48.59	49.38	48.53	44.24	31.81
Norm Plag Comp	54.34	47.50	63.05	49.03	53.83	68.25	46.01	53.96	45.15
mg	56.69	36.76	64.38	57.33	56.91	62.13	57.87	58.21	55.71

Appendix 3. Chemical analyses of Ordovician plutonic rocks from the Graveyard Creek Subprovince. Samples refer to the Department of Resource Industries Rock and Microslide catalogue. Analyst - Queensland Government Chemical Laboratory. C.I.P.W. normative mineralogy calculated on a volatile-free basis using the method of Kelsey (1965).

Sample	11028	12511	11030	11031	11060
Unit	Netherwood Tonalite	Netherwood Tonalite	Saddington Tonalite	Saddington Tonalite	Saddington Tonalite
Rock type	Hornblende tonalite	Hornblende tonalite	Hornblende tonalite	Biot-hbl tonalite	Hornblende diorite
1:100 000	7859	7859	7859	7859	7859
Grid ref	675443	675443	780770	780769	792823
Field	B13/40/1	-	B5/26/13	B5/26/14	B4/08/1
Analysis	RGMP08/85	RGMP89/86	RGMP09/85	RGMP10/85	RGMP11/85
SiO_2	61.70	61.00	66.20	72.00	52.30
TiO_2	.69	.65	.40	.35	.99
Al_2O_3	16.70	16.80	13.40	14.00	17.50
Fe_2O_3	1.20	1.30	1.90	1.20	4.20
FeO	3.40	3.20	4.20	2.30	6.80
MnO	.07	.08	.09	.09	.22
MgO	4.10	3.50	3.00	1.00	4.20
CaO	3.50	4.60	5.10	3.50	9.60
Na_2O	5.50	5.40	3.40	3.70	2.80
K_2O	1.00	.90	.79	.82	.13
P_2O_5	.17	.18	.05	.04	.31
H_2O+	1.90	1.64	1.60	1.10	1.70
H_2O-	-	.24	-	-	-
CO_2	<.10	.30	<.10	.20	<.10
Rest	.17	.15	.15	.11	.13
Total	100.10	99.94	100.28	100.41	100.88
Trace elements (ppm)					
Ba	425	315	175	215	20
Rb	9	11	13	9	<2
Sr	465	460	249	222	329
Pb	<2	2	3	7	<2
Th	<2	5	<2	<2	<2
U	-	<1	-	-	-
Zr	55	110	67	83	40
Nb	<2	6	2	2	<2
Y	15	15	23	21	21
La	18	13	4	3	<2
Ce	17	22	11	7	<2
V	92	95	111	53	205
Cr	180	-	380	200	180
Co	-	20	-	-	-
Ni	40	40	<20	<20	<20
Cu	12	40	14	14	56
Zn	38	57	52	36	59
Ga	-	16	-	-	-
C.I.P.W. normative mineralogy (weight %)					
Q	10.93	10.60	27.25	37.50	8.42
C	.54	-	-	.72	-
Or	6.03	5.45	4.74	4.90	.78
Ab	47.46	46.81	29.18	31.62	23.91
An	16.87	19.45	19.26	17.41	35.14
Di	-	2.42	5.10	-	9.03
Hy	14.71	11.74	10.75	5.33	13.94
Mt	1.80	1.95	2.82	1.77	6.19
Cm	.04	-	.08	.04	.04
Il	1.34	1.26	.77	.67	1.90
Ap	.41	.44	.12	.10	.74
Diff. Index	64.43	62.86	61.17	74.01	33.11
Colour Index	17.88	17.37	19.52	7.81	31.10
Norm Plag Comp	26.23	29.35	39.76	35.52	59.50
mg	68.24	66.09	56.00	43.65	52.40
SI index	1.04	0.94	0.86	1.06	0.82

NOTES

NOTES

ERRATA

Figure 73. The fault bounded area south of the Mount Spectacle Fault between the lower and upper subunits of the Ewan Formation is incorrectly shown as Running River Metamorphics. It should be shown as the middle subunit of the Ewan Formation.

Figures 75 and 82a. Symbols used for samples from the Wairuna Formation and Perry Creek Formation are open squares and open triangles respectively, rather than the symbols used in Figure 74.

NOTES

V. R. Ward, Government Printer, Queensland—1993
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LEGEND

		Cg_1, Cg_3	Montgomery Range Igneous Complex
Bundock Creek Group		Ch	Harry Creek Formation
		Co	Boroston Formation
		DCe_d	Dyraaba Member
		DCe	Teddy Mount Formation
		Dt	Turrets Formation
		Du	Bulgeri Formation
		Du_s	Stopem Blockem Conglomerate Member
		Du_r	Rockfields Member
Broken River Group		Dm	Mytton Formation
	Wando Vale Subgroup	Dw	undivided
		Dp	Papilio Formation
		Db	Burges Formation
		Do	Dosey Limestones
		Dh	Storm Hill Sandstone
		Da	Lomandra Limestones
		Dr	Bracteata Formation
		Ds	Shield Creek Formation
		Sgi	Dido Tonalite
Graveyard Creek Group		SDj	Jack Formation
		SDo, SDo_c	Poley Cow Formation
		Oj	Judea Formation

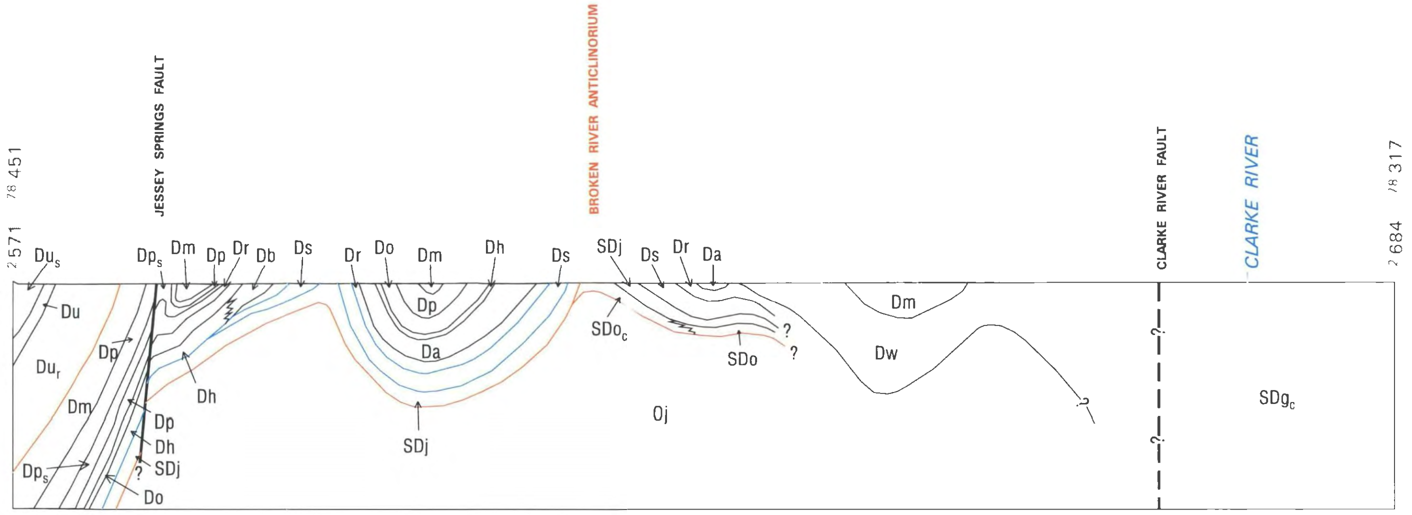
Fault

Conformable Boundary

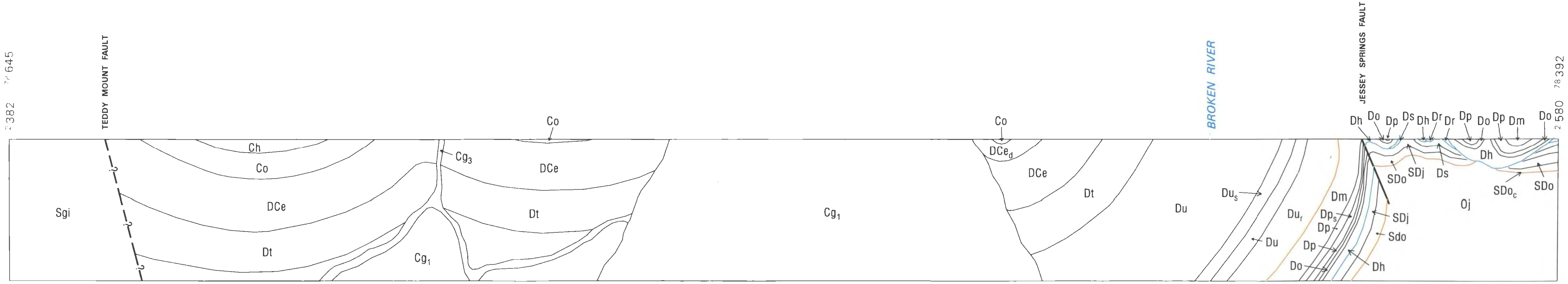
Disconformity

Major Unconformity

Facies Boundary



CROSS SECTION ACROSS THE AXIS OF THE GRAVEYARD CREEK SUBPROVINCE



CROSS SECTION ACROSS THE AXIS OF THE GRAVEYARD CREEK SUBPROVINCE

Scale 1:100 000

1 0 1 2 3 4 5 6 7 8 9 10 Kilometers

$\frac{V}{H} = 1$

Sections compiled 1989 by L.Marcault (University of Queensland)