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BOWEN BASIN COAL SYMPOSIUM

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BOWEN BASIN COAL SYMPOSIUM

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MILESTONES IN THE INTERPRETATION OF BOWEN BASIN GEOLOGY

P.W. Goscombe, CSR Limited

In 1845, the "scientific explorer" Ludwig Leichhardt discovered coal in the banks of the Mackenzie River while on his epic journey to the remote northern outpost of Port Essington. Squatters attracted to Central Queensland by Leichhardt's reports of good land found more outcrops of coal and also made intersections in wells put down for water. By the 1860's, the population of the Leichhardt District, as the Fitzroy Region was then known, was growing rapidly with the added influx of copper miners and gold diggers to the Peak Downs Mineral Field. However, little interest was shown in the coal potential of the district until the Geological Survey of Queensland was established in 1868.

The Survey's attention was directed initially to the Bowen River area, near the present site of Collinsville. Richard Daintree, who was instrumental in establishing the GSQ, investigated the area in the 1860's and made the important distinction between the *Taeniopteris* coal measures of South Queensland, which he assigned to the Mesozoic, and the *Glossopteris* coal measures of Central Queensland, which he assigned to the upper Palaeozoic. Robert Jack followed Daintree and in the 1870's made the threefold subdivision of the Bowen River beds into a lower formation containing volcanic agglomerates, a middle formation of essentially marine origin and an upper formation of freshwater sediments. The widespread adoption of Jack's Bowen nomenclature to the upper Palaeozoic sediments of Central Queensland led eventually to the term being ascribed to the basin as a whole.

However, the commercial prospects of developing the Bowen River coalfield were unfavourable at the time because of the prohibitive cost of carting coal to the coast. By 1879, the Central Railway had been extended to Emerald and beyond and priority was switched to finding workable deposits in close proximity to the line. In the ensuing years, Julian Tennison-Woods and Andrew Gibb-Maitland reported favourably on the prospects of finding coal close to the line but little eventuated until Benjamin Dunstan systematically mapped the surrounding country in the late 1890's.

Dunstan traced the "Glossopteris Beds" from Kianga homestead to a point on the Dawson River near the present site of Baralaba, recognised their presence in the Bluff-Walton-Stanley area and their continuation farther northwards to the Mackenzie River near Jellinbah homestead. Later, in 1904, Walter Cameron established the continuity of the coal measures from the Dawson-Mackenzie area of Dunstan to the Bowen-Isaacs area of Jack, reinforcing the growing belief that Central Queensland would one day become a major exporter of coal.

As a result of Dunstan's work, there was an upsurge in prospecting activity by mining syndicates resulting in the establishment of significant mines at Bluff and Baralaba. Together with production from Blair Athol, which was found by chance in a water well, and Collinsville, these mines satisfied the requirements of local industry and the Railways Department for the next 50-60 years.

The early pioneering days of coal exploration culminated in 1913 with the presentation by Dunstan of the first estimates of the reserves of coal in the Basin to the International Geological Congress held that year in Canada. The estimation of actual, probable and possible reserves was made in accordance with guidelines for the Coal Resources of the World project and were as follows (million (approx.) metric tonnes):-

Actual	Probable	Possible
350	1,020	Enormous

Not suprisingly, the Basin had already become known as the "Great Coal Basin".

John Reid was the most noteworthy individual to contribute to Bowen Basin geology during the 1920's, 30's & 40's. His work centred mainly on the known coalfields and provided an invaluable reference for those who followed in the post-war revival of activity in the 1950's.

Also noteworthy during these otherwise quiet years was the start of oil exploration in the Basin with the drilling by Oil Search Limited of Hutton Creek in 1938 and Arcadia in 1939. Arcadia produced flows of wet gas which was the first indication of oil in the Permian of Queensland. Shell (Queensland) Development Limited made a comprehensive survey of the Roma-Springsure-Comet area in the 1940's but abandoned the search in 1950 after drilling at Morella proved negative. The stratigraphic record afforded by these oil wells, especially of the marine sequences, was also an invaluable reference during the revival of activity in the 1950's.

The modern era of geological exploration in the Bowen Basin began in earnest with the Federal Government's Petroleum Search Subsidy Act of 1957. The theory that deep-seated Permian sediments were the source of oil and gas in the Roma district lead to an upsurge in interest in the Basin. Geological mapping and test drilling of the marine sediments in the central and south-western parts of the Basin by private oil interests, noteably Associated Freney Oil Fields NL, was followed in the 1960's by the systematic mapping of the whole of the Basin at 1:250 000 by the Bureau of Mineral Resources and the GSQ. Studies of the basin-wide stratigraphy and depositional character of the Permo-Triassic succession were further progressed in the early 1970's with the GSQ's deep core drilling programme.

However, it has been coal not oil that has commanded the attention of most geologists over the past twenty-five years. The pioneering development of the coking coal trade with the Japanese by Sir Leslie Thiess attracted the attention of Utah Development Company whose strong commitment to exploration geology has made that company pre-eminent amongst the coal producers of the Basin. The painstaking research of old records by Don King, and the consequent recognition of geologically related trends in the rank of the coal, led to the discovery of much of Utah's coking coal. Also, their detailed geological mapping and exploratory drilling laid the foundation for much of the coal measure stratigraphy in place today.

Credit for Utah's success is due in no small measure to the founding manager of UDC in Australia, Richard Ellett, a geologist who encouraged regular reconnaisances of the Basin in the search for ever more prospective acreage. He also encouraged the pursuit of excellence and in so doing set technical standards which have become a feature of geological investigations in the Bowen Basin. The summation of the work of geologists representing governments and private interests is reflected in current estimates of the reserves of coal in the Bowen Basin, viz (million (approx.) metric tonnes):-

Measured	Indicated	Inferred
6,560	17,118	Very large

The old prophecy has come true; more coal is now exported from the Bowen Basin than from any other coal province in the world. The earnings from these exports are contributing upwards of 20% to the State's revenue (excluding Commonwealth tax sharing funds). The role geologists have played in this great achievement is one which the profession can feel justifiably proud.

TECTONIC SETTING OF THE BOWEN BASIN

C.G. Murray, Geological Survey of Queensland

INTRODUCTION

When considering its tectonic setting, the Bowen Basin cannot be treated in isolation, but must be regarded as part of the larger Bowen-Gunnedah-Sydney Basin. Probably the most widely accepted origin for the basin is that it was a foreland basin to the New England Fold Belt. This paper reviews the main features of foreland basins (Fig. 1), and compares this idealised model with actual observations, mainly from the Bowen Basin. Other possible tectonic models for the Bowen-Gunnedah-Sydney Basin are listed by Harrington (1982).

The Bowen-Gunnedah-Sydney Basin extends along the entire western margin of the New England Fold Belt, and separates this orogen from the older Thomson and Lachlan Fold Belts to the west (Fig. 2).

FORELAND BASIN MODEL

A foreland basin (also referred to by various workers as an exogeosyncline, marginal basin or foredeep) forms along the junction between a stable continental craton or platform (represented in this case by the cratonised Thomson and Lachlan Fold Belts) and a marginal orogenic belt (New England Fold Belt). The rocks of the orogen are thrust or overfolded towards the foreland basin along a zone called a foreland thrust belt. Typically the basin has an asymmetric shape, becoming gradually deeper towards the thrust belt and adjacent orogen (Fig. 1).

Foreland basins may form in more than one tectonic setting. In continent-continent collisions, foreland basins may be created on both sides of the suture zone (Dickinson, 1974, 1978). The model which best fits the Bowen Basin is a retroarc foreland basin, which forms behind a continental margin volcanic arc (Fig. 1).

Two general mechanisms have been proposed for the subsidence of foreland basins (Beaumont, 1981):-

1. Downwarping is an isostatic response to the additional load produced by tectonic stacking of upper crustal rocks in the foreland thrust belt (Price, 1973).

2. Bending of the cratonic lithosphere in response to horizontal stresses across the entire orogenic belt - foreland basin couple. This process can be envisaged as partial subduction or underthrusting of the craton beneath the orogen or magmatic arc, and is analogous to the bending of oceanic lithosphere at an oceanic trench (Fig. 1).

Only the first mechanism has been examined by any sort of quantitative modelling (Beaumont, 1981).

FEATURES OF A RETROARC FORELAND BASIN MODEL

Features of retroarc foreland basins have been listed by Dickinson (1974, 1978), Beaumont (1981) and Miall (1984), and include:-

1. Retroarc foreland basins form behind continental margin magmatic arcs.

2. The basement is normal continental crust, and pre-existing basement structures can affect isopach and facies patterns.

3. One margin of the basin is a fold-thrust belt (foreland thrust belt) which forms an additional load contributing to the flexural subsidence of the basin.

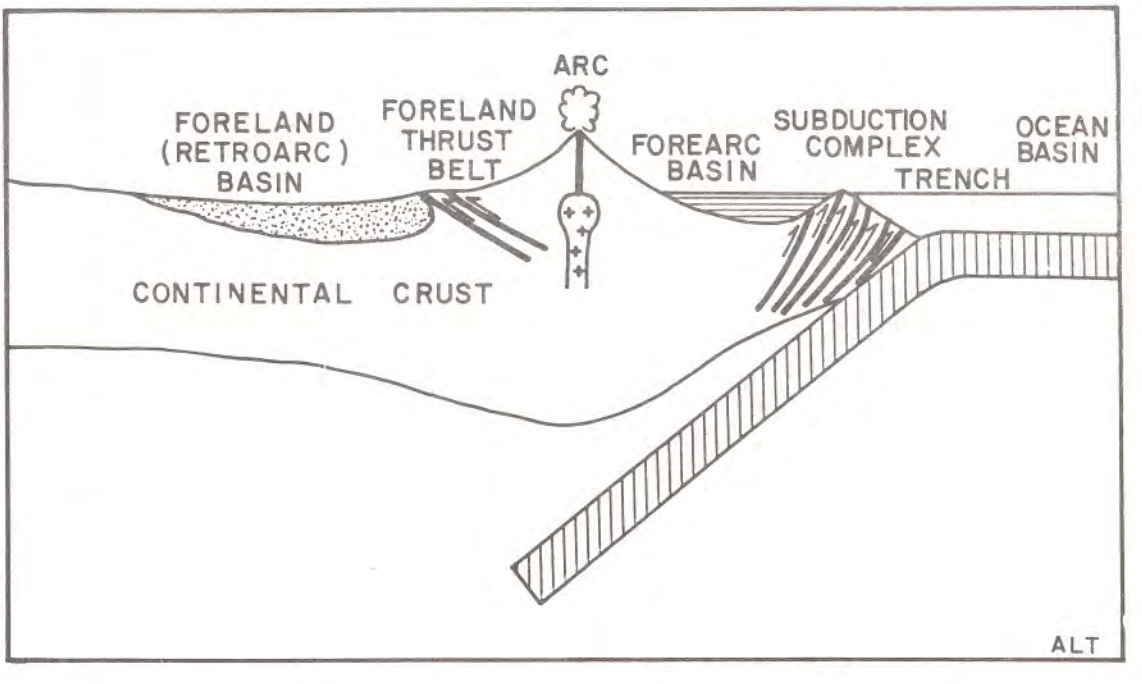

Fig. 1: Idealised retroarc foreland basin (after Dickinson, 1974).

4. Transverse profiles are strongly asymmetric, gradually deepening towards the foreland thrust belt.

5. The cratonic flanks of the basins may merge gradually with platform sequences.

6. Sediments are dominantly shallow marine to nonmarine clastics. Deeper marine strata are rare, although flysch-type sediments may be deposited early in the history of the basin. An upward coarsening sequence from marine to nonmarine, including coal, is common. The most characteristic deposits are fluvio-deltaic strata shed mainly from the adjacent magmatic arc or uplifted foreland thrust belt, but also from the cratonic hinterland.

7. Coal rank variations are consistent with tectonic modelling.

8. Structural style is dominated by compressional folds and faults. Tectonism is concentrated along the orogenic flank of the basin, and basin sediments may be incorporated into the migrating fold-thrust belt. The basin may either be extensively deformed or remain relatively undisturbed apart from low angle intraformational unconformities. Stress may be relieved by movement on décollement surfaces.

APPLICATION OF MODEL TO THE BOWEN BASIN

The Bowen-Gunnedah-Sydney Basin, and the Bowen Basin in particular, fits many of the features of retroarc foreland basins outlined above.

1. Development behind continental margin magmatic arc

Major subsidence of and widespread deposition in the Bowen Basin commenced in the Early Permian, at the beginning of Fauna II time of Dickins and others (1964), when the sea entered the basin for the first time. Prior sedimentation, if it occurred, was entirely nonmarine and restricted to relatively small infrabasins.

Development of the Bowen Basin coincided with or may have been slightly preceded by the formation of the Camboon Volcanic Arc along its eastern margin (Fig. 2). The arc appears to have been relatively short lived, but of major proportions. Isotopic dates suggest that it was active from about 290 Ma to 270 Ma (Webb and McDougall, 1968; Runnegar, 1979). Published descriptions indicate that andesitic volcanics are dominant, and that a full range of calcalkaline compositions from basalt to rhyolite is present (Malone and others, 1964, 1969; Jensen and others, 1966; Clarke and others, 1971; Dear and others, 1971; Whitaker and others, 1974). Initially the Camboon Volcanic Arc was emergent and must have formed the eastern margin of the Bowen Basin. Subsequently parts of the arc subsided and were covered by the sea.

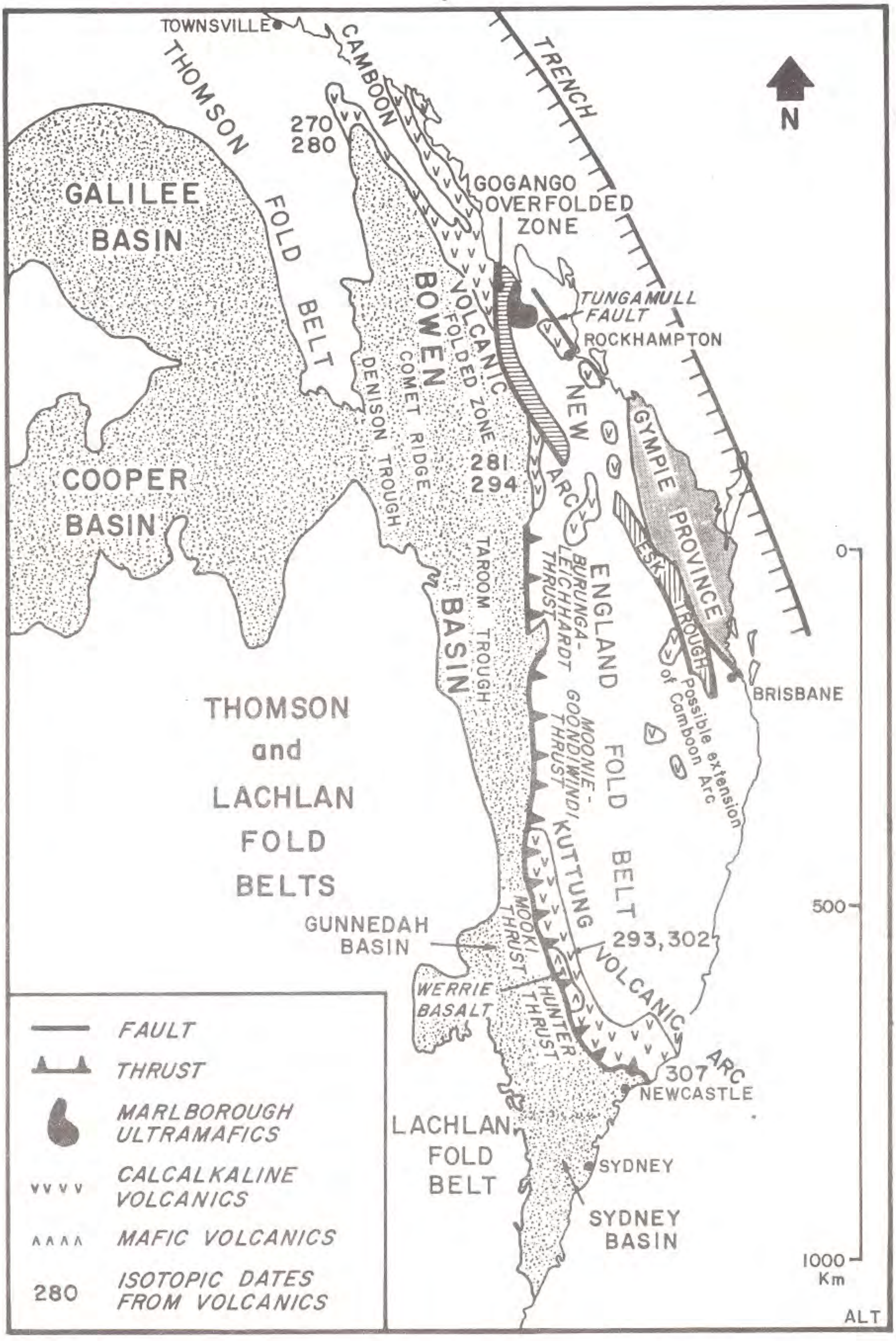

Fig. 2: Selected tectonic elements, Bowen Basin and New England Fold Belt.

The position of the Camboon Volcanic Arc, and its Early Permian age, are entirely consistent with interpretation of the Bowen Basin as a retroarc foreland basin.

The Gunnedah-Sydney Basin does not appear to have been a retroarc basin at this time. If the Camboon Volcanic Arc continued to the south, it must have trended SSE through the Warwick area in southeast Queensland and the Paddys Flat-Emu Creek area in northeast New South Wales, where calcalkaline volcanics containing Fauna II are preserved (Fig. 2; Olgers and others, 1974; Murray and others, 1981). Calcalkaline volcanics do occur along the eastern margin of the Gunnedah-Sydney Basin, but they are part of the Kuttung Volcanic Arc system, which was active during an earlier tectonic stage than the Camboon arc (Day and others, 1978; Korsch and Harrington, 1981). The Kuttung Volcanic Arc was essentially a Carboniferous feature. Compositions of the volcanics range from intermediate to silicic and become more silicic with decreasing age (Nashar, 1969). It is feasible that the Gunnedah-Sydney Basin developed as a retroarc basin associated with the Kuttung Volcanic Arc, because (a) the arc was active until the beginning of the Permian, as indicated by dates of 302 and 293 Ma from ignimbrites in the Currabubula Formation (McPhie, 1984), and (b) the earliest deposits of the Sydney Basin, which contain the Allandale fauna of Runnegar (1969) or the Trigonotreta campbelli - Martiniopsis elongata - Martiniopsis konincki zones of Runnegar and McClung (1975), are older than those of the Bowen Basin. Volcanism continued into Permian time, but there is debate whether silicic volcanics such as the Boggabri and Gunnedah Volcanics represent the final, restricted products of the Kuttung Volcanic Arc (McPhie, 1984), or are part of a bimodal sequence including the Werrie Basalt (Fig. 2) which indicates a rift setting (Harrington, 1982). In either case, a fundamental problem with the hypothesis that the Gunnedah-Sydney Basin is a retroarc basin related to the Kuttung Volcanic Arc is that the basin formed either during the waning stages of activity in the arc, or immediately after it had ceased to exist as an active feature. This is certainly not typical of other retroarc basins, and appears to rule out a retroarc origin. However, the Gunnedah-Sydney Basin may still have formed as a foreland basin.

2. Continental crust

Although sparse, the available data suggest that the Bowen-Gunnedah-Sydney Basin was floored by continental crust. Part of the Bowen Basin overlies the continental Late Devonian-Early Carboniferous Drummond Basin, and seismic investigations have revealed a comparatively thick continental-type crust.

It is not known to what extent structures in the basement rocks controlled deposition in the Bowen Basin. Possibly they were partly responsible for the migration of depocentres in the basin noted by Malone (1964) and Flood (1983).

3. Foreland thrust belt

Much of the eastern margin of the Bowen-Gunnedah-Sydney Basin is characterised by the occurrence of major westward directed thrusts which bring older rocks of the New England Fold Belt over Permian sediments of the basin (Fig. 2). The Hunter-Mooki thrust system has been known since the beginning of this century through the work of David and others, and is now well established (Voisey, 1959). Northwards, this fault system is concealed beneath Mesozoic sediments, but it is assumed to be continuous with thrusts along the eastern edge of the Taroom Trough. Here, the Moonie-Goondiwindi and Burunga-Leichhardt thrusts have been clearly defined on seismic reflection profiles (eg Thomas and others, 1982). West of Rockhampton, the Gogango Overfolded Zone (Malone, 1964) is a typical foreland fold-thrust belt. Deformation involved a substantial component of westward thrusting, and tight folds with a well developed axial plane cleavage are consistently overturned to the west (Olgers and others, 1964; Malone and others, 1969). Further evidence of westward thrusting in this region is provided by ultramafic rocks in the Marlborough area NW of Rockhampton. An interpretation of gravity anomalies by Darby (1969) showed that the largest ultramafic mass is a flat sheet about 2 km thick which partly overlies Permian sediments of the Gogango Overfolded Zone. Murray (1974) suggested that the sheet had been thrust westward at least 60 km from its root zone in the northern extension of the Tungamull Fault (Fig. 2). No thrusting has been recognised along the eastern boundary of the Bowen Basin north of Rockhampton, but Reid (1930, p. 85) stated that ".... a marked tendency to overthrust westwards .... seems greatest along the eastern edge of the Great Syncline (Bowen Basin) from Collinsville southwards".

If tectonic stacking of thrust sheets and consequent loading of the cratonic margin is indeed the main cause of subsidence in foreland basins, the observed thrusting along the eastern edge of the Bowen-Gunnedah-Sydney Basin presents a problem. All the thrusts bring older rocks over Permian sediments, and were therefore too young to contribute to the formation of the basin - the basin was already in existence. One solution is that the observed thrusts are merely a later expression of the same style of tectonics which formed the basin in the first place. In typical foreland basins, the fold-thrust belt migrates over the basin, incorporating successively younger deposits, and causing the axis of the basin to migrate towards the craton also (Beaumont, 1981). It is possible that the early thrusts associated with the genesis of the Bowen-Gunnedah-Sydney Basin either have not been recognised or have subsequently been removed by erosion.

Another explanation is that subsidence was related primarily to some other mechanism. One of the best examples of a modern retroarc foreland basin occurs in the western part of Indonesia, immediately north of the active volcanic arc on the islands of Sumatra and Java. A fold-thrust belt has not yet developed here, although the basin itself contains northward directed folds and thrusts. The formation of the basin has been attributed largely to subsidence beneath the weight of the volcanic and plutonic rocks in the magmatic arc (Hamilton, 1979). The Indonesian foreland basin is considered to be the best modern analogue of the Early Permian Bowen Basin, and it is possible that initial subsidence of the latter was due to the excess load of the volcanic and plutonic rocks of the Camboon Volcanic Arc. Other possibilities include bending of the cratonic lithosphere across the orogen - foreland basin couple, and limited extension of the crust expressed by NNW trending dyke swarms in the area of the volcanic arc. The lack of coarse clastics along the eastern edge of the Bowen Basin indicates the absence of an elevated mountain range which is normally produced by stacking of thrust sheets, and therefore lends support to one or a combination of the last three explanations.

On similar grounds, there is also no evidence for the existence of a substantial stack of thrust sheets along the eastern margin of the Gunnedah-Sydney Basin. If it was a foreland basin but not a retroarc basin, the only mechanism for its origin which seems possible is simple compressional bending of the cratonic lithosphere.

4. Asymmetric profile

Reflection seismic surveys across the Taroom Trough (Thomas and others, 1982) show a markedly asymmetric profile typical of the idealised foreland basin model. The trough slopes down from a simple unconformity along its western edge to reach its maximum depth near the eastern margin, the Moonie-Goondiwindi Thrust.

5. Relationships with platform sequences

To the west, the sediments of the Bowen Basin are continuous with those in the shallow, intracratonic Galilee and Cooper Basins (Fig. 2).

6. Characteristic sediments

Fluvio-deltaic deposits, the most characteristic strata of retroarc foreland basins (Dickinson, 1978), are certainly the dominant facies along the western edge of the Bowen Basin. However, Early Permian sediments along the eastern margin are all shallow marine (J.J. Draper, pers. comm.). It was not until the Late Permian that deltaic and alluvial fan deposits became significant. The change may reflect westward movement of the main axis of the basin with time, and would be consistent with continued westward displacement of the foreland thrust belt. The lack of coarse clastics along the eastern margin of the basin clearly indicates that no elevated mountain range was produced by orogenic processes in the western part of the New England Fold Belt. Overall, the sediments of the Bowen-Gunnedah-Sydney Basin show the upward transition from marine to nonmarine strata which is typical of foreland basins, although local fluctuations are common.

Major coal deposits are commonly found in the upper, nonmarine sequences of foreland basins, eg the Alberta foreland basin contains reserves of more than 100 billion tonnes (Latour and Christmas, 1970).

The coal is interpreted to have formed in a variety of environments ranging from anastomosed river systems with intervening peat swamps (Smith and Putnam, 1980) to paralic (coastal plain and deltaic). The widespread occurrence of coal in the Bowen-Gunnedah-Sydney Basin, and the variety of depositional environments it represents, are entirely compatible with a foreland basin model.

7. Coal rank

Regional and stratigraphic variations in coal rank in the Alberta foreland basin have been examined by comparison of reflectance measurements (Hacquebard and Donaldson, 1974). Within each coal-bearing unit, rank increases across the basin towards the marginal fold-thrust belt. Coal rank reflects pre-orogenic depth of burial or stratigraphic position, being independent of geologic age, depth of mining, or degree of tectonic disturbance. Beaumont (1981) found that the observed variation in coal rank was entirely compatible with his detailed quantitative evaluation of subsidence and tectonic evolution of the Alberta foreland basin assuming no change in geothermal gradient from present values.

Coal rank variations in the Bowen Basin show similar trends to those in the Alberta foreland basin, increasing in individual formations from west to east towards the postulated fold-thrust belt, and reflecting depth of burial rather than tectonism (Staines and Koppe, 1980; Beeston, 1981). The similarity of coal rank variations strongly supports a foreland basin model for the Bowen Basin, and appears to rule out any thermal model for the origin of the basin (Beaumont, 1981).

8. Structural style

The structural style of the Bowen Basin is dominated by compressional folds and faults. This has been clearly recognised in recent years by seismic reflection profiling. Folding and thrusting have been demonstrated in the Denison Trough in the west of the Bowen Basin (Fig. 2; Bauer and Nelson, 1980; Nelson and Bauer, 1980) and in the Taroom Trough (Thomas and others, 1982).

The degree of syndepositional deformation in the basin is variable. Along the eastern margin of the Taroom Trough, basin sediments were involved in westward thrusting (Thomas and others, 1982). Further north, the extended time break between the Buffel and Pindari Formations (Draper, 1985) presumably reflects syndepositional movements. In the Denison Trough, low angle intraformational unconformities have been recognised on seismic records (Bauer and Nelson, 1980; Nelson and Bauer, 1980).

One anomalous area of deformed rocks within the Bowen Basin is the Folded Zone (Malone, 1964) west of the Gogango Overfolded Zone (Fig. 2), which consists of tight, large amplitude folds. Seismic surveys reveal a flat-lying basement beneath a possible décollement surface at a depth of 6 000 m (Robertson, 1961). Such a décollement could have been produced by lateral gravitational spreading (Price, 1973).

PERSISTENCE OF BOWEN BASIN AS A RETROARC BASIN

It is uncertain whether the Camboon Volcanic Arc persisted after the Early Permian, as there appears to have been a major hiatus in magmatic activity in mid-and Late Permian time. In the northern part of the arc, Early Permian magmatism concluded with the intrusion of the Thunderbolt Granite (age 265-281 Ma; Webb and McDougall, 1968). At the southern end, the large Rawbelle Batholith, with ages from 226 to 258 Ma (Whitaker and others, 1974), was emplaced after the cessation of volcanism. The only volcanic unit known to be younger than Early Permian is the localised Mount Wickham Rhyolite, dated at 238 Ma or Early-Middle Triassic (Webb and McDougall, 1968), at the northernmost extremity of the Camboon Volcanic Arc.

The apparent hiatus in magmatic activity in the Camboon Volcanic Arc in mid-and Late Permian time is not consistent with the widespread distribution of tuff bands in the Late Permian coal measures of the northern Bowen Basin (Staines and Koppe, 1980). If proximal volcanics equivalent to these tuff bands were present in the Camboon Volcanic Arc, they either have not been recognised or have subsequently been completely removed by erosion.

In view of the conflicting evidence, it is not possible to determine when activity ceased in the Camboon Volcanic Arc and the Bowen Basin ceased to be a retroarc basin.

TERMINATION OF DEPOSITION IN THE BOWEN BASIN

Deposition ceased in the Bowen-Gunnedah-Sydney Basin and also in the interconnected Galilee and Cooper Basins towards the end of Middle Triassic time, when the basin sequences were deformed and uplifted. This event affected the eastern half of Australia (Harrington and Korsch, 1985), and was therefore of major significance. Harrington and Korsch (1985) attributed the deformation and cessation of deposition to docking or accretion of the Gympie Province, a possible exotic terrane at the eastern edge of the New England Fold Belt (Fig. 2). However, the relationship between the Middle Triassic strata of the Esk Trough and the adjacent Gympie Province suggests that the time of accretion must have been earlier, probably Early Triassic. In the Kilkivan area, the eastern boundary of the Esk Trough is a simple unconformity along which volcanics dated at 241 and 242 Ma (Murphy and others, 1976) overlie a variety of rock types of the Gympie Province.

CONCLUSIONS

Almost all features of the Bowen Basin are compatible with and explicable by a retroarc foreland basin model. The basin formed behind the continental margin Camboon Volcanic Arc in Early Permian time. There is no evidence to suggest that stacking of thrust sheets in the foreland thrust belt along the eastern side of the basin ever formed a topographically elevated mountain range. Therefore, an origin involving downwarping as an isostatic response to loading by such a thrust pile can probably be discounted. By analogy with modern foreland basins in western Indonesia, the most probable origin was by subsidence under the weight of volcanic and plutonic rocks in the magmatic arc.

The origin of the interconnected Gunnedah-Sydney Basin is more problematical, because it was unlikely to have formed as a retroarc basin. It may have been a foreland basin, but a specific mechanism to account for its subsidence cannot be determined, and its precise relationship to the Bowen Basin must therefore remain unclear.

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THE PERMIAN WORLD, FLORAS AND COAL DEPOSITS

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INTRODUCTION

The Permian Period was a time of great variety and dramatic change in climate. With evidence of bipolar ice caps, extensive deserts, huge coal deposits and highly variable terrestrial floras and marine faunas, the Permian was a time of latitudinally well differentiated climatic belts. Extensive coal deposits (especially in the fragments of Gondwana and in the Soviet Union), oil and gas fields, copper, uranium, phosphate and extensive salt deposits are part of the economic legacy of the Permian.

A PERMIAN TIME SCALE

The striking differences between Permian terrestrial floras, marine faunas and sedimentary sequences from one region to another make it difficult to correlate accurately on a world wide basis within the Permian. The Permian has been subdivided into a series of stages and substages, although there is not yet a uniformity of usage. The Permian System was established in European Russia in the eastern Russian Platform and the Ural Mountains (Murchison, 1841). The scope of the Permian has changed but many of the stage and substage names (Table 1) are based on the classic Russian sequences, with some reference to sequences in the Caucasus and the Salt Range (Pakistan). Global correlations are achieved primarily by the use of marine invertebrate faunas (Waterhouse, 1976) but terrestrial macrofloras provide useful data within floral realms and provinces, and palynology provides some data between the realms (Foster, 1978) as well as critical data within realms. The value of palynological data between floral realms is, however, hampered by homeomorphy and convergent evolution (Foster, 1978).

Correlations must be refined if time controlled global or inter-regional events are to be accurately documented. For example, eustatic changes in sea level may alter the delicate sediment and tectonic balance required for thick peat accumulations. One such broad regional rise in sea level occurred at the end of the main early Permian (Asselian) glacial period in Gondwana (Dickins, 1978). The resultant widespread marine transgressions throughout much of Gondwana are recognised by their distinctive marine faunas of Tastubian age (Archbold, 1982). These marine transgressions were

PERMIAN	TATARIAN	DORASHAMIAN
		DJULFIAN
		CHHIDRUAN
	KAZANIAN	Late
		Early
	KUNGURIAN	Ufimian
		Irenian
		Filippovian
	ARTINSKIAN	Baigendzhinian
		Aktastinian
	SAKMARIAN	Sterlitamakian
		Tastubian
	ASSELIAN	

Table 1. Subdivision of the Permian Period

relatively short-lived in many areas of Gondwana (Peninsula India, Southern Africa and areas of South America) where a return of terrestrial sedimentation (with coals) occurred in the Late Sakmarian and into the Artinskian. The Parana - Karroo Basin structures of Southern Africa and South America became isolated as a vast 'lake-sea' cut off from normal oceanic waters (Runnegar, 1984). It is perhaps of note that a substantial (100 m) eustatic drop in sea-level has been postulated to explain the formation of the stromatolitic and evaporitic sequences of the European Zechstein Sea (Smith, 1979) during Late Kazanian - Early Tatarian times. This age matches the final withdrawal of the sea from the Sydney and Bowen Basins and hence the onset of conditions suitable for the deposition of extensive peat deposits in both Basins. Approximately contemporaneous marine regressions also occurred in the Russian platform and other Boreal regions of the Soviet Union (Likharev, 1966). Glacially derived sediments are known from the Kazanian of the Kolyma - Omolon block (north-eastern Siberia).

THE PERMIAN WORLD

During the last decade, a wealth of data from studies on regional geology, tectonics, faunal and floral distributions and palaeomagnetic investigations has substantially modified the classic view of a Permian Pangea (Rowley et al., 1985). The earlier view of the Permian world with a large Tethyan ocean between eastern Gondwana to the south and eastern Laurasia to the north is no longer tenable.

Various studies (e.g. McElhinny et al., 1981; Archbold et al., 1982; Audley-Charles, 1983; Lin et al., 1985) indicate that the so-called Tethyan Gape was occupied by numerous smaller continental slabs which are now incorporated within China, Tibet and South-east Asia. This new understanding of the Permian world (Figure 1) provides a framework for considering climatic patterns and the associated distributions of Late Palaeozoic floras and coal deposits.

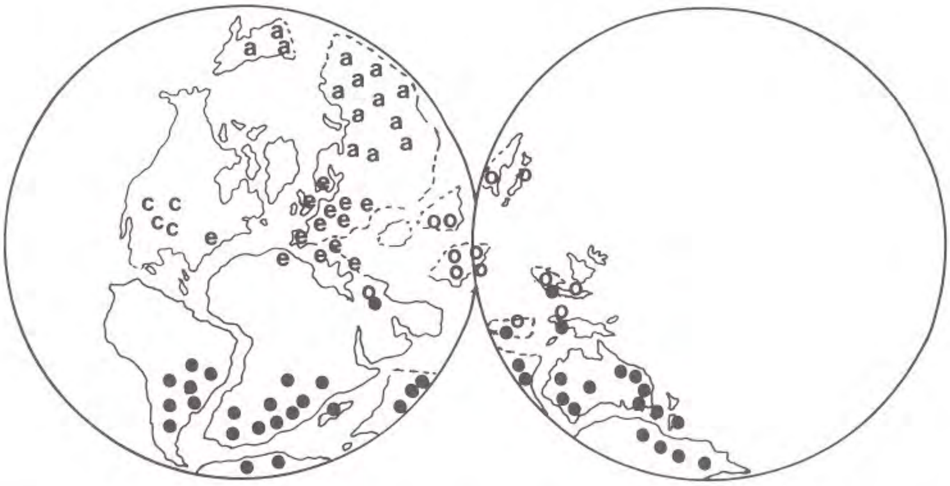

Figure 1. A reconstruction of the Permian world with a generalized distribution of Permian floras (compiled from various sources - see references)

a = Angara
c = Cordilleria
e = Eurameria
o = Cathaysia
● = Gondwana

THE PERMIAN FLORAS

The fact that Permian floras were highly provincial has been known for over 80 years. Detailed reviews of Permian floral distributions by Chaloner and Meyen (1973), Chaloner and Lacey (1973), Plumstead (1973) and Kremp (1974) have been modified subsequently only in terms of further understanding the regions of overlap between the provinces and realms, and in greater control over the age assignment of particular fossil horizons. The latter point is a major problem in any global review (Chaloner and Meyen, 1973) where age assignments are not always well established.

By the Early Permian, plant life was characterised by a regional differentiation of world floras which show a degree of divergence unrivalled in any other period of geological time with the possible exception of the Late Tertiary to Recent (Chaloner and Meyen, 1973). The major floral realms of the Permian are the Gondwanan, Cathaysian, Angaran, Euramerian and Cordillerian (the last shows links with the Cathaysian Realm). Characteristic genera of the realms are provided in Table 2.

Table 2. Selected genera, regarded on a subjective basis as characterising each of the five palaeofloristic realms shown in Figure 1. (From Chaloner and Lacey, 1973).

Genus	Realm				
	Gondwana	Cathaysia	Angara	Cordilleria	Eurameria
Glossopteris	*				
Gangamopteris	*				
Neoggerathiopsis	*				
Gondwanidium	*				
Tingia		*			
Lobatannularia		*			
Gigantopteris		*		*	
Protoblechnum		*		*	
Supaia				*	
Glenopteris				*	
Rufloria			*		
Angaridium			*		
Paragondwanidium			*		
Intia			*		
Tschernovia			*		
Callipteris			*	*	*
Pecopteris		*	*		*
Cordaites		*	*		*
Sigillaria					*
Calamites					*
Alethopteris					*

The cores of the various realms were characterised by distinct climates (e.g. see Kremp, 1974; Ziegler *et al.*, 1977). The Gondwanan Realm ranged from cold to warm temperate climates and extended over a huge area. The form genus *Glossopteris*, a major contributor to the Gondwanan peat deposits (Runnegar, 1984), was well adapted to wet, acid soil and peat environments (Gould, 1975). Gondwanan floras penetrated warm temperate to subtropical regions along the northern fringes of eastern Gondwana into New Guinea, Thailand and the Lhasa Block (see Archbold *et al.*, 1982; Li *et al.*, 1985) and westwards into Turkey where mixed Gondwanan - Cathaysian floras also occur. It is of note that south of Turkey, in Saudi Arabia, a mixed Cathaysian - Euramerian flora has been recorded (Lemoigne, 1981) so that regions of the present Middle East appear to have been a region of overlap for three major floral types.

The Cathaysian floras of China, Korea, Japan and most of South east Asia developed in tropical to subtropical humid regions on scattered areas of land between the eastern Tethyan seaways. Many of these Asian land areas had a separate origin (e.g. Lin *et al.*, 1985) but distinctive Cathaysian elements such as *Tingia*, *Cathaysiopteris* and *Gigantopteris* unite the floras. Transition from the humid tropical Cathaysian Realm to the temperate and cold Angaran Realm occurred throughout the modern regions of Northern China, Mongolia, Manchuria and the Soviet Far East. Floras of these regions, ranging from Late Kungurian to Tatarian in age, are well known (Durante, 1971,

1980) and recent studies (Wang, 1985) indicate strong links with contemporaneous Euramerian subtropical dry floras. Here again elements of three realms are present. Also of note is the presence of Gondwanan elements (e.g. Glossopteris and Gangamopteris) from the Soviet Far East (Zimina, 1967, 1983) in distinctive floras reflecting a mix of elements from four realms.

The Angaran Realm covered an extensive region ranging from cold to warm temperate climates. Warmer transition regions to the Euramerian Realm to the west occurred in eastern Europe, e.g. the Pechora Province, particularly during the Late Permian (Chaloner and Meyen, 1973). The core of the realm (Siberia), characterised by such genera as Rufloria and Cordaites, offers comparison with Gondwana, in that Kazanian glacially derived sediments are known from the Kolyma and Verkhoyansk regions (e.g. Andrianov and Andrianova, 1962).

The Euramerian and Cordillerian Realms were of tropical and subtropical climate. The former reflects the progressive drying of the climate after the widespread, lush, humid coal floras of the Carboniferous into the hot, dry desert climate of the European Zechstein. Floras of the western side of North America (the Cordillerian Realm) were differentiated from the Euramerian floras by Artinskian and Kungurian times. Links between the Cordillerian floras and the Cathaysian floras are significant (Chaloner and Meyen, 1973; Ziegler et al., 1977) and are not readily explained by current plate tectonic reconstructions.

PERMIAN COALS

Major economic deposits of Permian coal are known from fragments of Gondwana (Runnegar, 1984), from Siberia and European Russia (see Likharev, 1966, for details of stratigraphy and Nalivkin, 1973, for resource details) and China (see Grabau, 1924, for a classic survey). This wide distribution throughout three of the floral realms reflects peat deposits that formed in cold to tropical climates. It is of note that marine intervals of sedimentation are part of the total sediment sequence in many coal basins, e.g. the Sydney and Bowen Basins of Australia, the Pechora Basin of European Russia, and the Hunan Basin of China. Notions that moderate to tropical climates are required for coal formation (Mackowsky, 1968) have to be abandoned for some Permian coals which formed in polar and subpolar regions. Permian Glossopteris coals are known from within a few degrees of the Permian southpole, implying that arborescent plants with large leaves could survive the winter months of darkness (Chaloner and Lacey, 1973). Northern Angara floras from North-east Siberia (Radchenko, 1971) were also subpolar in habitat.

Permian floras provided an abundance of material for peat accumulations throughout a wide range of climatic belts. Association with sea level and eustatic changes in sea level, and probably gentle tectonic movements in some regions of peat accumulation, appear to be major factors in the preservation of the peat in coal measure sequences. The widespread withdrawal of shallow water Permian seas as a global event during the Tatarian, and the progressive warming of post-Kazanian climates (Dickins, 1983), undoubtedly assisted in the formation of suitable environments for the widespread peat accumulations of the Late Permian, such as those described by Mallett (1983) for the Late Permian Rangal Coal Measures of the Bowen Basin.

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STRATIGRAPHY

STRATIGRAPHY OF THE SOUTH-EASTERN BOWEN BASIN

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The south-eastern Bowen Basin is considered here as the area between Banana and Cracow (Fig. 1) where Permian and Triassic rocks form the eastern limb of the Mimosa Syncline. Summaries of the stratigraphy of the area can be found in Dickins & Malone (1973), Gray & Heywood (1978), McClung (1981), and Waterhouse (1983a). Recent mapping in the area by GSQ has clarified some of the stratigraphic problems, and the current stratigraphy is summarised in Table 1.

Basement rocks, exposed to the east, are granites of the Carboniferous to Mesozoic Auburn Complex and the volcanic Torsdale beds of Carboniferous age.

Camboon Volcanics is used in preference to the older term "Camboon Andesite", as there is a much broader suite of volcanic rocks present that the term "Andesite" implies. The Camboon Volcanics represent the base of the Permian sequence and is of early Permian age. Lithologies present include andesite, dacite, rhyodacite, basalt and rhyolite as flows and tuffs; minor volcaniclastic sediments are also present. The Camboon Volcanics unconformably overlie the Torsdale beds although the contact is difficult to map because of lithological similarities. The thickness is difficult to estimate but is probably in excess of 3000 m.

The Back Creek Group includes all Permian marine rocks overlying the Camboon Volcanics. The lowermost unit of the Back Creek Group is the Buffel Formation. Waterhouse (1983b) proposed upgrading the Buffel Formation to sub-group status. However, the relationship and distribution of the contained rock units is not understood and the individual units have limited aerial extent and thickness. Until the unit is more clearly understood, Buffel Formation should be used to refer to rocks occurring between the Camboon Volcanics and the Pindari Formation. Rock types include volcaniclastic sandstone, conglomerate and breccia, skeletal limestone, calcareous siltstone and sandstone, siltstone, mudstone and impure limestone. The unit is richly fossiliferous and of early Permian age. Although the Buffel Formation unconformably overlies the Camboon Volcanics in the Cracow-Theodore area, fossils from the Camboon Volcanics near Thangool are correlative with those in the Buffel Formation (Parfrey, in preparation). The thickness of the Buffel Formation is extremely variable but rarely exceeds 100 m.

A major unconformity separates the Buffel Formation from the overlying Pindari Formation which comprises white spicule-rich sandstone and siltstone. Much of the Pindari Formation crops out as a silica-kaolinite rock of replacement origin; similar rocks occur within the Buffel and Oxtrack Formations, providing difficulties in mapping the units. The Pindari Formation contains few fossils and is of late Permian age. The maximum known thickness is 100 m.

Mudstone, siltstone and fossiliferous sandstone of the Brae Formation conformably overlie the Pindari Formation. The late Permian unit has a maximum known thickness of 160 m. The Oxtrack Formation is richly fossiliferous and contains skeletal limestone, calcareous siltstone, siltstone and sandstone. It conformably overlies the Brae Formation and is of late Permian age. The maximum known thickness is 200 m.

Conformably overlying the Oxtrack Formation is the Barfield Formation comprising mudstone and siltstone with calcareous concretions, lithofeldspathic sandstone and conglomerate. The unit, which has a maximum known thickness of 900 m, is fossiliferous and of late Permian age. In the Banana area, the Barfield Formation contains the Station Mudstone Member, the Cottenham Sandstone Member and the Four Mile Mudstone Member.

The Flat Top Formation, which conformably overlies the Barfield Formation is the uppermost unit of the Back Creek Group. Siltstone, sandstone, mudstone, conglomerate, limestone and tuff are present, but the unit becomes finer and less marine southwards. The maximum known thickness is 660 m, and the unit is of late Permian age.

The Blackwater Group overlies the Back Creek Group and contains Permian, non-marine, mainly coal-bearing units. Siltstone, labile sandstone, mudstone, conglomerates (in the upper part) and tuffs form the late Permian Gyranda Formation which conformably overlies the Flat Top formation. The unit has a maximum known thickness of 914 m.

Completing the Permian sequence is the Baralaba Coal Measures which conformably overlie the Gyranda Formation. Feldspathic sandstone, siltstone, coal, conglomerate and tuff are the main rock types. The tuffaceous Kaloola Member occurs at the base of the unit and also contains sandstone, siltstone, mudstone and thin coals. The maximum known thickness of the Baralaba Coal Measures is 450 m with Kaloola Member being 90-120 m thick.

The Triassic Rewan and Clematis Groups and the Moolayember Formation constitute the remainder of the Bowen Basin sequence. The Triassic sedimentary rocks are entirely continental (Jensen, 1975) and include sandstone, mudstone, siltstones, conglomerates. Although tectonism occurred intermittently throughout the Permian and Triassic, a major folding episode occurred during the late Triassic. A late Triassic peneplaned surface has been preserved in the Cracow area.

Following the folding and peneplanation, deposition of the Jurassic-Cretaceous Surat Basin occurred and the erosional rim of this basin occurs south of Cracow. Cainozoic sediments and basalts are also present in the area. Intrusive rocks in the area include Carboniferous granites, Mesozoic (?Triassic) gabbro and Tertiary basalt.

DEPOSITIONAL HISTORY

Bowen Basin deposition in this area began with the deposition of mainly continental Camboon Volcanics in a volcanic arc environment, with the Bowen Basin forming as a foreland basin. The marine Buffel Formation was deposited on a very uneven surface. The younger Pindari and Brae Formations were deposited as a transgressive sequence on a more smoothed surface. The Oxtrack Formation was deposited in a relatively uniform, low energy shelfal environment. Continued subsidence resulted in deposition of a thick mudstone and turbidite sequence in the Barfield Formation. Shallowing followed, with the Flat Top Formation, a complex of marine to deltaic rocks, representing the end of marine deposition in the area. Lacustrine, deltaic, fluviatile and alluvial fan sequences all occur within the Gyranda Formation. The Baralaba Coal Measures are mainly fluvial and pass upwards into the fluviatile red bed sequence of the Rewan Group.

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TABLE 1: STRATIGRAPHY OF THE SOUTH-EASTERN BOWEN BASIN

TRIASSIC	
Moolayember Formation	Micaceous lithic sandstone, calcareous in places; micaceous siltstone; plant fossils
Clematis Group	
Expedition Sandstone	Sandstone; conglomerate; siltstone
Glenidal Formation	Sandstone; siltstone; mudstone
Rewan Group	
Arcadia Formation	Sandstone; mudstone
Sagittarius Sandstone	Red beds; sandstone; mudstone; siltstone
PERMIAN	
Blackwater Group	
Baralaba Coal Measures	Feldspatholithic sandstone; siltstone; coal; conglomerate; tuff
Kaloola Member	Tuffaceous sandstone; siltstone; mudstone; tuffs; thin coals
Gyranda Formation	Siltstone; labile sandstone; conglomerate; mudstone; tuff
Back Creek Group	
Flat Top Formation	Siltstone; sandstone; mudstone; conglomerate; limestone; tuff; fossiliferous
Barfield Formation	Mudstone; siltstone; lithofeldspathic sandstone; conglomerate; fossiliferous
Station Mudstone Member	Mudstone; siltstone; minor sandstone
Cottenham Sandstone Member	Feldspatholithic sandstone; siltstone
Four Mile Mudstone Member	Mudstone; siltstone; minor sandstone
Oxtrack Formation	Limestone; silty limestone; calcareous siltstone; sandstone; very fossiliferous
Brae Formation	Mudstone; siltstone; sandstone; fossiliferous
Pindari Formation	Sandstone; siltstone; silica-kaolinite rock; spicules
Buffel Formation	Volcaniclastic sandstone; conglomerate; breccia; limestone; calcareous siltstone; siltstone; mudstone; calcareous sandstone; very fossiliferous
Camboon Volcanics	Andesite; basalt; dacite; rhyolite; tuffs and flows; volcaniclastic conglomerate; sandstone; siltstone; breccia

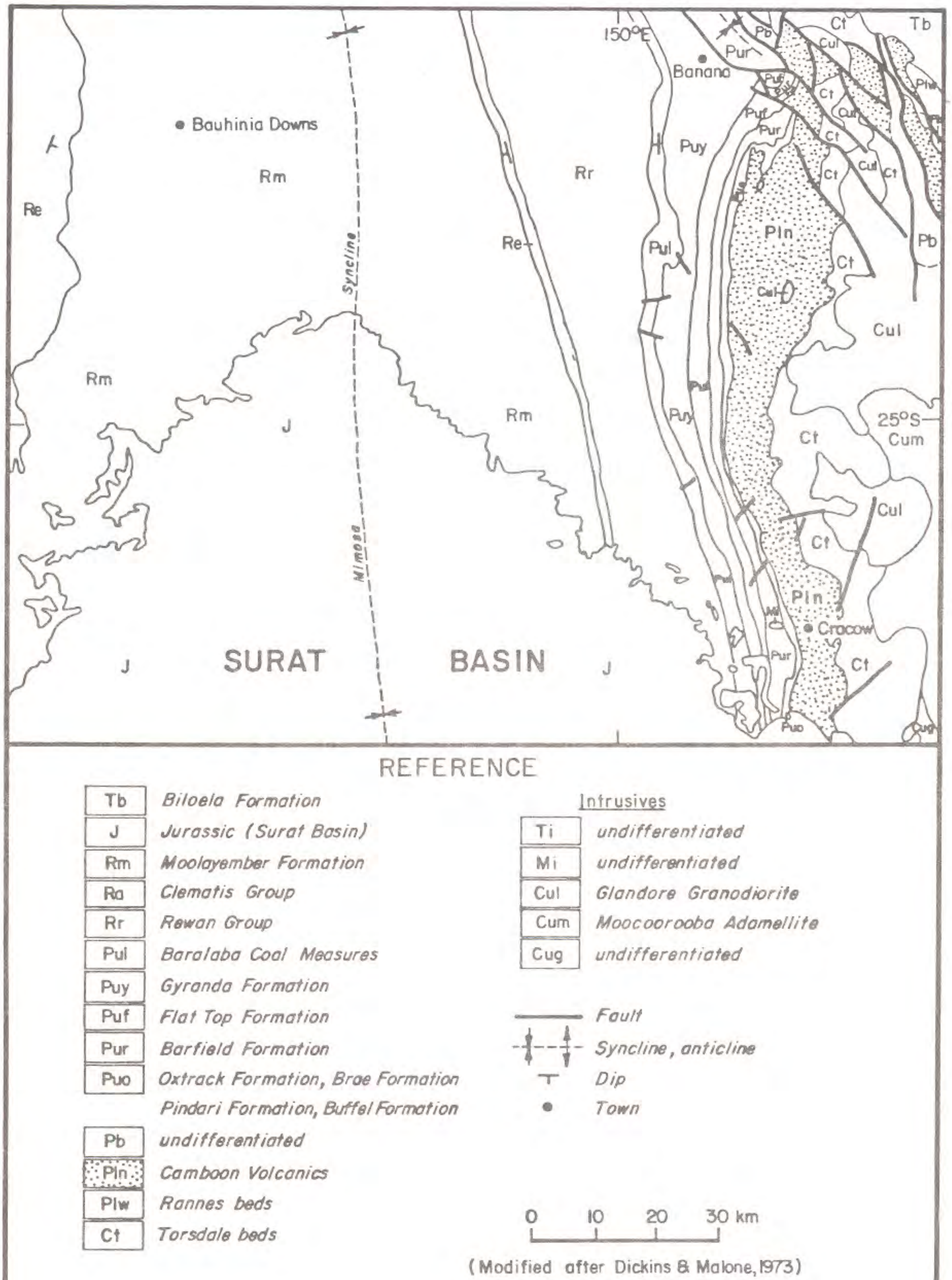


Figure 1. : Generalised Solid Geology, South-Eastern Bowen Basin

THE STRATIGRAPHY OF THE DENISON TROUGH

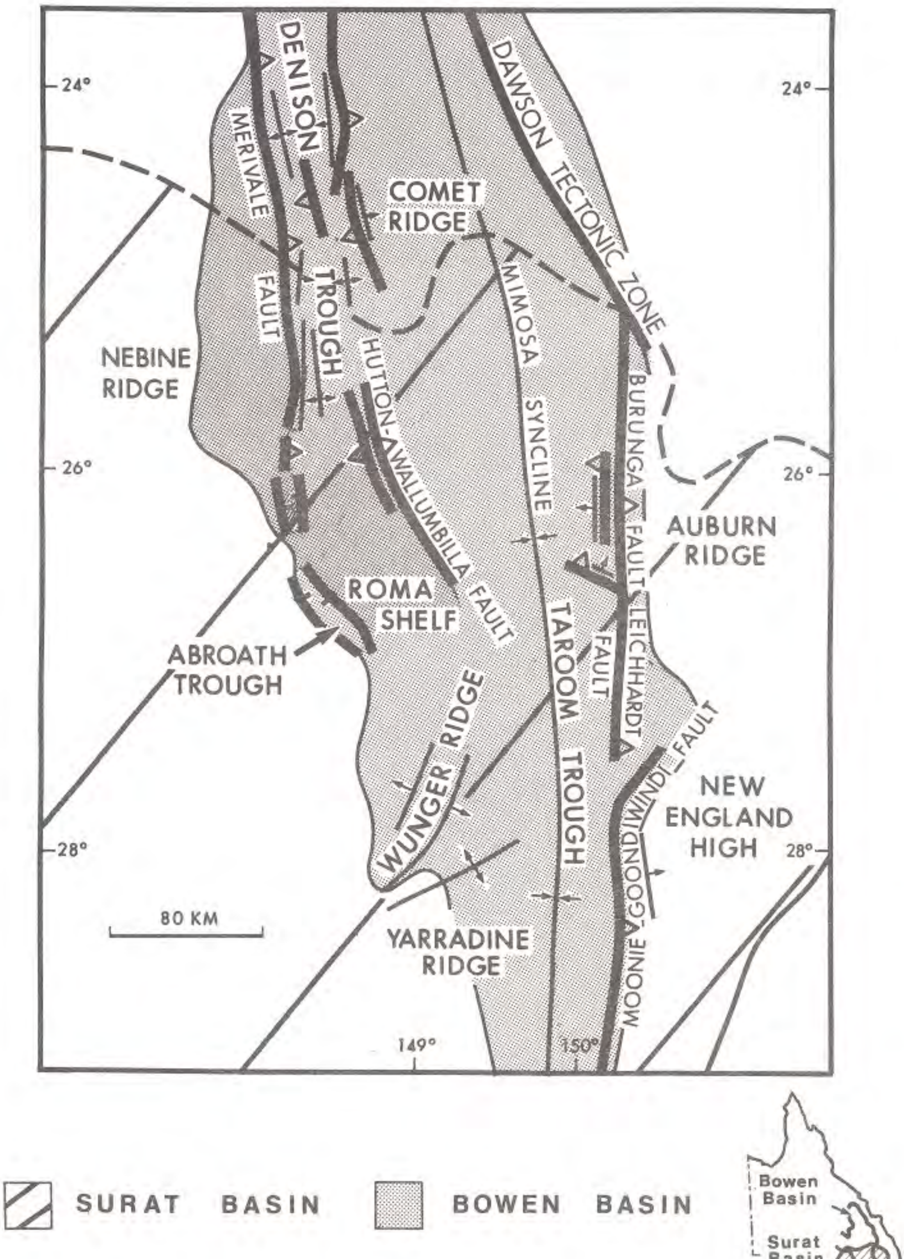
L. Elliott, AAR Limited (CSR Oil and Gas Division)

The Denison Trough is the area of outcropping Permian-Triassic sediments between Emerald and Injune, and forms the western part of the Bowen Basin. The "Trough" is a series of Permian graben and half grabens which controlled the type and distribution of sediments accumulated in the area. Figure 1 shows the location of the Denison Trough with respect to other important tectonic elements in the central and southern Bowen Basin.

The stratigraphy of the area has been summarized by Power (1967), Dickens and Malone (1973), Paten and McDonagh (1976), Paten and others (1979) and Brown and others (1983). Figure 2 shows the lithostratigraphic subdivision from Brown and others (1983) and was the lithostratigraphy current at the beginning of this decade. During the 1970's and early 1980's the Queensland Department of Mines drilled a large number of cored stratigraphic holes. This together with the data obtained by the AAR Limited and Oil Company of Australia NL joint venture in the search for petroleum, has allowed a refining of the lithostratigraphy shown in Figure 2. The main areas which have been refined are the Reids-Dome Beds - Cattle Creek Formation and the Aldebaran Sandstone intervals.

It has been known from palynology for some time that there are breaks in the Permian section (Price, 1983). Most of these unconformities are difficult to map from outcrop data. With the recording of over 3000 km of reflection seismic data in the area, the breaks identified by palynology plus a number of other unconformities or sequence boundaries can be identified. This grid of data allows the mapping of these events over the whole of the Denison Trough and in some cases into the Taroom Trough.

A number of the sequence boundaries occur at well established lithological breaks. Others occur within presently defined formations. Some show onlap of one sequence over another, others are significant erosional events. The most significant erosional phases are at the seismic sequence boundaries numbered Va and IX in Figure 3. Up to 350 m of section has been removed during the Va erosional phase. Ziolkowski (This Volume, Figure 2a) shows the seismic expression of this event as well as other sequence boundaries in the Warranilla area, south of Rolleston. Figure 4 is a chronostratigraphic sketch of the



STRUCTURAL ELEMENTS

FIGURE 1

AGE	PALYNOLOGIC ZONATION (AFTER PRICE, 1983)		UNIT	THICKNESS (metres)	DEPOSITIONAL ENVIRONMENT
TRIASSIC	"Ipswich Microflora"				Non Deposition
	TR 3 c-d		MOOLAYEMBER FM.	150	Fluvial, Lacustrine
	TR 3 a-b		CLEMATIS SST.	100	Fluvial, Nearshore
	TR 1a, 1b, 2		REWAN FM.	200	Oxidizing Fluvial
LATE PERMIAN	UPPER STAGE 5	U5c	BANDANNA FM.	370	Fluvial, Marsh Deltaic
	P3c →		BLACK ALLEY SHALE	150	Offshore Marine
		U5b	MANTUAN FM.	135	Nearshore / Offshore
			PEAWADDY FM.	210	Offshore Marine
EARLY PERMIAN			CATHERINE SST.	160	Nearshore
		U5a	INGELARA FM.	200	Offshore Marine
			FREITAG FM.	120	Nearshore
	LOWER STAGE 5	L5a – L5c	ALDEBARAN SST.	650	Fluvial Nearshore
	UPPER STAGE 4	U4a – U4b	CATTLE CREEK FM.	765	Offshore Marine Nearshore Offshore Marine
	LOWER STAGE 4				
	STAGE 3	3b	REIDS DOME BEDS	2770+	Nearshore Fluvial Marsh
		3a			Alluvial Fan
CARBONIFEROUS DEVONIAN			BASEMENT		

FIGURE 2

IVa to Vb boundaries in the Merivale - Eddystone area northwest of Injune. This cross section shows the relationship between the lithology as represented by the wireline logs and the mapped seismic sequence boundaries. The areas of non deposition and erosion can be identified easily in this style of correlation section and support the seismic interpretation. The major erosional event is the Va boundary which is within the presently defined Aldebaran Sandstone. The boundary separates the basal marine Aldebaran Sandstone from the typical outcropping fluvial upper Aldebaran Sandstone.

Figure 5 shows the seismic expression of the Late Triassic sequence boundary XI. This seismic line in the Merivale area shows around 800 m of erosion prior to the deposition of the Early Jurassic Precipice Sandstone. It is possible that up to 3000 metres of section has been eroded at this unconformity in some areas of the basin.

The presently understood relationships in the Reids-Dome Beds - Cattle Creek Formation interval are shown in Figure 3. The breakdown of the Aldebaran Sandstone is also shown. The notional stratigraphy shown in Figure 3 is an early attempt to create some order to the lithostratigraphy in the Reids-Dome Beds to Aldebaran Sandstone interval. The potential new units have not as yet been defined but this should occur in 1986.

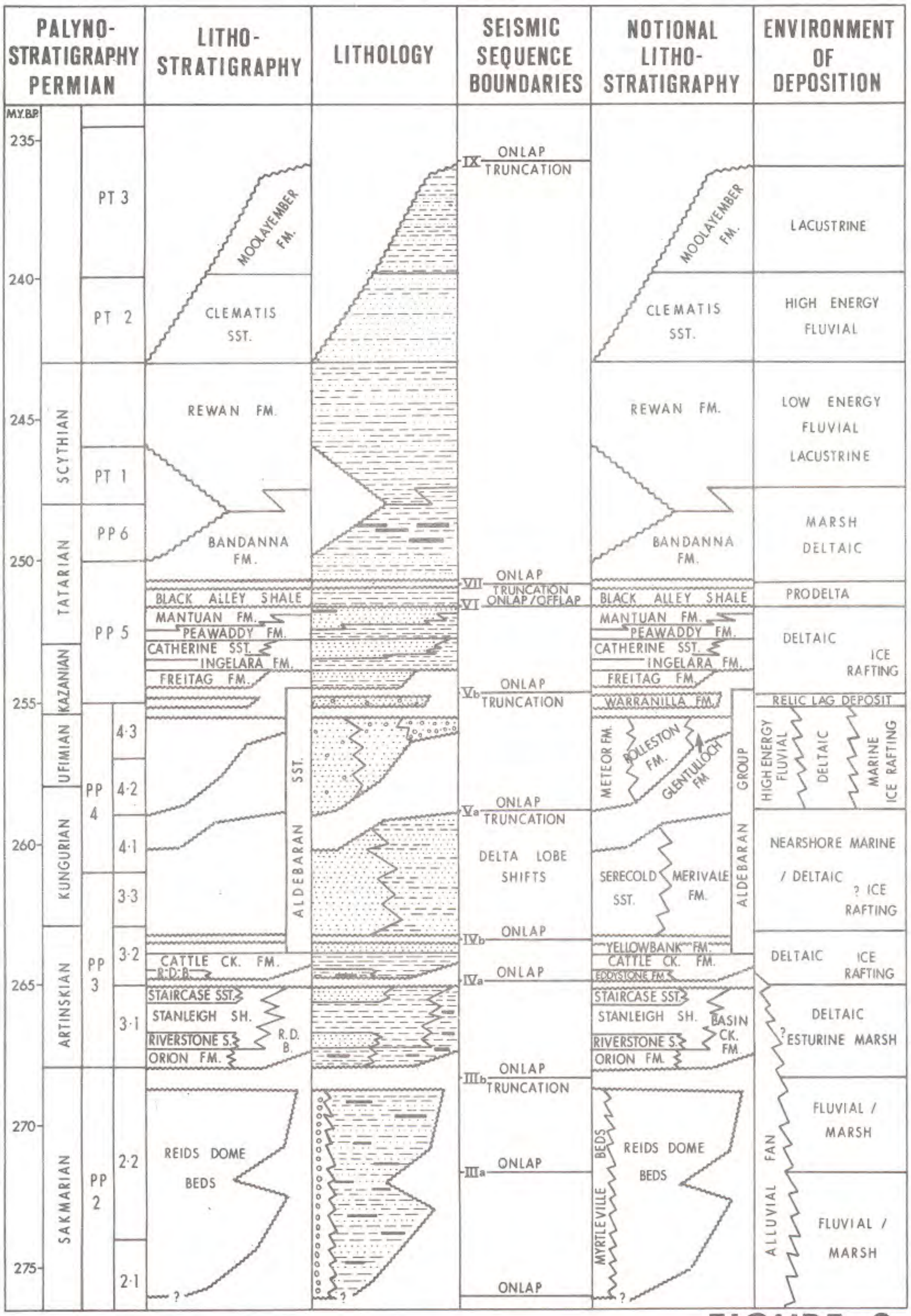

PALYNO-STRATIGRAPHY PERMIAN
LITHO-STRATIGRAPHY
LITHOLOGY
SEISMIC SEQUENCE BOUNDARIES
NOTIONAL LITHO-STRATIGRAPHY
ENVIRONMENT OF DEPOSITION
M.Y.B.P.
235
240
245
250
255
260
265
270
275
SCYTHIAN
TATARIAN
KAZANIAN
UFIMIAN
KUNGURIAN
ARTINSKIAN
SAKMARIAN
PT 3
PT 2
PT 1
PP6
PP 5
PP 4
4·3
4·2
4·1
3·3
PP 3
3·2
3·1
PP 2
2·2
2·1
MOOLAYEMBER FM.
CLEMATIS SST.
REWAN FM.
BANDANNA FM.
BLACK ALLEY SHALE
MANTUAN FM.
PEAWADDY FM.
CATHERINE SST.
INGELARA FM.
FREITAG FM.
ALDEBARAN SST.
CATTLE CK. FM.
R.D.B.
STAIRCASE SST.
STANLEIGH SH.
RIVERSTONE S.
R.D. B.
ORION FM.
REIDS DOME BEDS
IX ONLAP TRUNCATION
VII ONLAP TRUNCATION
VI ONLAP/OFFLAP
Vb ONLAP TRUNCATION
Va ONLAP TRUNCATION
DELTA LOBE SHIFTS
IVb ONLAP
IVa ONLAP
IIIb ONLAP TRUNCATION
IIIa ONLAP
ONLAP
WARRANILLA FM.
METEOR FM.
ROLLESTON FM.
GLENTULLOCH FM
ALDEBARAN GROUP
SERECOLD SST.
MERIVALE FM.
YELLOWBANK FM.
CATTLE CK. FM.
EDDYSTONE FM.
BASIN CK. FM.
MYRTLEVILLE BEDS
LACUSTRINE
HIGH ENERGY FLUVIAL
LOW ENERGY FLUVIAL LACUSTRINE
MARSH DELTAIC
PRODELTA
DELTAIC
ICE RAFTING
RELIC LAG DEPOSIT
HIGH ENERGY FLUVIAL
DELTAIC
MARINE ICE RAFTING
NEARSHORE MARINE / DELTAIC
? ICE RAFTING
DELTAIC ICE RAFTING
DELTAIC ?ESTURINE MARSH
FLUVIAL / MARSH
ALLUVIAL FAN
FLUVIAL / MARSH

FIGURE 3

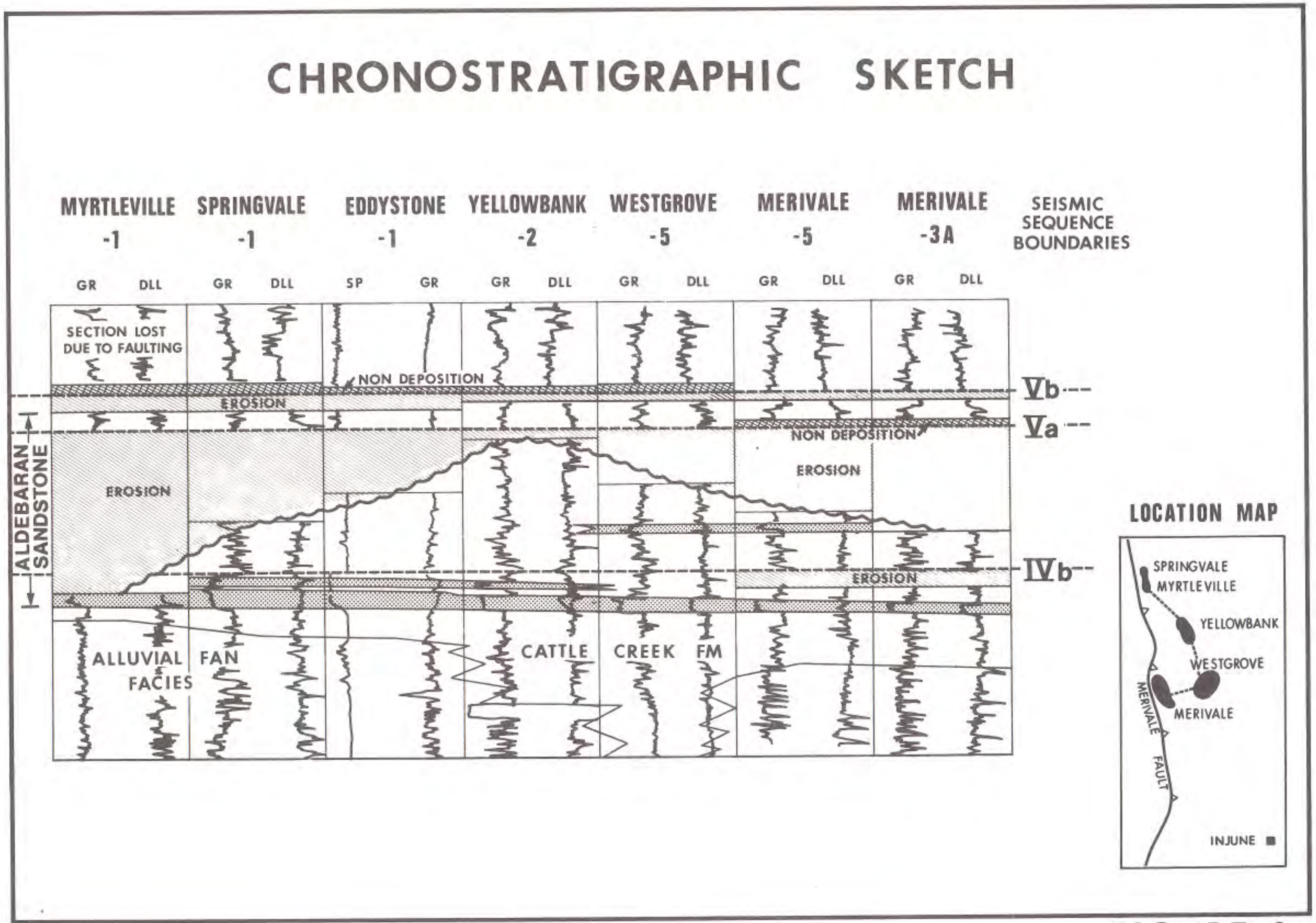

CHRONOSTRATIGRAPHIC SKETCH
MYRTLEVILLE -1
SPRINGVALE -1
EDDYSTONE -1
YELLOWBANK -2
WESTGROVE -5
MERIVALE -5
MERIVALE -3A
SEISMIC SEQUENCE BOUNDARIES
GR DLL
SP GR
SECTION LOST DUE TO FAULTING
NON DEPOSITION
EROSION
ALDEBARAN SANDSTONE
ALLUVIAL FAN FACIES
CATTLE CREEK FM
Vb
Va
IVb
LOCATION MAP
SPRINGVALE
MYRTLEVILLE
YELLOWBANK
WESTGROVE
MERIVALE
MERIVALE FAULT
INJUNE

FIGURE 4

LINE 79-K15

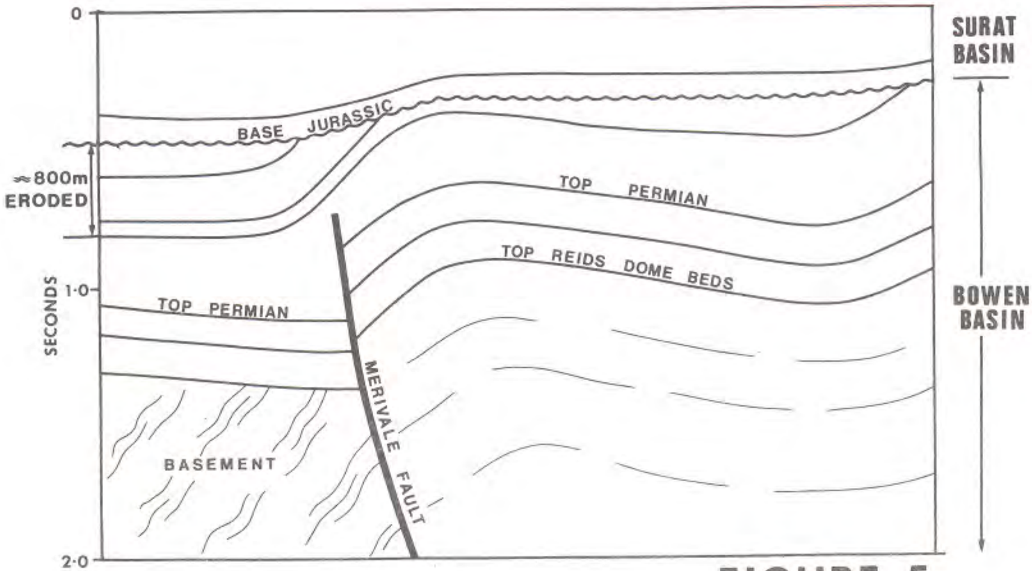


FIGURE 5

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STRATIGRAPHY OF THE NORTHERN BOWEN BASIN

J.J. Draper, Geological Survey of Queensland

The Permian and Triassic rocks of the northern Bowen Basin (Fig. 1) crop out in the Nebo Synclinorium. Summaries of the stratigraphy of the area (Table 1) can be found in Dickins & Malone (1973), Staines & Koppe (1980), and McClung (1981).

Basement rocks to the east of the northern Bowen Basin are granites of the Carboniferous to Mesozoic Urannah Complex and minor outcrops of the Devonian to Carboniferous Connors Volcanics. To the west are the Carboniferous Bulgonunna Volcanics, Carboniferous intrusions, and Devonian and Carboniferous sedimentary and volcanic rocks.

The basal unit of the Bowen Basin in this area is the Lizzie Creek Volcanics which comprise andesitic to dacitic flows and tuffs, rhyolite, agglomerate and black siltstone. There are numerous plant fossils near the top of the unit and marine fossils have also been found. The unit, which is in excess of 4000 m thick, is of early Permian age.

Marine sedimentary rocks are included in the Back Creek Group. The lowermost unit of the group is the poorly outcropping Tiverton Formation which unconformably overlies the Lizzie Creek Volcanics and is up to 700 m thick. Lithic sandstone, coquinite, calcareous sandstone and siltstone, and conglomerate at the base make up this richly fossiliferous unit of early Permian age. A conformable boundary between the Tiverton Formation and the Gebbie Formation is placed at the base of the Wall Sandstone Member and not lower as supported by some authors. The Gebbie Formation, which is up to 600 m thick comprises quartzose sandstone, lithic labile sandstone, sandy siltstone, siltstone, carbonaceous shale, calcareous sandstone and coquinite. Marine fossils are common and indicate an early Permian age. The Wall Sandstone Member at the base of the unit is quartzose sandstone; similar sandstones, with pebbles and silty beds form the Moonlight Sandstone Member at the top of the unit.

Laterally equivalent to the Gebbie Formation are the Collinsville Coal Measures which comprises upper and lower coal measure sequences separated by the burrowed Glendoo Sandstone Member which contains marine fossils. The unit unconformably overlies the Lizzie Creek Volcanics and has a maximum thickness of 250 m. Conformably overlying both the Collinsville Coal Measures and the Gebbie Formation is the Blenheim Formation of late Permian age. Micaceous siltstone (which is pebbly in places), labile sandstone, coquinite, limestone, quartzose sandstone and conglomerate form the unit. The Scottville Member, in the lower third of the unit, comprises coquinitic siltstone and mudstone, and minor sandstone. The maximum thickness of the formation is 725 m. Uppermost of the units in the Back Creek Group is the late Permian Exmoor Formation which conformably overlies the Blenheim Formation. Sandstone, siltstone, mudstone with rare marine fossils, and minor coal are present in the unit which is up to 110 m thick.

Overlying the Back Creek Group is the late Permian, non-marine, coal bearing Blackwater Group. The lowermost formation in the group is the Moranbah Coal Measures containing labile sandstone, siltstone, mudstone and coal; the unit also contains conglomerate in the east. A maximum thickness of 800 m is known for the unit which conformably overlies the Exmoor Formation and is conformably overlain by the Fort Cooper Coal Measures. The Fort Cooper Coal Measures contain lithic sandstone, conglomerate, mudstone, carbonaceous shale, coal and tuff and are up to 500 m thick. At the top of the group is the Rangal Coal Measures which are up to 220 m thick and contain calcareous sandstone, carbonaceous shale, mudstone, coal and concretionary limestone.

The Triassic Rewan and Clematis Groups and the Moolayember Formation complete the Bowen Basin sequence. The Triassic sedimentary rocks are entirely continental and include sandstone, mudstone, siltstone, conglomerates. Although tectonism occurred intermittently throughout the Permian and Triassic, a major folding episode occurred during the late Triassic. Young cover rocks include Cainozoic sediments and basalts. Intrusive rocks include the Carboniferous to Mesozoic granitic Urannah Complex and unnamed Cretaceous and Mesozoic suites; the Cretaceous suite intrudes the Permian sediments including the coal seams. Tertiary intrusives are also present.

DEPOSITIONAL HISTORY

The Lizzie Creek Volcanics were deposited in a mainly terrestrial environment in a volcanic arc. The Tiverton Formation is transgressive over the volcanics. A subsequent regressive phase resulted in deltaic to barrier and shoreline deposition in the Collinsville Coal Measures and lower Gebbie Formation. Transgression resulted in deposition of the Glendoo Sandstone Member and the middle of the Gebbie Formation; this was followed by regression and the deposition of the upper coal measures of the Collinsville Coal Measures and the upper part of the Gebbie Formation. A major transgression led to the widespread deposition of the Blenheim Formation. The last major regression in the northern Bowen Basin resulted in the deposition of the Exmoor Formation and Moranbah Coal Measure in a deltaic depositional system. The subsequent coal measure sequences (Fort Cooper and Rangal Coal Measures) were deposited under deltaic to fluviatile conditions. The Triassic rocks represent the widespread onset of purely continental fluviatile and lacustrine deposition.

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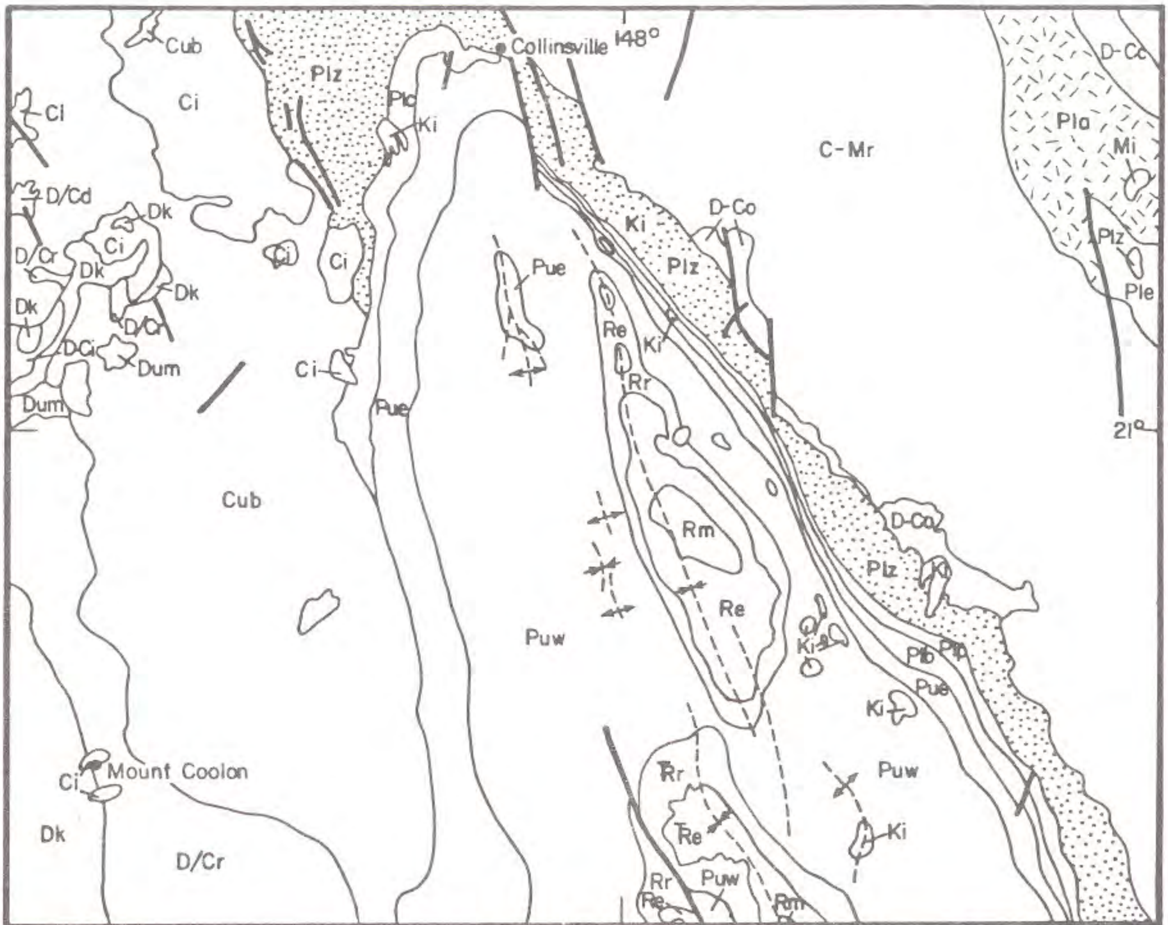
TABLE 1: STRATIGRAPHY OF THE NORTHERN BOWEN BASIN

TRIASSIC	
Moolayember Formation	Micaceous lithic sandstone, calcareous in places; micaceous siltstone; plant fossils
Clematis Group	
Expedition Sandstone	Sandstone; conglomerate; siltstone
Glenidal Formation	Sandstone; siltstone; mudstone
Rewan Group	
Arcadia Formation	Sandstone; mudstone
Sagittarius Sandstone	Red beds; sandstone; mudstone; siltstone
PERMIAN	
Blackwater Group	
Rangal Coal Measures	Calcareous sandstone; carbonaceous shale; mudstone; coal; concretionary limestone
Fort Cooper Coal Measures	Lithic sandstone; conglomerate; mudstone; carbonaceous shale; coal; cherty tuff
Moranbah Coal Measures	Labile sandstone; siltstone; mudstone; coal; conglomerate in the east
Back Creek Group	
Exmoor Formation	Sandstone; siltstone; mudstone; rare fossils
Blenheim Formation	Micaceous siltstone, pebbly in places; labile sandstone; quartzose lithic sandstone; coquinite; limestone; quartzose sandstone; conglomerate fossils
Scottville Member	Calcareous mudstone; silty sandstone; fossiliferous
Gebbie Formation	Quartzose sandstone; lithic labile sandstone; sandy siltstone; siltstone; carbonaceous shale; calcareous sandstone; coquinite; fossiliferous
Moonlight Sandstone Member	Quartzose sandstone; silty sandstone; fossiliferous
Wall Sandstone Member	Quartzose sandstone; fossils
Tiverton Formation	Lithic sandstone; coquinite; calcareous sandstone and siltstone; conglomerate; fossiliferous
Collinsville Coal Measures (≡Gebbie Formation)	Quartzose sandstone; conglomerate; siltstone; coal
Glendoo Sandstone Member	Sandstone; siltstone; fossiliferous; burrowed
Lizzie Creek Volcanics	Andesite flows, sills; crystal and lithic tuffs; agglomerate; black siltstone; fossiliferous



REFERENCE

Rm	*Moolayember Formation*
Re	*Clematis Group*
Rr	*Rewan Group*
Puw	*Blackwater Group*
Pue	*Blenheim Formation*
Plb	*Gebbie Formation*
Plc	*Collinsville Coal Measures*
Ple	*Calen Coal Measures*
Plp	*Tiverton Formation*
Plz	*Lizzie Creek Volcanics*
Pla	*Carmila beds*
Cub	*Bulgonunna Volcanics*
D/Co	*Connors Volcanics*
D/Cd	*unnamed volcanics*
D/Cr	*Mt. Rankin Formation*
D-Cc	*Campwyn beds*
Dum	*Mt. Wyatt Formation*
Dk	*Ukalunda beds*

Intrusives

Ki	*unnamed*
Mi	*unnamed*
C-Mr	*Urannah Complex*
Ci	*unnamed*
D-Ci	*unnamed*

Fault

Syncline, anticline

Town

0 10 20 30 km

(Modified after Dickins & Malone, 1972)

Figure 1 : Generalised Solid Geology map of the Northern Bowen Basin and environs.

SUMMARY OF THE PERMIAN STRATIGRAPHY OF THE BOWEN BASIN

J.J. Draper, Geological Survey of Queensland

Permian rocks of the Bowen Basin are not easily correlated and debate exists over the relationship between the various rock units. Although there are areas of good outcrop in the northern, south-eastern and south-western Bowen Basin, the remainder of the basin is obscured by Cainozoic sedimentary and volcanic rocks. Structural movements pre-, syn- and post-deposition created difficulties which are most profound in the folded zone and along the eastern margin. Suitable biostratigraphic schemes have yet to be developed; existing marine invertebrate schemes are not universally accepted. Palynological schemes suffer from a lack of subdivision in the late Permian and preservational problems preclude the universal application of palynology. Stratigraphic philosophies have differed, leading to major disagreements; Back Creek Group and Blackwater Group are widely accepted and used but attempts to utilise sub groups have been less successful.

An understanding of the relationship between rock units is essential in coal and petroleum exploration, to minimise costs and more effectively locate targets. Correlation has been facilitated in recent years by extensive coal and petroleum exploration and by stratigraphic drilling undertaken by GSQ. This activity has stimulated stratigraphic studies and provided a large store of subsurface data that can be used for correlation purposes.

Major stratigraphic summaries have been provided by Dickins & Malone (1973) and Staines & Koppe (1981) whilst McClung (1981) summarised the main bio- and lithostratigraphic schemes. A summary will also be included in the final report of the NERDDC project 'Permian Coals of Eastern Australia' being undertaken by BMR.

Many stratigraphers are preoccupied with formal definition and naming of units. This leads to be proliferation of names in local areas and tends to obscure the overall depositional picture. Given the contingencies of the original 1:250 000 mapping in the Bowen Basin it is understandable that this situation did arise; no other approach was possible at the time. From a regional or basinal view point, it is preferable to deal with depositional systems or genetic units to assist in understanding the relationship between rock units. The current situation retards a better knowledge of the depositional architecture of the basin. A depositional system approach has been used by Koppe (1978) and Draper & Balfe (1985) for parts of the Bowen Basin. Future stratigraphic studies must be aimed at understanding the broad depositional processes using biostratigraphy as a tool rather than the focus of study.

A regional correlation scheme for the Bowen Basin is given in Fig. 1. The diagram is modified from McClung (1981) and the correlations proposed are based on a variety of evidence; lithological similarity, biostratigraphy, coal seam correlation, tuffs, major transgressive and regressive sequences, and unconformities. In considering local areas, it is worth keeping in mind local tectonic effects, and variations in sedimentary style.

Major aspects of this correlation scheme, which could be considered as a preliminary deposition model, are:

(I) The occurrence of volcanic rocks at the base of all sequences. The exact age relationships between the volcanics is unknown and those in the western and central areas probably have older upper boundaries.

(II) The Reids Dome beds. These are non-marine graben-filling coal measure sequences restricted to the Denison Trough although similar sediments of similar age occur in the Arbroath and Bogong Troughs. Coal measure sedimentation continued in some areas during deposition of the first marine units.

(III) First major transgression. This is represented by the Tiverton Formation, the Cattle Creek Formation and equivalents, and the Buffel Formation which are approximate age equivalents. Within the Cattle Creek Formation several lesser transgressive and accompanying regressive phases occur.

(IV) First major regression. This is represented by the Gebbie Formation, the Aldebaran Sandstone and undifferentiated sediments. Within the Gebbie Formation and Aldebaran Sandstone there are lesser transgressions and regressions. Tectonism affected deposition in the Aldebaran Sandstone (Ziolkowski, this volume) resulting in a widespread unconformity.

(V) Slow transgression. A slow transgression followed the structural stabilisation and is represented by the lower part of the Blenheim Formation, the Freitag Formation and the Pindari, Brae and Oxtrack Formation, which represent near shore marine sequences.

(VI) Rapid transgression. The middle Blenheim, Ingelara, Maria and Barfield Formations were deposited as a result of a rapid transgression which covered the Bowen Basin and the Springsure and Roma Shelfs (lower Muggleton Formation). This transgression represents a major change in sedimentary style within the basin.

(VII) Major regression. This is represented by the upper Blenheim Formation-Exmoor Formation-lower Moranbah Coal Measures, German Creek Formation, Crocker Formation and Catherine Sandstone which lenses out in the Denison Trough. The Lorelle Sandstone Member of the Muggleton Formation may represent the regression on the Roma Shelf. Deep water sedimentation continued in the Taroom Trough.

(VIII) Transgression. This transgression was less extensive than the earlier one (VI) and coal measure deposition continued in the Moranbah Coal Measures. The MacMillan, lower Peawaddy, and upper Muggleton Formations represent this transgression.

(IX) Regression. Coal measure deposition became more widespread (Fort Cooper Coal Measure, Fair Hill Formation, Wallabella Coal Member of the Tinowan Formation and within the Flat Top Formation) although marine and marginal marine continued in the upper Peawaddy Formation (including 'Mantuan Formation' (Elliot, this volume)), the Tinowon and Flat Top Formations. This regressive phase coincides with the onset of major tuff deposition.

(X) Final transgression. The final transgression is marked in the Roma Shelf and Denison Trough area by the conquinitic Mantuan Productus bed and the P3c acritarch Swarm (Micchystridium evansii Acme zone). The Black Alley Shale is the final marine or restricted marine phase and passes laterally into the deltaic Burngrove Formation. On the Roma Shelf coal measure deposits are present within the Black Alley Shale (Winnathoola Member). The relationship between the non-marine Gyranda Formation and Black Alley Shale is uncertain.

(XI) Final Regression. Deltaic and fluviatile coal measure sequences (Rangal Coal Measures, Bandanna Formation and Baralaba Coal Measures) represent the culmination of coal measure sedimentation in the basin.

(XII) Continental basin. Overlying the Coal Measures are the fluviatile and lacustrine rocks of the Rewan Group, Clematis Group and Moolayember Formation. These Triassic sequences represent another major change in sedimentary style in the Bowen Basin.

(XIII) Major folding. Although tectonism continued throughout deposition of the Bowen Basin sequence, the present configuration of the basin resulted from a late Triassic folding event. Subsequently, the southern part of the basin was obscured by Surat Basin rocks and most of the remainder by Cainozoic rocks and soil.

The preliminary depositional model for the basin presented here will require refinement. To develop a detailed model of the basin a lot more study is required in a number of critical areas. Firstly detailed local and regional depositional models are required. Secondly, the shape and distribution of rock units must be better understood. Thirdly, further elucidation of the structure of the basin in terms of basin geometry, tectonic history, and the inter-relationship between deposition and tectonism is needed. Fourthly, reliable biostratigraphy and chronostratigraphy are necessary to place the various rock units and depositional systems into a coherent frame-work. In the area of invertebrate palaeontology, systematic description and documentation of the fossils and a better understanding of ranges and effect of facies are urgently required. A multi-disciplinary approach using interrelated criteria will provide the sole means of deciphering the history of the basin and providing a useful depositional model.

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EXMOOR AREA	COMET PLATFORM	DENISON TROUGH	ROMA SHELF	THEODORE AREA
Rewan Group				
Rangal Coal Measures		Bandanna Formation		Baralaba Coal Measures
Fort Cooper Coal Measures	Burngrove Formation	Black Alley Shale		Gyranda Formation
	Fair Hill Formation	Peawaddy Formation (upper) (Mantuan Formation)	Tinowon Formation	Flat Top Formation
Moranbah Coal Measures	Mac Millan Formation	Peawaddy Formation (lower)	Muggleton Formation	Barfield Formation
Exmoor Formation	German Creek Formation / Crocker Formation	Crocker Formation / Catherine Sandstone		
Blenheim Formation	Maria Formation	Ingelara Formation	? ?	
	undifferentiated	Freitag Formation		Oxtrack Formation
Gebbie Formation		Aldebaran Formation		Brae Formation
				Pindari Formation
Tiverton Formation	Blair Athol Coal Measures and Cattle Creek Formation equivalents	Cattle Creek Formation		Buffel Formation
? ?	? ?		? ?	? ?
Lizzie Creek Volcanics	? ? volcanics	Reids Dome beds ? ? volcanics	Combarngo Volcanics	Camboon Volcanics

Table 1. Proposed regional correlation for rock units in the Bowen Basin (modified after McClung, 1981)

COAL MEASURE DEPOSITION

THE REIDS DOME BEDS - CAPELLA, CENTRAL QUEENSLAND

S.J. Edenborough, Pacific Coal Pty Limited

The Reids Dome Beds in the Capella area occur at the northern end of the Denison Trough, 30 km southwest of Capella, Central Queensland. Coal exploration commenced in 1968 and field programs have been carried out at regular intervals to the present.

The Reids Dome Beds, consisting of a sequence of non-marine sandstones, siltstones, conglomerate and coal, form the basal sequence of the early Permian in the Denison Trough. The estimated maximum thickness is in the order of 3600 m in the Westgrove area. The unit was deposited in a series of grabens and half grabens within a closed basin but was subsequently influenced by marine transgression (Draper and Beeston, 1985). Palynological data suggest that sedimentation of coal bearing lithological equivalents of the Reids Dome Beds continued in places, whereas the Cattle Creek Formation was being deposited in areas under the influence of the marine transgression.

In the Capella area a sequence of non-marine, coal bearing, predominantly arenaceous sediments overlying pre-Permian metamorphic and igneous rocks have been equated with the Reids Dome Beds (Fig.1). These sediments appear to be fault bounded against basement rocks to the west and in part to the northeast. A narrow zone containing Reids Dome Beds continues to the north to at least the Wolfang area.

The stratigraphy of the Reids Dome Beds at Capella has been described by Wilson (1975). A lower sequence of clastic sediments fining upwards (Lower Coal Measures) is overlain by a monotonous sequence of siltstone, mudstone and some fine sandstone (Barren Unit). The Barren Unit passes conformably up into the Upper Coal Measures consisting of sandstone, siltstone, conglomerate and coal seams. Wilson subdivided the Reids Dome Beds into an upper and lower unit based on palynology and the apparent confinement of coking coals to the lower portion of the unit. Current interpretation does not support the subdivision and the "Upper Reids Dome Beds" are regarded as the upper part of the Upper Coal Measures (Table 1).

The coal seams in the Upper Coal Measures are predominantly thin but in isolated areas coalescence and seam thickening have permitted extremely banded coal accumulations of up to 36 metres to have been deposited. The current seam nomenclature is shown in Table 2.

To the southeast the Reids Dome Beds are overlain by sediments which, on lithological grounds, have been equated with the Aldebaran Sandstone. The basal portion of the Aldebaran Sandstone is bioturbated and contains rare polyzoa and possibly some shell fragments.

In general, within the Reids Dome Beds spore assemblages are sparse, lack diversity and are poorly preserved. The presence of certain forms and the general character of assemblages have indicated that the majority of samples may only be regarded as no older than Stage 3. The occurrence of Granulatisporites trisinus is generally restricted to the upper portion of the sequence where in some samples the spore preservation has been referred to as fair to good however Granulatisporites trisinus has been recorded in one sample immediately above the Anakie Seam.

The coal quality data presented in Table 3 indicate that the three lower seams have strong caking properties whilst the succeeding seams show a decrease in caking properties. High swells are recorded for some plies within the basal portion of the Capella Seam where the seam is more fully developed. Limited reflectance measurements indicate a slight increase in rank down the sequence which is reflected in the moisture, carbon and oxygen contents however the increase in volatile matter is not as expected. Maceral analyses show an overall increase in vitrinite content with depth whilst the exinite content remains fairly constant. Ultimate analyses indicate that the coal generally occurs within Seylers normal coal band straddling the metalignitous - parabituminous boundary.

The Reids Dome Beds were deposited under deltaic conditions confined by highlands on the west and northeast. Complex half graben structures confined the deposition of the sediments northwards to at least the Wolfang area. Contemporaneous movement on faults restricted thick sedimentation with overlap onto basement in places. The Barren Unit probably represents a type of prodelta environment with the more clastic sediments being deposited in the higher reaches. The prograding delta allowed the deposition of relatively widespread continuous seams in the lower portion of the Upper Coal Measures. The encroaching more fluvial environment caused changes in vegetation and coal swamp environments. Water table fluctuations probably caused more oxidation of the peats resulting in the vertical increase in inertinite content. Thick fan deposits interfinger along the western margin and possibly in the east. Figure 2 is a diagrammatic cross-section of the area depicting the distribution of the gross depositional environments. The interplay of tectonically unstable conditions, the restriction of the depositional area by highlands and the prograding more fluviatile conditions have given rise to the juxtaposition of a number of coal forming environments.

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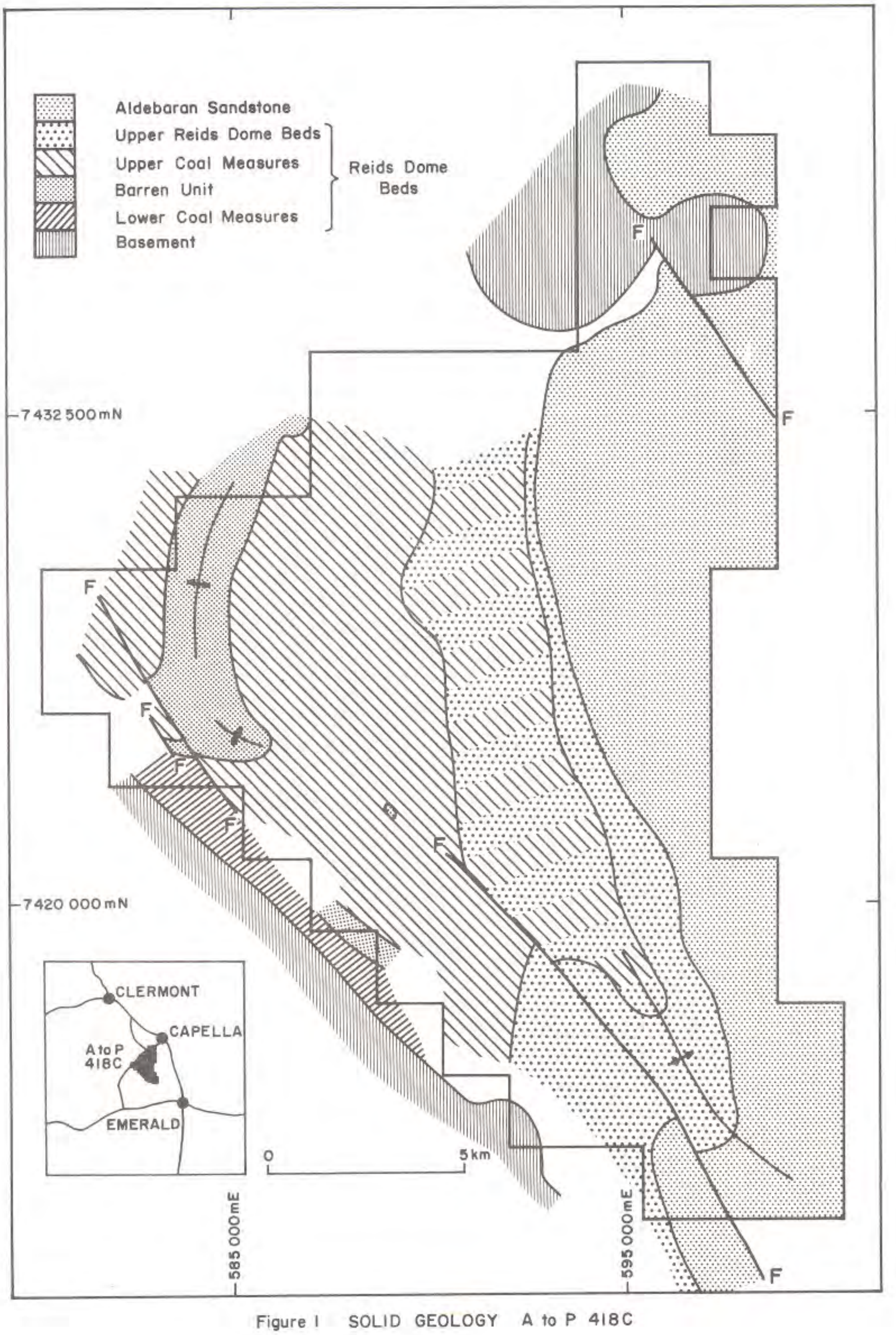

Figure 1 SOLID GEOLOGY A to P 418C

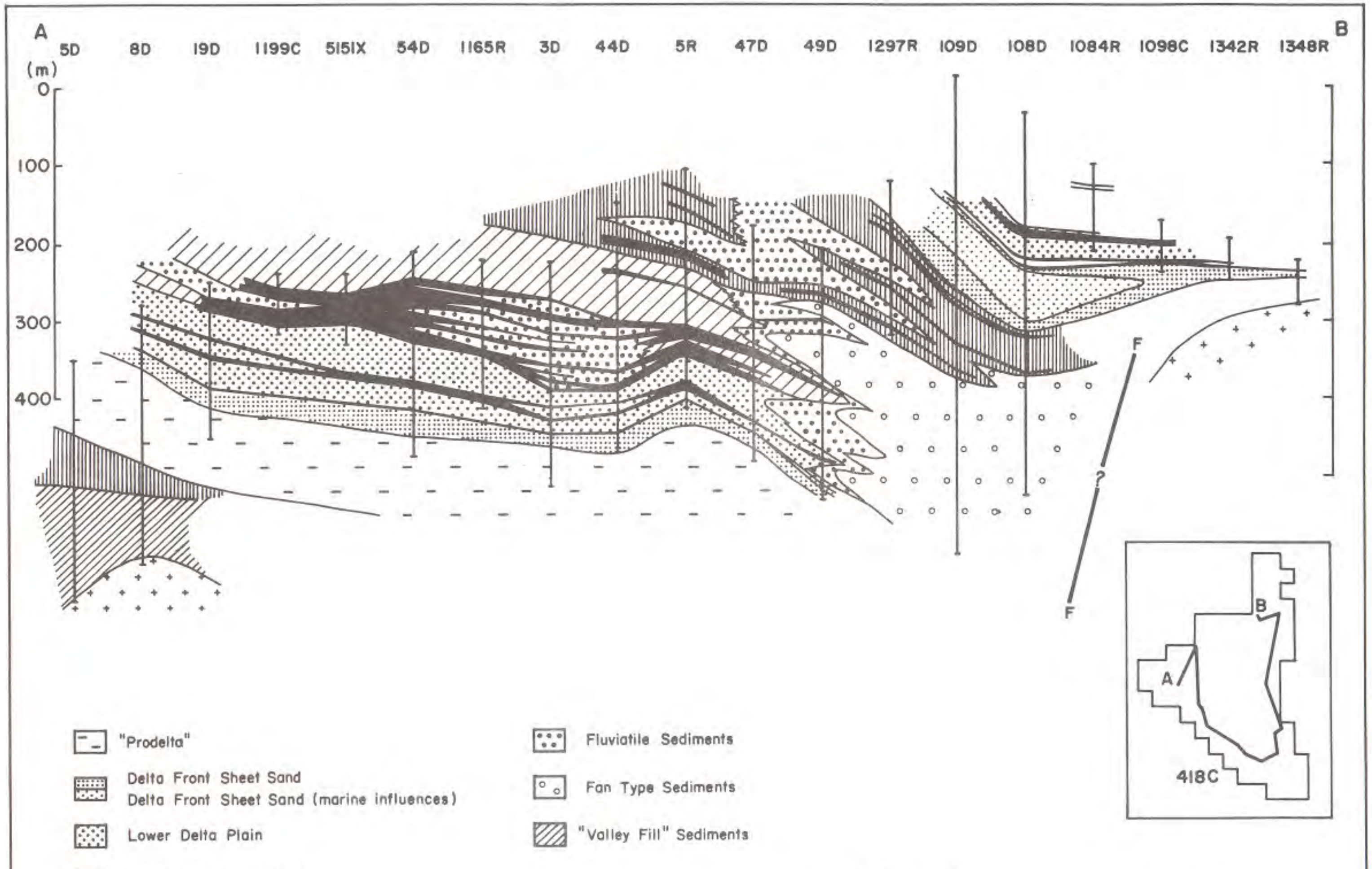

Figure 2

A to P 418C INTERPRETED GROSS DEPOSITIONAL ENVIRONMENTS

TABLE 1

STRATIGRAPHIC UNITS			
UNIT			THICKNESS (m)
ALDEBARAN SANDSTONE			305+
REIDS DOME BEDS		UPPER REIDS DOME BEDS	(200)
	UPPER COAL MEASURES		500+
	BARREN UNIT		60–140
	LOWER COAL MEASURES		208+

TABLE 2

CURRENT SEAM NOMENCLATURE		
STRATIGRAPHIC UNIT	SEAM NOMENCLATURE	
	CURRENT	WILSON (1975)
ALDEBARAN SANDSTONE	THERESA	J
	CARBINE	K
REIDS DOME BEDS	LA POULE	M
	BURN	N
	KETTLE	O
	SELMA	P
	SLATEFORD	E
	CAPELLA	D, E Split
	LLANDILLO	C
	GARDNER	B
	ANAKIE	A

TABLE 3

COAL QUALITY DATA - CAPELLA AREA

SEAM	SAMPLE TYPE	AIR DRIED		DRY ASH FREE				$\bar{R}o$ max	VITRINITE	EXINITE	INERTINITE
		MOIST %	CSN	C %	H %	O %	VM %	%	%	%	%
THERESA	COMPOSITE	4·6	1	82·42	5·36	9·49	39·1	0·66–0·70	49	11	40
CARBINE	COMPOSITE	5·6	1	82·63	5·21	8·96	37·5	0·66–0·74	49	8	43
LA POULE	F2·00	4·5	1	81·98	5·10	10·59	37·8	0·77	45	6	49
BURN	F2·00	4·2	1	82·50	5·35	9·36	37·3	0·77	45	6	49
KETTLE	F2·00	3·1	½	82·13	5·83	8·50	40·5	~ 0·76	53	11	36
SELMA	F1·50	2·8	2						57	7	36
CAPELLA 1-4	F1·5–2·0	3·9	2	83·49	5·42	8·38	37·7	0·72–0·74	61	9	30
CAPELLA 5-6	F1·5–1·8	4·0	3½	83·73	5·29	8·26	38·1	0·75–0·76	62	9	29
LLANDILLO	F1·50	2·2	7				40·1		70	8	22
LLANDILLO - GARDNER								0·75	67	7	26
GARDNER	F1·50	2·2	7				40·4		64	9	27
ANAKIE	F1·50	2·2	7½				41·4	0·77	68	7	25

THE BLAIR ATHOL COAL MEASURES

K.B. Preston, Pacific Coal Pty Limited

RECENT EXPLORATION

Accumulated knowledge from exploration programs carried out up to 1970 was documented by Osman & Wilson in 1975. Exploration of the coalfield was accelerated in 1979 and with the exception of one year, exploration programs have been carried out annually since. Virtually all of the five hundred and thirty-five holes drilled in this period have been geophysically logged and this has facilitated a better understanding of the disposition of the coal measures.

GEOLOGICAL SETTING

The Blair Athol Coal Measures exist as a semi-isolated remnant of Permian sedimentation preserved on the western margin of the Bowen Basin. Recent work has shown that the Blair Athol Basin which contains the coal measures, is one of a number of intracratonic basins occurring within the Clermont Stable Block.

STRATIGRAPHY

Historically the term Blair Athol Coal Measures has been restricted to describing all sediments within the Blair Athol Basin, younger than the Anakie Metamorphics but excluding all Cainozoic deposits. However coal measure sediments of similar age are now known to exist in other sedimentary basins nearby, although the term may not yet have been extended to include these. No type section exists as such. Instead a composite type section based on borehole intersections and exposures in the opencuts is proposed (Fig.1).

For descriptive purposes it is convenient to divide the measures into an upper and a lower section.

Lower Coal Measures (Basal Conglomerate)

This sequence comprises a suite of coarse grained, well indurated conglomerates and sandstones with interspersed carbonaceous shales and minor dirty coal seams. The maximum recorded thickness of this sequence is, at 116 metres, slightly less than the estimated typical thickness of 130-150 metres.

The upper boundary of the conglomeratic sequence is transitional, with some interfingering between the lower coal seams and associated sediments. The lower boundary is of course unconformable on the early Paleozoic Anakie Metamorphics. No palynological dating has been carried out; however dating of similar sediments in the Karin and Wolfang Basins indicates an age of Stage 3 to Lower Stage 4, i.e. early Permian.

It has been suggested that the conglomeratic sequence is of glacial origin. None of the recent investigations carried out at Blair Athol either suggest or support this view.

Upper Coal Measures

The upper part of the coal measures is predominated by sandstones, siltstones and coal, together with minor mudstones and shales. Maximum preserved thickness is around 100 metres, or which up to 43 metres may be coal.

Mineralogical composition is consistent throughout the range of lithologies and similar to that of the lower coal measures. Quartz is the dominant mineral accompanied by a lesser proportion of metamorphic rock fragments, set in a carbonaceous clay matrix.

Palynological dating has indicated a stratigraphic position for the upper part of the coal measures, equivalent to Upper Stage 4a.

Four coal seams are recognised within the sequence, namely the No. 1 Seam (Upper), No. 2 Seam (Top), No. 3 Seam (Big) and No. 4 Seam (Bottom).

The No. 1 Seam is lenticular in character and known to occur in only two discrete locations. The lenticular character is considered to be largely an intrinsic feature although modified in part by post depositional oxidation. Maximum known thickness is 7 metres. The coal is interbanded bright and dull.

The No. 2 Seam exhibits a greater lateral persistance, commensurate with its lower stratigraphic position. Its normal form is that of a thicker upper split (1.0-1.5 m) and thin (0.2-0.6 m) lower split. The coal is similar to No. 1 Seam coal, being generally interbanded bright and dull.

The No. 3 Seam is known for its remarkable seam thickness and lateral uniformity. The extraordinary thickness is most fully developed and preserved over the southwestern and central parts of the field, where a range of between 29 and 33 metres is maintained. Here the seam can be regarded as having attained its maximum natural thickness.

Seam thinning occurs outside this zone of maximum thickness. Some natural thinning is recognised, through formation of less coal either in the basal part of the seam (to the north) or throughout the entire seam interval (eastern margin). However the seam virtually never pinches out. In situ oxidation of the upper part of the seam and reduction of the coal to soot is by far the most important seam thinning process. Erosion of the seam roof has not been observed.

Physically the No. 3 Seam has an overall distinctive uniform appearance, i.e. dull, massive and free of mineral matter. Detailed lithotype logging has shown relatively brighter sections at the top and base. An unusual feature is the frequent occurrence of fusain bands, from a few centimetres to 15 centimetres thick. Stone bands are absent from the upper 20 metres of the seam although a thin high ash section is evident, 7 metres from the seam roof. Five thin stone bands occur in the lowermost 8.0-11.0 metres and these are notable geophysical markers (Fig.1).

The No. 4 Seam occurs between 2 and 12 metres below the No. 3 Seam and by virtue of its lower stratigraphic position, it persists outside the No. 3 Seam edge. It is not related or connected to the No. 3 Seam as was suggested by Osman & Wilson. An unsplit No. 4 Seam of around 5 metres thickness occurs in the south of the coalfield. It splits to the northwest and southeast, into an upper split of 3 metres and a lower split of 1.2 metres. The upper split persists to the north where it deteriorates and dies out. In most respects the No. 4 Seam coal is similar to the No. 3 Seam, except that it is stonier.

The upper part of the coal measure sequence has been weathered to a distinctive off white colour. It is unfortunate that the term "White Section" has been used to describe this sequence, as it implies that it is a stratigraphic unit, distinct from the rest of the coal measures. It has also been suggested that there is an unconformable contact between the "White Section" and the fresh coal measures. In 1978 Beeston demonstrated a Permian age for this sequence. Recent exploration work has shown conclusively that the "White Section" is simply the oxidised section of the coal measures and that there is no unconformity, or need for one. It is proposed that the use of the term "White Section" be discontinued.

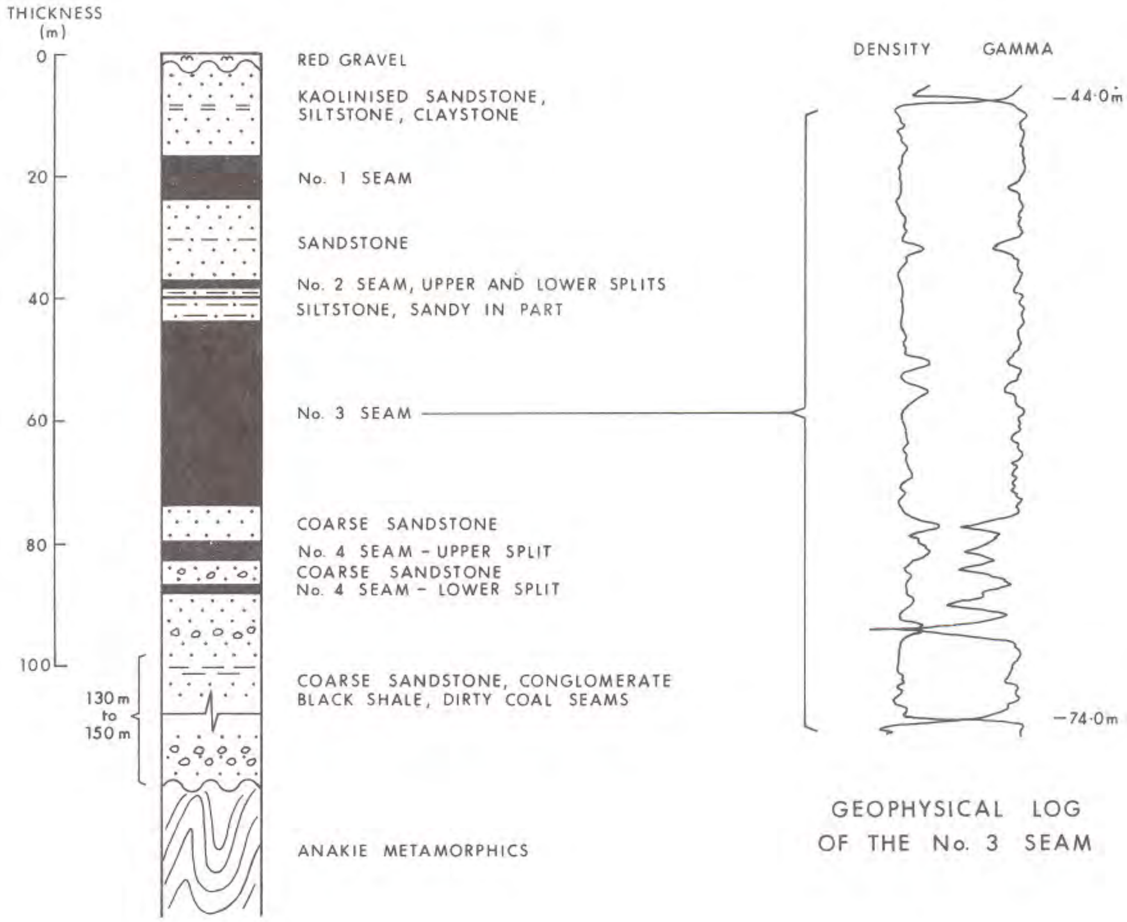

FIGURE 1 COMPOSITE SECTION OF THE BLAIR ATHOL COAL MEASURES

STRUCTURE

The basin is an irregular oval in shape with slight elongation north-south. It is considered that coal was deposited conformably within the margins of the basin, such that the structural configuration of the seam reflects to a large extent the shape of the basin floor (Fig.2).

Within the central part of the basin the sediments and coal seams are draped over undulating basement topography and overall are relatively flat lying (1^0-2^0). However local variability of seam dip is common. This undulation is attributed to contemporaneous deformation particularly differential compaction. Rates of subsidence and compaction over basement highs or conglomeratic pods would have been quite different from that over fine soft sediments. It is also evident that the basin floor was itself subsiding and contributing to the folding.

On the margin of the basin, seam dips rise. Along the western and southwestern margin the average dip is 5^0-7^0, indicating a sharply rising basement surface under rapidly thinning Permian sediments. Along the eastern margin the rise is more gradual at 2^0-3^0. Two basement highs occur on the eastern and southeastern margin. One has had considerable local influence on seam disposition and is the cause of a coal want in this area.

Minor faulting, generally of a reverse nature, has been described from the underground workings. Recently a large reverse fault has been identified on the western margin. It strikes at 315^0, virtually perpendicular to the basin margin.

DEPOSITIONAL HISTORY

At some time in the early Permian (Stage 3-Lower 4a) the Blair Athol Basin and several other semi isolated basinal structures developed on what was otherwise an essentially stable shelf area. This development is believed to be related to the formation and evolution of the Denison Trough, particularly the basement fault zone suggested by Dickens & Malone (1973). The Blair Athol Basin together with its known neighbours, developed in an area which straddles a postulated northwesterly extension of this basement fault zone.

Sediment and later coal accumulation in these structures was the result of active subsidence of small sections of the basement floor; not by infilling of deep topographic depressions. At Blair Athol there is no evidence of active faulting on the margins and certainly the basin shape is not consistent with that of a graben or half graben. The Blair Athol Basin is believed to have formed through buckling of the basement floor by compressional stresses acting in a general east-west direction. Downwarping rather than upwarping was ensured by the pre-existence of a topographic depression.

Subsidence and deposition was initially rapid and resulted in partial infilling by conglomeratic material. A slowing down of this activity saw the deposition of finer sediments and formation of some coal swamps on the basin margins. These were of limited extent. An improvement in conditions brought about the formation of the No. 4 Seam, both on a shelf to the south and in the more active central part of the basin.

Further subsidence and sedimentation occurred, prior to the onset of a long period in which virtually ideal conditions for coal formation prevailed. In this period the No. 3 Seam developed. Petrographic characteristics of the coal suggest the predominance of herbaceous plants, ferns and algal material, and that frequent imbalances between accumulation and burial occurred.

Smyth (1980) suggested that the No. 3 Seam formed as a raised bog. This assumes that coal accumulated over a stable basement and infilled a deep topographic depression. However this is inconsistent with the current knowledge of the deposit; evidence supports formation and draping over a subsiding basement, rather than static accumulation within a deep depression.

As subsidence and sedimentation continued the seams began to assume a shape similar to that which they now have, i.e. a relatively flat shelf area, a steep marginal zone and a main zone of deposition in the basin centre.

How long sedimentation continued in the basin after coal formation is not known. However in the Moorlands Basin to the west, flora of upper Stage 5a & 5b have been reported. This equates to late Early Permian to Middle Permian and it is reasonable to expect that sedimentation continued at Blair Athol until that time. Certainly it is necessary to explain the rank that the coal has developed and this requires considerably greater depth of burial than is presently evident. Sedimentation in the Bowen Basin was terminated by regional uplift in the Triassic. This was followed by the onset of erosion which continued throughout the Mesozoic and effectively removed a large proportion of the strata overlying the coal.

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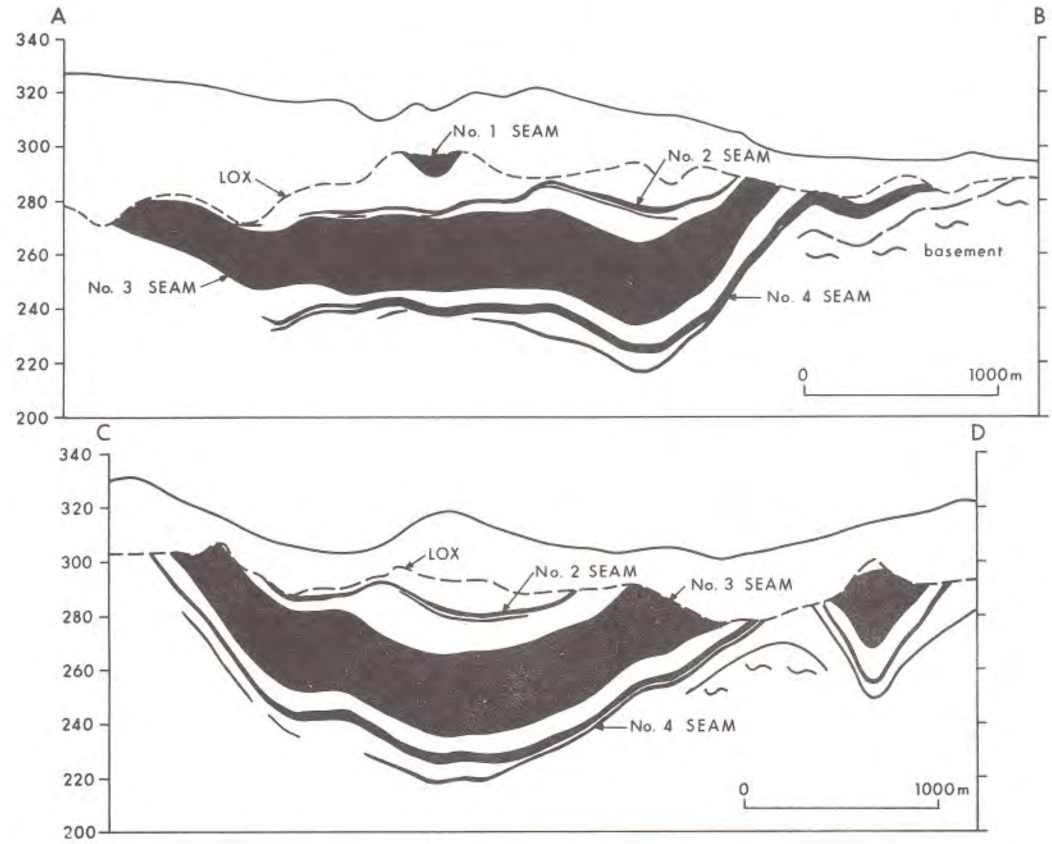


FIGURE 2 BLAIR ATHOL COALFIELD – CROSS SECTIONS A-B AND C-D

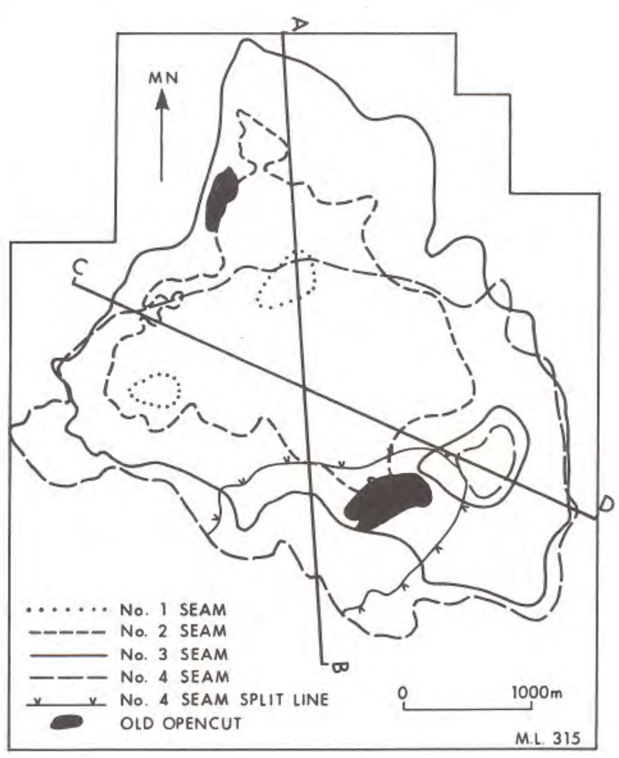


FIGURE 3 BLAIR ATHOL COALFIELD – COAL SEAM DISTRIBUTION MAP

GEOLOGY OF THE COLLINSVILLE COAL MEASURES

R. Clare, M.I.M. Holdings Limited - Coal Technical Services

STRATIGRAPHY

The Lower Permian Collinsville Coal Measures occupy the northern extremity of the Bowen Basin. They are underlain by the Crush Creek Coal Measures which are intercalated with the top of the Lizzie Creek Volcanics. The Lizzie Creek Volcanics mark the onset of deposition in this part of the Bowen Basin. The marine Blenheim Formation overlies the Collinsville Coal Measures and together they constitute the Back Creek Group.

The coal measures grade rapidly to the south into paralic sediments. Coal seams thin and shale out and along the western margin of the basin become increasingly intruded.

The coal measures consist of upper and lower members separated by the marine Glendoo Sandstone. The lower member contains six coal seams and the upper member three coal seams. These are illustrated in Fig. 1.

STRUCTURE

The location of the coal measures on the orogenic margin of the basin has resulted in a relatively high degree of deformation which is manifested in the frequency of thrust faulting, high rank of the coal and widespread igneous intrusions.

COAL SEAMS

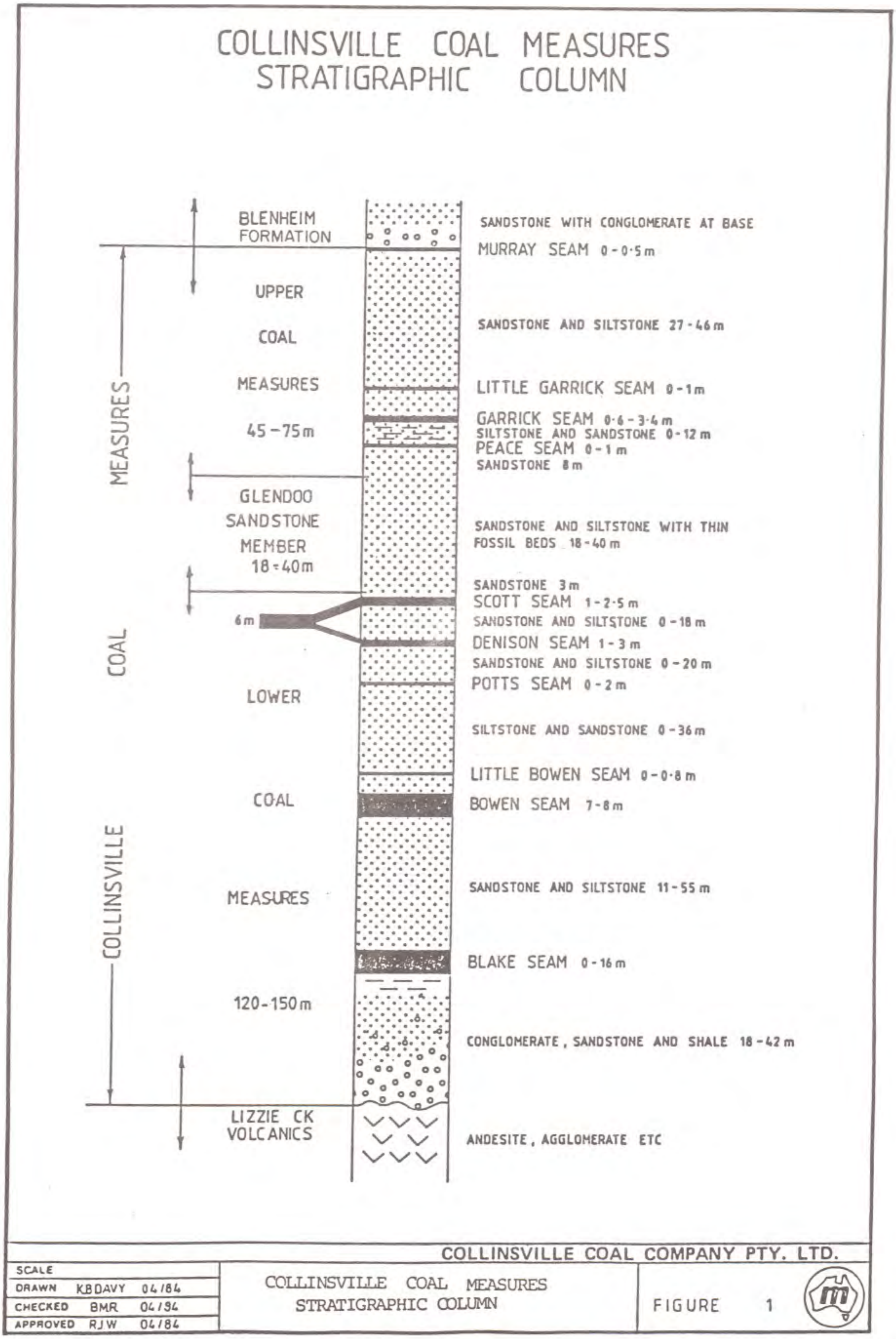
The principal commercial seams are the Garrick, Scott, Denison, Bowen and Blake seams. Coal in general is low ash, medium volatile bituminous.

The Garrick, Scott and Denison seams are mined for export coking coal. The Bowen and Blake seam coals are lower in volatiles. The Bowen seam is mined for both steaming and coking purposes. The Blake seam contains steaming coal only, being duller and of higher ash than the Bowen seam.

INTRUSIONS

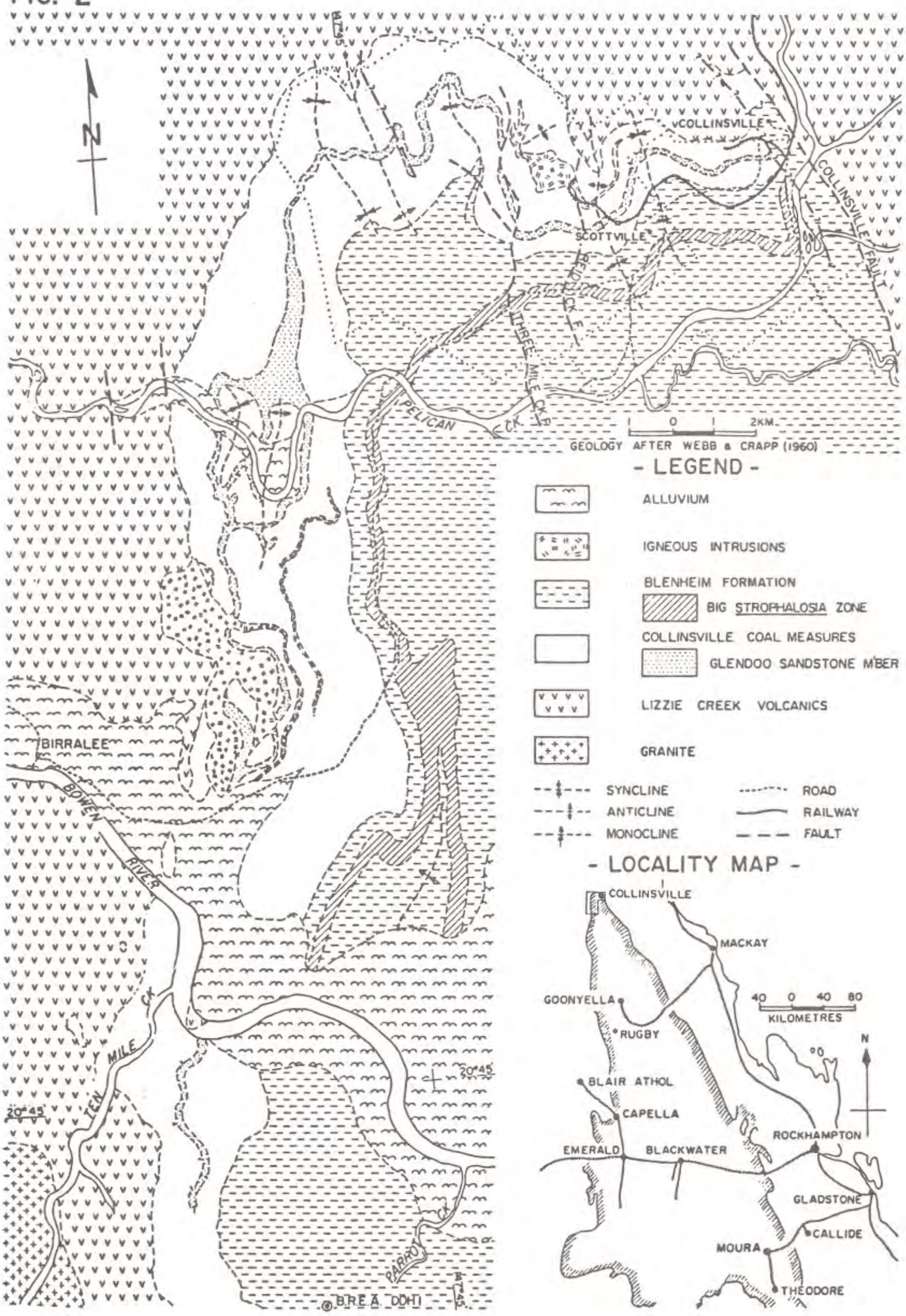
Feldspar porphyry sills invade each seam. Insitu coking is extensive and in some areas seams are entirely assimilated.

In the underground mines seam gas is primarily CO_2 which is considered to be intrusive induced. Excessive CO_2 in sheared areas has resulted in outburst conditions.


COLLINSVILLE COAL MEASURES
STRATIGRAPHIC COLUMN
BLENHEIM FORMATION
SANDSTONE WITH CONGLOMERATE AT BASE
MURRAY SEAM 0-0·5 m
UPPER COAL MEASURES 45-75 m
SANDSTONE AND SILTSTONE 27-46 m
LITTLE GARRICK SEAM 0-1 m
GARRICK SEAM 0·6-3·4 m
SILTSTONE AND SANDSTONE 0-12 m
PEACE SEAM 0-1 m
SANDSTONE 8 m
GLENDOO SANDSTONE MEMBER 18-40 m
SANDSTONE AND SILTSTONE WITH THIN FOSSIL BEDS 18-40 m
SANDSTONE 3 m
SCOTT SEAM 1-2·5 m
6 m
SANDSTONE AND SILTSTONE 0-18 m
DENISON SEAM 1-3 m
SANDSTONE AND SILTSTONE 0-20 m
POTTS SEAM 0-2 m
LOWER COAL MEASURES 120-150 m
SILTSTONE AND SANDSTONE 0-36 m
LITTLE BOWEN SEAM 0-0·8 m
BOWEN SEAM 7-8 m
SANDSTONE AND SILTSTONE 11-55 m
BLAKE SEAM 0-16 m
CONGLOMERATE, SANDSTONE AND SHALE 18-42 m
COLLINSVILLE COAL MEASURES
LIZZIE CK VOLCANICS
ANDESITE, AGGLOMERATE ETC
COLLINSVILLE COAL COMPANY PTY. LTD.
SCALE
DRAWN KBDAVY 04/84
CHECKED BMR 04/94
APPROVED RJW 04/84
COLLINSVILLE COAL MEASURES STRATIGRAPHIC COLUMN
FIGURE 1

GEOLOGICAL MAP COLLINSVILLE AREA

FIG. 2



THE COLLINSVILLE COAL MEASURES: DEPOSITIONAL SYSTEMS

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INTRODUCTION

The Middle Permian Collinsville Coal Measures of the northern Bowen Basin illustrate a range of cold-climate, fluvial-paralic coal-forming environments. These coal measures are of limited extent and were deposited while most of the Bowen Basin experienced marine sedimentation (Back Creek Group). The Coal Measures overlie the Lower Permian Lizzie Creek Volcanics, and are overlain by the Blenheim Formation of the Back Creek Group, the Gebbie Formation.

SEDIMENTARY SEQUENCES

The Collinsville Coal Measures contain three units (Webb and Crapp, 1960). The middle unit, Glendoo Sandstone Member has been formally defined, while the upper and lower Collinsville Coal Measures remain informal members. The Coal Measures pass laterally into a much thicker section of Gebbie Formation at Gebbie Creek (Fig. 1). Along the northeastern margin of the Bowen Basin there is a prominent quartzose sandstone, the Wall Sandstone Member, which lies at the base of the Gebbie Formation. Martini and Johnson (in prep.) have recognised six distinct sedimentary sequences which are interpreted as forming in the following settings: fluvial, fluvio-paralic, barrier-strandplain, back-barrier, tidal flats and open marine.

Fluvial

Fluvial sequences contain organised pebble conglomerates and medium to coarse, quartzose lithic sandstone, such as at the base of the Collinsville Coal Measures. Conglomerates have subrounded to subangular pebbles, primarily of volcanics and quartzites, and a coarse sandy matrix. Locally there are concentrations of coalified wood. The conglomerates grade upward and interfinger with poorly sorted coarse to very coarse pebbly sandstones. This sequence below the Blake Seam is characterised by thin (0.3-0.7m) units of plane-bedded conglomerate and pebbly sandstone. The part above the Blake Seam is more sandy and contains repeated units with medium to large-scale cross-bedding and planar beds separated by thin layers of fine sandstone and siltstone. Upward-fining cycles, 1-2m thick, occur and show a transition from massive to plane beds at the base to cross-beds and ripple cross-lamination at the top. Erosional contacts occur, with cut and fills range from small intrastratal scours to channels several meters deep and tens of metres wide. Rare Glossopteris leaves occur in fine sediments and bioturbation by roots is locally developed.

The environment of deposition is interpreted as fluvial with wide, shallow, low sinuosity braided channels. The lower gravelly portion probably formed as sheet or longitudinal bars: whereas the upper part suggests development of transverse bars.

Fluvio-Paralic

Fluvio-paralic sequences comprise complex interstratification of medium to coarse, lithic sandstone intervals, laminated sandy silty sandstones and shales. Thin conglomeratic layers occur. The Bowen-Potts interval displays the characteristics of this sequence. In some places, thin lenses of laminated, non-bioturbated shales and siltstones lie directly on top of the Bowen Seam. These shales are cut in part by channellised coarse sandstones containing penecontemporaneous slump structures. Channellised sandstones locally incise the coal, particularly in the eastern area of the coalfield. In northern, open cut exposures, the top interval of the fluvio-paralic sequence is a sandy siltstone containing lenticular sandstone interbeds. In downdip, southeastern parts of the coalfield, an upward-coarsening, well-sorted, quartz sandstone sequence (Potts sandstone) is developed immediately under the Potts seam.

The sequence in the Bowen-Potts interval, and similar sequences just below the Bowen Seam and in some of the Garrick-Murray interval, were probably formed along river-dominated coasts (perhaps lower deltaic plain), periodically reworked by tidal, brackish waters. Unbioturbated shales indicate small temporary freshwater lakes formed over the peatland, but no deep bay existed. Elsewhere the horizontally-bedded sandstones formed as fluvial splays, perhaps affected by tidal waters. As the fluvial channellised belt migrated onto this area pre-existing deposits were deeply incised. The channellised sandstones were deposited in slightly-meandering coastal streams. To the north the sandstones are overlain by floodplain deposits, while to the south they are overlain by quartz sandstones formed in coastal barrier setting.

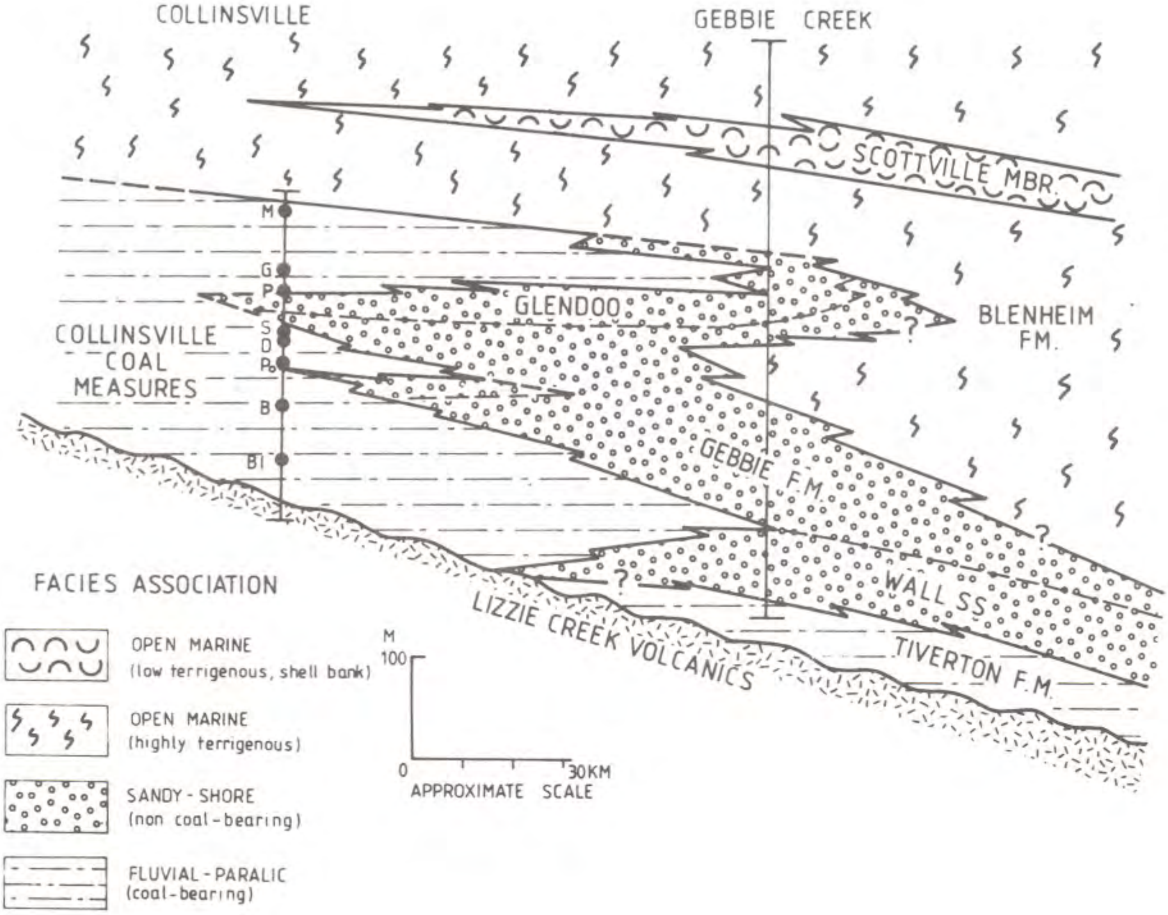

Figure 1. Proposed lithofacies model relating the Collinsville Coal Measures, and the Gebbie and Blenheim Formations. Seams within the Coal Measures initialled as follows: Blake (Bl), Bowen (B), Potts (Po), Denison (D), Scott (S), Peace (P), Garrick (G) and Murray (M).

Barrier-Strandplain

Barrier-strandplain sequences occurring in the Collinsville Coal Measures and the Gebbie Formation are typically thick (12-20m), upward-coarsening, composite sandstone bodies. Some sequences are known locally as the Potts and Peace sandstones, and the Wall Sandstone Member. The main part of these sequences is fine to very coarse, quartz sandstone, and some sections contain thin, pebble layers, micaceous partings, and thin laminated silty, carbonaceous units. Sedimentary structures are dominantly undulose plane beds to low angle cross-beds. Sinuous ripple marks and cross-lamination are present but not common. Low and high angle accretionary surfaces and herringbone cross-beds occur near the top of the Wall Sandstone Member. Single, vertical burrows occur at several horizons, but shelly fossils are rare. Rootlets may be present especially at the top.

The Glendoo Sandstone Member is a complex unit, the uppermost part of which is a winnowed, quartzose sandstone (Peace sandstone) overlying a 20m thick interval of fine to medium quartz sandstones, locally bioturbated and fossiliferous, generally with massive to plane beds, and local cut and fills. The middle part of the Glendoo Sandstone Member is generally a thick (7-10m) unit of fine to medium sandstone which shows recurring cycles (0.5-1.0m thick) characterised by a basal, very coarse sandstone or pebble layer (one clast thick), overlain by well-sorted fine sandstone showing horizontal or very low angle plane beds. Traces of shells are present. The lowermost part of the Glendoo Sandstone Member is characterised by fine sandstone, showing pervasive ripple cross-lamination with local flaser and irregular wavy bedding.

These sequences are interpreted as shoaling upward, prograding sandy shorelines. Some developed complete barriers and back-barrier differentiation (Wall Sandstone Member), while others maintained strandplain form (Glendoo Sandstone Member). The lower part of most prograding sequences was deposited in a silty environment where bioturbation flourished, but shelly faunas were either absent or have been removed by physical or chemical processes.

Back-barrier

The back-barrier sequence is typically thinly to medium bedded shales with lenticular sandstones, for example, is just above the Wall Sandstone Member where the section can be divided into two parts. The lower part consists of a generally upward-shaling section with medium sublithic sandstone and minor shales at the base, grading to shales with minor lenticular sandstones at the top. The shales are generally not bioturbated, and grade vertically into coaly shales and dirty coals. The upper part consists of alternating, thin to medium bedded, fine, moderately sorted sandstones. Some beds are intensely bioturbated but others retain plane laminations and traces of ripple cross-laminations. While the sandstones are mainly horizontally bedded, some are scoured and others pass laterally into large (1-2m thick) steeply dipping foresets.

Deposition of this lower part ranges from sandy washover deposits with tidal channels at the base to muddy lagoonal deposits at the top. The high carbonaceous content, the thin coaly layers and lack of bioturbation of the shales may indicate brackish to freshwater conditions. Emergence is recorded by the coal at the top of the lower part. The upper part is interpreted as coastal flats dissected by channels, possibly with tidal influence. The bioturbation indicates the re-establishment of marine conditions, probably associated with reduced influence of the submerging barrier.

Tidal Flat

Wavy bedding characterises the tidal flat sequences and consists of rippled fine to very fine sandstone alternating with drapes of thin, dark laminae of organic-rich mudstone on a 1-2cm scale. The wavy bedded intervals alternate with medium to thick beds of fine sandstone showing ripple cross-lamination some with flasers. Medium beds of medium to coarse sandstone, showing low angle cross-beds and channellised scours, also occur.

Sandier versions of the tidal flat sequences are found in the upper Collinsville Coal Measures, where there are thick (1-3m) rippled sandstones with flaser in some layers, and irregular wavy bedding in others. Ladder and flat-topped marks occur just above the Scott Seam, and above the Garrick Seam there are wide (20m), shallow (2m) scour channels, filled in part by lensing mudstone layers and in part with wavy bedded and rippled sediments. Bioturbation is generally uncommon and consists primarily of isolated subhorizontal burrows filled with sand.

Tidal flat sequences recur at several levels in the Collinsville Coal Measures and the Gebbie Formation, but are most common towards the top. Tidal origin is indicated by the rhythmically variable lithologies, especially wavy bedding and flasers, and by the ladder and flat-topped ripple marks. Relatively minor amounts of bioturbation may be due to a brackish water environment or to locally intense reworking of the sediments by waves and tides. Occurrence of ripple cross-laminated sandstone sheets without flasers records temporary sandflat development due perhaps to changes in sediment supply or higher energy situations.

Open Marine

Marine sequences contain body fossils, intense bioturbation and burrows lined with dark organic muddy material. The sediments are lithic sandstones to sandy siltstones, generally poorly sorted due in part to homogenisation by bioturbation. Thin layers of pebble conglomerate, commonly only one clast thick recur through the sequence. Lonestones (pebbles and boulders) are also present.

Lithostratigraphic Model

Tentative lithostratigraphic correlations for the northern Basin were proposed by Dickins and Malone (1973) and McClung (1981) on the basis of transgressive marine intervals identified by the presence of body fossils, increased intensity of bioturbation and characteristic shoreline deposits. Gross correlation of the fluvial-dominated Collinsville Coal Measures with the paralic to shallow marine Gebbie Formation is reasonably well established (Dickins and Malone, 1973; Staines and Koppe, 1980; McClung, 1981). The next logical step is to extend this concept of lateral and vertical facies relationships to the offshore marine units of part of the Blenheim Formation. The Blenheim Formation records a relatively large transgression which affected the whole region and which was in turn followed by a major regression in the late Permian which deposited the fluvial coal measures of the Blackwater Group (Jensen, 1975). The time equivalence of the correlations is suggested by the diachronous contact between the Back Creek Group and the Blackwater Group (Milligan, 1971; Koppe, 1978) and does not conflict with different faunas within each lithofacies, each fossil assemblage indicating palaeoecology rather than time (McClung, 1981).

The generalised stratigraphic relation that emerges for the Back Creek Group is an overall transgression, periodically halted and reversed by prograding shorelines. The interplay of semi-stable to mildly tectonic conditions, a slow relative rise of sea-level and a continuous sizeable amount of riverine sediment input generated a complex system of transitional environments. Slight changes in any one of these factors would have induced extensive shifts of sedimentary environments on the gently sloping shores of the shallow basin.

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STRIP MINE HIGHWALL GEOLOGY IN THE MORANBAH AND GERMAN CREEK COAL MEASURES

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INTRODUCTION

The Moranbah and German Creek Coal Measures contain a number of thick, low ash, highly productive hard coking coal seams. These are exploited by eight, large, open cut strip mines. The mines lie along the shallower subsurface expression of these mainly easterly dipping coal measures, on the western flank of the Bowen Basin over a distance of some 240kms. Six of the mines are located in a roughly N-S line with the two other mines being placed further to the west-south-west. The mines lie between 150 and 250kms west of the Central Queensland Coast, railing coal to the coast near Mackay and Gladstone. In order, N to S, the mines are Riverside/Goonyella, Peak Downs, Saraji, Norwich Park and German Creek and then going south of west, Oakey Creek and Gregory. Further open cut exploitation of the coal measures is envisaged plus underground mining downdip at several existing mine centres.

The mine highwalls afford excellent strike length exposures of interseam geology and provide for an increase in the understanding of the geology of the coal measures concerned. However, it should be emphasised that only the lower section of the Moranbah Coal Measures between the "P" tuff and the Lower Goonyella (and their southern equivalents) are exposed.

GENERAL GEOLOGICAL SETTING

The Moranbah and German Creek Coal Measures are of early Late Permian age. They were deposited on the relatively stable Collinsville Shelf/Comet Platform lying as part of the Clermont Stable Block on the western edge of the actively subsiding Taroom Trough which runs up the centre of this northern section of the Bowen Basin.

The Moranbah Coal Measures extend southwards from the northern apex of the Bowen Basin near Collinsville occurring down both sides of the basin largely as subcrop under a thin Tertiary/Quaternary cover. On the western side in the north they lie on the marine Exmoor "Formation" which changes laterally into the marine lower portion of the German Creek Formation about just north of Goonyella. This continues southwards, underlying the Moranbah Coal Measures with a distinctive quartz sandstone, until their change over with the German Creek Coal Measures at Norwich Park.

The Moranbah Coal Measures also occur on the north eastern side of the Bowen Basin achieving thicknesses of up to 760m in a series of steep, westerly dipping beds. (On the western side they achieve thicknesses of between 200 and 400m).

The Moranbah Coal Measures are overlain in the North by the tuffaceous Fort Cooper Coal Measures.

The Moranbah Coal Measures contain good quality mineable coking coals throughout their length with the exception of an area in the far north where extensive coking (from intrusives) and/or faulting make mining difficult. Some areas (e.g. around Moranbah township) are covered in thick basalts but extensive reserves still remain for exploitation (e.g. some 2,000 m.t. between Goonyella and Peak Downs alone).

The German Creek Coal Measures are up to 160m thick and form the upper portion of the 270m thick (in the type section) German Creek Formation. After taking over in an interfingering relationship from the Moranbah Coal Measures around Norwich Park they continue to trend in a southerly direction before turning south westerly to the south of German Creek Mine. They continue in this general direction through to Gregory Mine. South and east of Gregory mine the coal seams appear to progressively thin out and/or deepen, though limited drilling in this area precludes a definitive assessment and economic coal may still exist here.

The Moranbah Coal Measures were deposited as fluvial and fluvio-deltaic sediments in the wake of a vigorous southerly regression of the marine conditions which existed in the Bowen Basin at the end of the Middle Permian.

The German Creek Coal Measures were formed as lower deltaic and marginal marine sediments at the south western edge of a huge flood plain, prior to a temporary transgression of the sea. The latter deposited the shallow marine MacMillan Formation sediments over the top of the German Creek Formation. This MacMillan Formation extended north to level with about half way along Peak Downs mine, preventing deposition of all Moranbah Coal Measures sediments above the "P" tuff south of this locality.

The German Creek Coal Measures pass down into the coal-less lower section of the German Creek Formation.

The use of the ubiquitous "P" tuff bed as a universal time marker in the northern section of the Bowen Basin coupled with seam ply correlation, has enabled Moranbah Coal Measures coal seams to be taken as passing laterally into German Creek Coal Measures seams; the Lower Goonyella - Dysart seam passing through to the German Creek seam as the one major seam consistently mined throughout the coalfield. (However, gaps in drilling cover cause the strongly suggested correlation to fall short of definitive proof).

The major provenance for the Moranbah Coal Measures was the Permo-Carboniferous volcanics of the Eungella-Cracow mobile belt. Rapid, sediment engorged drainage from these recently uplifted highs to the north and east provided massive, but episodal, sedimentation across a vast floodplain occupied on the western basin flanks by extensive, thick, peat swamps. Sandstones deriving from this sedimentation are volcanilitharenites of 5 to 20% quartz grain content. Volcanic fragments in them are largely altered to secondary clays and the rock is a clay-rich pseudomorph. Lutites consist largely of well bedded fluvial overbank and flood plain deposits with minor lacustrine sediments and some fluvio-deltaic sediments to the south.

Increasing quartz content in the sandstones of the Moranbah Coal Measures comes in progressively southwards from the northern Peak Downs area. This may reflect a contribution to the sedimentation from rivers deriving material from the granite rich provenance to the west.

The German Creek Coal Measures sediments derived their material from a westerly source of Devonian granitoids and low grade metamorphics of the Anakie High. The sandstones are either quartzose sandstones or sub-labile greywackes with white mica as a common constituent of both types. Quartzose sandstone units occur as massive beds or thinner horizons interbedded within the massive sub-labile greywacke units.

M.G.C.C.M. sedimentation occurred in wet, cold temperate climates with a restricted flora and subject to seasonal flooding deriving from upland ice thaw.

DATA SOURCES

The open cut mine highwalls provide a notable strike length exposure for the far western/northern edge of the Moranbah and German Creek Coal Measures (as appropriate). Company drilling downdip of the open cuts is limited largely to chip drilling and the frequency of this falls off rapidly towards the east with increasing depth to mined coal seams (except where underground mine feasibilities have been studied). Much of the chip logging is less than fully reliable and back up wireline logging has only come in in the last few years.

Geological Survey of Queensland diamond core drilling covers much of the area in question downdip of the open cut mines but is widely spaced.

Thus, whilst the open cut mines afford excellent strike length exposure they are limited to small "windows" of observation which only present limited aspects of a much wider picture involving a very complex sedimentary situation. There are many gaps in the information supply and much further drilling is required before a more complete picture is obtained.

COAL SPLITTING

C.Q.C.A., however, have done sufficient drilling to indicate that a complex system of joining and splitting of coal seams exists for the southerly M.C.M. plus M.C.M. to G.C.C.M. transition areas, where up to 200 discrete seams and splits have been found. There appears to be an increase in splitting and joining of coal seams which is accompanied by an overall thinning of seams south of the northern end of Peak Downs mine. The same tendency also appears to the east of the mines areas. These phenomena could be due to increasing proximity to a lower deltaic environment in the south and to the edge of the stable shelf in the east, respectively.

The frequency of splitting and joining decreases south of Norwich Park, there being five to seven seams and splits within the German Creek Coal Measures at German Creek mine.

However, between Gregory and Oakey Creek mines a major series of channel sands, derived from a large river system draining southwards, has caused much splitting and attenuation of the German Creek seam.

MAJOR MINE GEOLOGY FEATURES

1. Riverside and Goonyella

Interseam sediments between the Lower and Middle Goonyella seams at Riverside and Goonyella mines consist of low sinuosity, massive, sheet channel sandstones, plus, commonly, sub-aqueous levee and crevasse splay sand-silt and silt-sand interbedded sequences. Lacustrine and sheet flood deposits are also present.

Sediments over the Middle Goonyella and between the Middle Goonyella and its Rider seam display extensive, peat-compaction-induced, lateral migration features, plus, differential-peat-compaction, basin and dome, reverse-topographic effects, respectively. Goonyella mine highwall displays extensive (4km long) massive sheet sandstones. These reach 60m thicknesses downdip in the underground mining area. Various sub-aqueous overbank, flood plain and lacustrine sediments are associated with this major channel feature. The basin and dome structures at the southern mine end are associated with extensive crevasse splay lens deposition.

Of note is a substantial gravity slide-slump structure in massive sandstones with accompanying tensional slump faulting, chaotic bedding and an associated mud lump fold. Plastic deformation of underlying and adjacent bedded lutites is also present.

Few really major faults occur at Riverside or Goonyella with the exception of a 150m overlap, low angle NNE trending thrust fault (west over east) in the Ramp 3 - 4 area. However, a modicum of high angle normal and reverse faulting of 2 to 8m throws plus extensive bedding plane shearing is also present. The latter often turns into reverse faulting with an associated capping anticline. One bed plane shear beneath the P2 coal seam can be traced continuously for nearly 3kms. The P seams are thrust faulted and horizontally sheared both in the open cut and in the proposed underground area mine area. (See D. Devey and K. Whitby, this volume).

2. Peak Downs

Thirty kilometres south of Goonyella, Peak Downs mine begins. In the northern highwall, lengthy sheets of low sinuosity, massive channel sandstones overlie pro-deltaic - interdistributary bay and overbank splay plus distributary mouth bar deposits.

The southern highwall is dominated by massive sheet sandstones of low sinuosity channel derivation which display classic, lateral migration, peat compaction features. These are associated with thick stacks of sub-aqueous levee and interdistributary lake and splay deposits to the north and underlying levee and splay sediments in the south.

Gentle warping is present, plus, localities of quite frequent high angle reverse and normal faulting with generally 2 to 10m and up to 30m throws, in both Dysart and Harrow Creek seam sediments.

3. Saraji

Peak Downs mine passes straight on to Saraji. Above the Dysart K seam in the north are thick stacks of parallel bedded lutites of interdistributary lake, sub-aqueous levee and distal splay sediments. However, the mine highwall length is largely dominated by massive, low sinuosity channel sandstones between the Dysart S and K seams. These overlie thin, dark grey carbonaceous lacustrine beds and laminates and layered overbank deposits.

Series of N-S trending, normal and reverse step faulting swarms define horst and graben structures and have cumulate throws of 6 to 14m. There are other infrequent, isolated high angle faults with throws of up to 6m and, again, gentle regional warping is present.

4. Norwich Park

Thirty-seven kilometres south of Saraji, Norwich Park mine begins. The highwall exposed above the Dysart R seam in the northern sections shows a thick stack of parallel laminated, dark grey mudstones. These coarsen upwards to thin, parallel, interbedded siltstones, mudstones and fine grained sandstones derived from a distal interdistributary lake environment. A few sheet sand beds occur towards the top of the stack as distal associates of a more prominent, massive sheet sandstone which increasingly takes up a greater proportion of the highwall from the top down, towards the south.

The southern mine area, with laminated muds, ripple drift and silt-sands, complex sand-silts and sheet bedded sands indicates prodelta sediments prograded over by distributary mouth bar and then massive, distributary channel sheet sand deposits.

At Norwich Park the NNW trending Leichhardt South Fault down throws 25m to the south west and divides a relatively uncomplicated southern zone from a region of complex faulting in the NE quadrant of Norwich Park which has caused seam repetition and thickening.

5. German Creek, Oakey Creek and Gregory

The German Creek, Oakey Creek and Gregory mine highwalls display a preponderance of massive, lower delta distributary channel sheet sands of sublabile nature, plus, reworked distal bar and distributary mouth quartz sandstones. Sublabile sandstones enclose thinner quartz sandstone units but thicker, massive units of this quartz sandstone also exist.

Well bedded, lower-deltaic to marginal marine mudstone/siltstones, plus, interdistributary bay laminated and thin bedded mudstones and distributary mouth bar silt-sands and sand-silts, are also present. The coal seams are usually overlain by a thickness of lutite sediment sufficient to protect the coal from sulphur derived from interseam marine incursions. Marine muds above the Corvus seam contain shells at German Creek mine and ice-rafted dropstone pebbles in sandstones and shelly beds in lutites are found above the Lilyvale (German Creek?) seam at Gregory mine.

CONCLUSIONS

The Moranbah and German Creek Coal Measures, as depicted in mine highwalls, show complex fluvial, fluvio-deltaic and marginal marine sedimentation patterns. These occur in a series of interseam lenses which are enveloped by a ramose system of coal seams, plies, splits. These sediment lenses were deposited as intermittent flood phase events of relatively short duration in terms of total peat formation time. They were also of limited areal extent at any one time compared to the huge peat swamp expanse that existed over some or all of the region during coal measures deposition.

Thick peat seams and very rapid episodal sedimentation stages caused comparatively abrupt and heavy loading of peat and concomitant severe peat compaction. This may well have generated sedimentation processes differing in some respects from those operating in the fluvio-deltaic environments of today.

This may help to explain the apparent predominance of widespread, low sinuosity, channel sheet sands and extensive and frequent lateral channel migration phenomena.

MORANBAH COAL MEASURES: DEPOSITIONAL SYSTEMS

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The Permian Moranbah Coal Measures comprise six lithofacies: sandstone, siltstone/sandstone, siltstone, claystone, clay rhythmite and coal. These are interpreted as forming in fluvial channel, proximal splay/levee, distal splay, marsh, lake and peatland environments respectively. Detailed mapping using gradational intertonguing and (isochronous) carbonaceous partings confirms their depositional equivalence.

Deposition occurred on a low relief terrain in a cold climate. A belt of meandering rivers up to 4km wide formed channel deposits of medium to coarse arkose up to 35m thick. Crevasses and levees formed wedges (15m thick, 400m across) of interbedded siltstone and sandstone grading downdip into siltstone. Larger composite splay mounds (to 20m thick, 2-3km across) were deposited further from the rivers by smaller, overflow channels. Distal deposition of sediment occurred in reed fens and shallow lakes.

Sandstone Lithofacies

The sandstone lithofacies forms massive, strongly-jointed outcrops typically medium to very thick bedded, and with large-scale trough and planar cross-strata, and scour-and-fill. Small-scale cross-strata are minor, and there is a tendency for upward-fining of structures and sediments. Sediments are medium to coarse, with minor fine, clayey arkose. Extraclastic gravel is rare, but basal sections commonly contain coalified logs and intraclastic mudstone pebbles.

The sandstone lithofacies was deposited in fluvial channels as evidenced by medium to coarse grainsize, abundant large-scale cross-strata with lateral accretion bedding, abundant coalified logs and intraclastic mudstone pebbles. Two sandstone types are developed.

Type 1 sandstone forms a continuous, sheet-like bodies at least 25-50m thick and extending 4km along strike. Internal structure is complex with lateral accretion bedding and horizontal discontinuities near the top. The base and sides are generally erosional against interbedded siltstone/sandstone. Size and form of individual channels is uncertain. Type 1 sandstone represents major, sinuous river belt deposit, probably containing several channel phases, which migrated laterally eroding levees and overbank deposits.

Type 2 sandstone forms smaller lenses, and ribbons 20 to 30m thick and up to 0.5km across, whose internal structure is generally sheet-bedded with minor channelling. These interfinger with surrounding interbedded siltstone/sandstone and have limited extents of erosional bases. Type 2 sandstone represents minor channels which were deposited during construction of splays, together with surrounding finer sediments. Limited channel migration occurred.

Siltstone/Sandstone Lithofacies

The siltstone/sandstone lithofacies forms sheet-bedded units which may be horizontal or dip up to 25° (generally 15°) onto the underlying coal. Units form irregular wedges, lenses and sheets, up to 30m thick and 1km across. Bedding is thin to medium with abundant small-scale sedimentary structures, including lamination, cross-lamination and ripple drift. In contrast to sandstone lithofacies large-scale cross-strata are virtually absent. Contacts between individual beds may be sharp of gradational; bases of sandstone beds may show small-scale scouring. Penecontemporaneous soft sediment deformation features such as slumping, convolute bedding, load casting and microfaulting are common. Sandstones are fine, clayey arkoses compositionally similar to those of the sandstone lithofacies, but with more mica and plant debris. The siltstones are more quartzose with abundant plant debris and mica.

The siltstone/sandstone lithofacies interfingers with sandstone, siltstone and claystone lithofacies, and less commonly directly overlies clay rhythmites. Rapid changes between sandstone and siltstone dominant phases, both vertically and horizontally, form an irregular bedded appearance. In general sandstone-rich phases pass downdip into siltstone-rich phases.

The siltstone/sandstone lithofacies represents proximal overbank deposition as levees and crevasse splays. High suspended/bed load ratios during deposition are indicated by ripple drift. Soft sediment deformation structures particularly convolute bedding, probably indicate high rates of deposition which incorporate large amounts of water in the sediment enabling liquefaction. Bedforms were always ripple scale in contrast to megaripples in the channel sandstones.

Siltstone Lithofacies

The siltstone lithofacies forms irregular mounds, wedges and lenses up to 25m thick and 1.5km across. Characteristic sheet cementation by ferroan dolomite/siderite gives a distinctive banded appearance. The lithofacies is thin to medium bedded, and composed of homogeneous to laminated grey siltstones with rare laminated and cross-laminated, fine sandstone beds. Mudcracks, amphibian footprints (Godfrey, pers. comm.) and small, sub-vertical burrows up to 4mm wide and 1.5cm deep occur. Carbonaceous rich partings along bedding planes, extending 300m or more along the wall, probably represent times of non-deposition and accumulation of vegetable material since they commonly overlie homogeneous beds with fine rootlets. The siltstones are composed of quartz, mica, fine plane debris and clays with pervasive carbonate cement. Bedding planes have concentrations of plant debris and micas. Recognisable plants are mainly *Glossopteris* and *Phyllotheca*. *In situ* stumps are common.

The siltstone lithofacies represents distal overbank deposition of fine sediments. Accumulation was probably intermittent allowing development of rootlet horizons and growth of plants.

Claystone Lithofacies

The claystone lithofacies forms very extensive layers up to 1.5m thick which can be traced over 10km, and it is composed of thin bedded, carbonaceous dark grey claystones and fossiliferous clayshale. Claystones are homogeneous, with common rootlets and irregular, wispy carbonaceous laminae and partings.

Claystones are always associated with coal seams and occur above and below them. They represent marsh deposition well removed from active channel and overbank deposition. Fine sediment accumulated with scattered *in situ* vegetation, common *Phyllotheca* and primary bedding was destroyed by roots and soil development. The claystones represent soils formed during establishment of vegetation.

Clay Rhythmite Lithofacies

The clay rhythmite lithofacies forms thin extensive sheets, up to 1m thick, of thin to medium bedded, rhythmically laminated to homogeneous sediment. Rare scour-and-fill (1cm deep), small burrows and slumping (1cm scale) occur. Bifurcating, pale, silty ripples up to 1cm high and 4cm across in darker clay probably represent isolated wave ripples. In section they appear as lenticular bedding. Very fine plant debris and mica occur on bedding planes, coarse debris is rare, stumps and rootlets are absent.

The clay rhythmite lithofacies represents lake deposition of fine sediment where there is shallow standing water to allow wave ripple formation. Water was sufficiently deep to preclude standing vegetation. Influxes of fine sediment were periodically reworked by low energy, waves and currents. Although superficially varve-like, no consistent upward fining laminae could be indentified.

Coal Lithofacies

The coal lithofacies comprises a major seam and two minor seams. Coal in the Goonyella Middle Seam is vitrinite-rich at the base and inertinite-rich towards the top (Beeston, 1974) and low in detrital mineral matter. An upward change from vitrinite to inertinite may represent increasing relative dryness of the peat with consequent degradation of the plant materials (Plumstead, 1962). Coal represents accumulation of vegetation in peatlands free of terrigeneous influx.

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GEOLOGY OF THE FORT COOPER COAL MEASURES INTERVAL

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INTRODUCTION

The Fort Cooper Coal Measures conformably occupy the stratigraphic interval between the Rangal Coal Measures above, and the Moranbah Coal Measures below. This nomenclature is applied to the northern Bowen Basin, but equivalents of the Fort Cooper and adjacent units are recognised throughout the rest of the basin.

While the Fort Cooper and some of its equivalents are coal bearing, all coal seams are intensively banded with tuffaceous claystones, and have marginal or no economic value at present. The stratigraphic name, therefore is appropriately applied to divide the section according to coal quality.

STRATIGRAPHY

Correlations

The stratigraphic relationship between the Fort Cooper Coal Measures and equivalent units is shown in Table 1. Correlation between the areas is based on the presence of tuffaceous mudstones throughout the interval, by microfossil evidence, and by geophysical log correlation:

> The tuffs provide the best correlation evidence, and are found where the environment of deposition was quiet enough to be preserved - particularly in coal swamps and in marine mudstones. Correlation is based on recognition of the gross tuffaceous interval. With only one exception, correlation of individual beds has not been attempted between areas.
>
> Microfossil evidence has been used to some extent, mainly in the Denison Trough. A distinctive acritarch swarm (P3C of Evans, 1962) occurs near the base of the Black Alley

Shale, and Price (1983) has refined the palynology of this part of the Permian. Unfortunately the microflora are effectively destroyed with mild metamorphism, corresponding to a vitrinite reflectance of 0.8 - 1.0, so palynology cannot be used over most of the coal areas of the Bowen Basin.

Some geophysical log characteristics tend to persist over long distances, and make excellent correlation features. intervals of marine mudstone, in particular, have recognisable signatures. Tuffs have distinctive log properties, and display low resistivity, low sonic velocity, and occasionally high gamma radioactivity.

North Bowen Basin

The Fort Cooper Coal Measures in their type section (in the Hail Creek Syncline) are some 400m thick, and are composed of green lithic sandstone, conglomerate, mudstone, carbonaceous shale, coal, and thin beds of greyish white cherty tuff containing abundant leaf impressions (Jensen, 1968).

The critical feature distinguishing the Fort Cooper from the Rangal Coal Measures above and the Moranbah Coal Measures below is the presence of the tuff beds. They occur mostly within the coal seams, and occupy up to 50% or more of the total seam interval. Individual tuff beds are thin, mostly less than 10cm, but some greater than 0.5m do occur. They are soft, and quickly break down on exposure, but are commonly associated with hard cherty beds at outcrop. Colour ranges from white through shades of green and brown, and fresh surfaces usually have a waxy lustre. Grainsize is commonly very fine, and the beds are, more accurately, tuffaceous claystones. Hard evidence for identifying them as tuffs is sparse. Some devitrified glass shards were found in thin sections of fine sandstone from the Burngrove Formation (Jensen, 1968) and from bentonite beds of the Black Alley Shale (Mollan et al, 1972). Presumably diagenesis has destroyed most of the pyroclastic textures.

A distinctively radioactive tuff occurs at the top of the Fort Cooper Coal Measures. It is in the process of being named the Yarrabee Tuff Bed, the topmost member of the Fort Cooper Coal Measures and the Burngrove Formation. The bed usually occurs within a coal seam, which unfortunately places the formation boundary within the seam.

The boundary between the Fort Cooper and the Moranbah Coal Measures is taken as the base of the lowermost very tuffaceous seam. This boundary is not as obvious as the upper boundary, because the underlying Moranbah Coal Measures do contain scattered tuffs.

Blackwater Area

In the Blackwater area, the Fort Cooper interval is occupied by the Burngrove and Fair Hill Formations of Malone et al., (1969). The Burngrove has an upper section of sandstones and siltstones, with tuffaceous coal seams, the Yarrabee Tuff Bed being the top member. The lower section of the Burngrove is dark mudstone with tuff beds, probably marine, and equates with the Black Alley Shale of the Denison Trough. This section loses its identity northwards, and grades into coal measures strata.

The Fair Hill Formation is mostly sandstone with tuffaceous coal seams. Below the Fair Hill is the MacMillan Formation as used by Prouza and Park (1973), a marine siltstone - mudstone sequence which also grades northwards to form the basal Moranbah Coal Measures. (Koppe, 1978). The boundary between the Formations corresponds approximately with the onset of abundant tuffs.

Denison Trough - Comet Ridge

The Fort Cooper Coal Measures interval in the Denison Trough - Comet Ridge is more marine, and contains little coal. The upper boundary lies within the Bandanna Formation as defined by Power (1967) and is recognised by the presence of tuffaceous coal, however the Yarrabee Tuff Bed itself has not been identified. The Black Alley Shale contains dark silty mudstones with tuff beds, and is marine. The P3C acritarch swarm occurs about 3m above its base in outcrop near the Carnarvon Gorge. The Peawaddy Formation is sandstone at the top and mudstone at the bottom. In the southern Denison Trough the upper Peawaddy is dominently marine, with a lenticular coquinite, the "Mantuan Productus Bed", at the top. Some tuffaceous coal seams were intersected in petroleum wells farther north, and would be better considered part of the Fair Hill Formation. The basal Peawaddy mustone is the lateral equivalent to the MacMillan Formation, so is not part of the Fort Cooper interval.

Moura Area

Precise correlation between the Fort Cooper Coal Measures and the Moura sequences is difficult. On the western side of the Bowen Basin, gaps between outcrop of the units is minimal, and exploration drilling is now relatively close. Between there and Moura, however, is a wide gap in Permian outcrop, and correlation features are not as apparent. A modification of the correlation presented by McClung (1981) is favoured. The top of the Fort Cooper interval is the Kaloola Member, the basal unit of Baralaba Coal Measures (Dear et al., 1971). The member is distinguished by its tuffaceous coal seams compared with the clean seams above. Geophysical log character of the Gyranda Formation in a petroleum well drilled west of Moura

(TEPL Moura I) compares reasonably closely with the Black Alley Shale - Fair Hill Formation character. Unfortunately the degree of metamorphism is too high to preserve microflora, so palynological correlation is impossible.

COAL SEAMS

The Fort Cooper Coal Measures contain numerous tuffaceous seams, some up to 30m thick,which comprise as much as 20% of the stratigraphic section. Coal plies, however, make up generally less than 50% of the gross coal seams, and themselves usually contain high proportions of mineral matter. The better quality seams occur towards the top of the unit and have been investigated to a limited extent. Raw ash content of the Girrah seam, a thick seam commonly found at or near the top of the Fort Cooper Coal Measures - Burngrove Formation, ranges between about 30 to 40%. A washed product yielding about 60 to 70% with an ash level of less than 20% and variable swelling properties is achievable. This type of coal could be blended in with other better quality coals, either coking or steaming.

The uppermost Fort Cooper seam at Winchester South, the Vermont Lower, was investigated in detail. It is some 4m thick, has an average raw ash content of 40%. Washability testing yielded an average cummulative float fraction of (for example) 55% for an ash content of 27%. A better quality ply, the Vermont Upper, overlies the Vermont Lower, separated by the Yarrabee Tuff Bed.

Mining conditions in the Fort Cooper seams would present geotechnical problems. The tuffs are weak, hydrate easily, and would cause floor and slope instabilities, and problems in a wash plant.

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TABLE 1

STRATIGRAPHIC CORRELATIONS
FORT COOPER COAL MEASURES INTERVAL

Denison Trough (Power, 1967)	Blackwater Area (Prouza and Park, 1973)	Northern Bowen (Koppe, 1978)	Moura Area (Dear *et al.*, 1971)
Bandanna Formation	Rangal Coal Measures	Rangal Coal Measures	Baralaba Coal Measures
	Yarrabee Tuff Bed	Yarrabee Tuff Bed	Kaloola Member
	Burngrove Formation	Fort Cooper Coal Measures	
Black Alley Shale			Gyranda Formation
Peawaddy Formation	Fair Hill Formation		
	MacMillan Formation	Moranbah Coal Measures	Flat Top Formation
Catherine Sandstone	German Creek Formation		

GEOLOGY OF THE RANGAL COAL MEASURES AND EQUIVALENTS

G.W. Quinn, Thiess Dampier Mitsui Coal Pty Ltd

INTRODUCTION

The Rangal Coal Measures and equivalents - the Baralaba Coal Measures in the south-east and the upper Bandanna Formation in the south-west are the youngest coal-bearing units in the Bowen Basin Permian sequence. They developed in the late Middle Permian after the seas had retreated from the basin in a southerly direction. By this time the basin was wholly terrestrial and paludal environments were extensively developed.

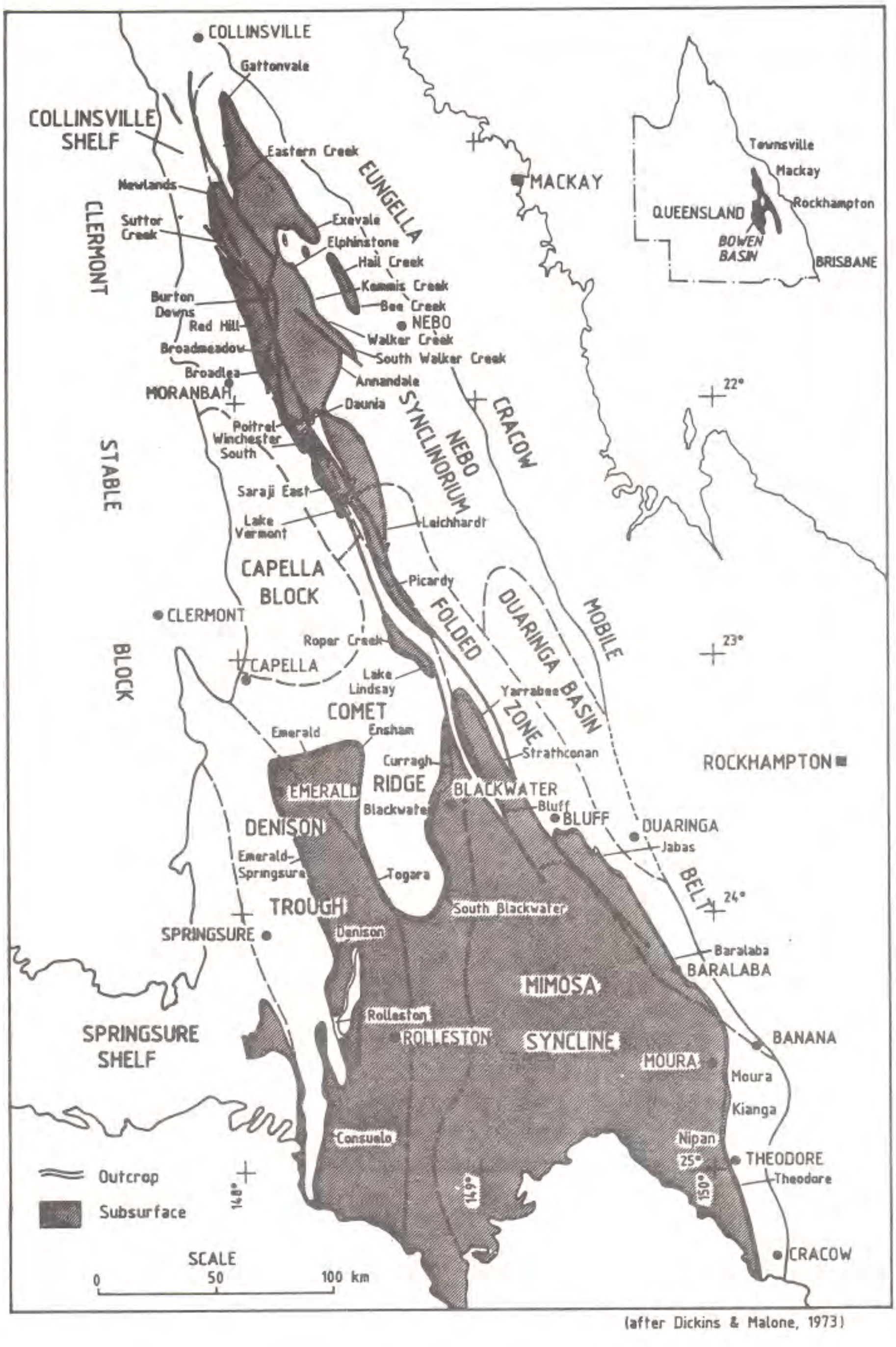
In the late Permian, a dramatic climate change which eventually resulted in a red-bed depositional environment brought the coal-forming process to a close and the overlying barren Rewan Group was deposited throughout the basin. Deposition of this unit continued into the early Triassic.

Occurrences of Rangal coal have been known and worked since the late nineteenth century from isolated outcrops in the south-east, central and northern regions of the basin. However it was not until 1957 when Thiess Brothers Pty Ltd began exploration between Baralaba and Theodore that the detailed stratigraphy and lateral extent of these measures were systematically investigated. This pioneering work culminated in 1961 with the opening of the Moura mine.

At present there are six opencut and four underground mines operating in the Rangal and Baralaba Coal Measures and for the year 1984 these mines produced 25% of the State's clean coal production (Queensland Coal Board, 1984). At least eight other potential coal-fields within these measures have been evaluated and await market availability.

DISTRIBUTION & NOMENCLATURE

The Rangal Coal Measures occur in the northern half of the Bowen Basin and lie on the Comet Platform, in the Folded Zone, on the Collinsville Shelf and in the Nebo Synclinorium (Figure 1).



<u>Figure 1</u>: <u>Distribution of the Rangal Coal Measures and Equivalents with Structural and Tectonic Elements of the Bowen Basin</u>

The Baralaba Coal Measures occupy the south-eastern quarter of the basin on the eastern limb of the Mimosa Syncline.

The Bandanna Formation occurs in the south-western quarter of the basin within the Denison Trough, on the southern Comet Platform and on the Springsure Shelf.

STRATIGRAPHIC POSITION

The Rangal Coal Measures and equivalents are the product of two major changes which were at least basin-wide, firstly a cessation of volcanic activity within the basin and later a probable change of climate.

The Upper Boundary

All three formations are everywhere conformably overlain by the Rewan Group. This group differs from the underlying coal measures by the absence of coal and carbonaceous material and by its colour which is green in the lower sandy section and red in the upper muddy section. The Rangal Coal Measures and equivalents are almost exclusively shades of grey. A change in climate has been proposed to explain the colour change and the absence of preserved plant material in the Rewan Group. The boundary is somewhat gradational and for convenience is often placed at the top of the uppermost carbonaceous horizon, usually the uppermost coal seam. However the colour change is the preferred criterion because such a boundary does not rely on the presence of lenticular coal seams (Anderson, this volume).

The Lower Boundary

Defined criteria for recognising the lower boundary are less distinct and the reader is referred to Anderson (ibid.) for a complete discussion. Anderson therein redefines the base of the Rangal Coal Measures as the top of the Yarrabee Tuff Bed (Kempton, 1975) primarily because it is the uppermost significant tuff bed in the Permian sequence and also because of the marked change in coal seams below this tuff.

In general terms the Rangal Coal Measures and equivalents everywhere overlie the 'interval of abundant tuffs' (Koppe, 1978). The uppermost unit of this interval is the Burngrove Formation in the central basin, the Fort Cooper Coal Measures in the northern basin, the Kaloola Member of the Baralaba Coal Measures in the south-east and the lower tuffaceous part of the Bandanna Formation in the south-west (Figure 2).

<table>
<tr><td>South-east</td><td>South-west</td><td>Central</td><td>Northern</td><td></td></tr>
<tr><td>Rewan Group</td><td>Rewan Group</td><td>Rewan Group</td><td>Rewan Group</td><td></td></tr>
<tr><td>Baralaba C.M.</td><td rowspan="2">Bandanna Formation</td><td>Rangal C.M.</td><td>Rangal C.M.</td><td></td></tr>
<tr><td rowspan="2">Kaloola Member
?——?</td><td rowspan="2">Burngrove Formation</td><td rowspan="3">Fort Cooper Coal Measures</td><td rowspan="3">top of interval of abundant tuffs</td></tr>
<tr><td>Black Alley Shale</td></tr>
<tr><td>Gyranda Fm.</td><td>Peawaddy Fm.</td><td>Fairhill Fm.</td></tr>
</table>

Figure 2: Stratigraphic Correlation of the Rangal Coal Measures and Equivalents.

PROPOSED CHANGES TO STRATIGRAPHIC NOMENCLATURE

The lithostratigraphic equivalence of the Rangal Coal Measures and the upper ′productive member′ of the Baralaba Coal Measures is well recognised amongst geologists who have worked in the Bowen Basin (e.g. Goscombe, 1968). The lower Kaloola Member is also widely recognised as being at least partly equivalent to the Burngrove Formation (Goscombe, 1968, Svenson et al., 1975). Because of the obvious differences in lithology and coal seams between the two members of the Baralaba Coal Measures, the stratigraphic position of the Kaloola Member at the top of the ′interval of abundant tuffs′ and the high degree of mappability of this member, it is recommended that the Kaloola Member of Dear et al. (1971) be raised to formation status (Figure 3).

As a consequence of the above recommendation and in recognition of the widespread acceptance of the lithostratigraphic equivalence of the upper productive member of the Baralaba Coal Measures and the Rangal Coal Measures, it is proposed that the name Baralaba Coal Measures be suppressed in favour of the only eligible alternative name, the Rangal Coal Measures. To retain the older name Baralaba Coal Measures for a smaller part of the original sequence so named would be contrary to the recommendations of the Australian Code of Stratigraphic Nomenclature (1973). Evidence of this equivalance is afforded by the consistency of their upper and lower boundaries (both lie between the ′interval of abundant tuffs′ and the Rewan Group) and by their overall similarity in lithology and included coal seams.

However, in view of the significance of the Baralaba area in the history of coal exploration in the Bowen Basin, it is proposed that formal recognition of this role be retained by the establishment of a new sub-group of the Blackwater Group which will apply to the south-eastern part of the basin and be known as the Baralaba Sub-Group. The Baralaba Sub-Group will comprise the Rangal Coal Measures and the Kaloola Formation where both are recognised. Thus the name Baralaba is preserved and the two formations of the Blackwater Group in this region having some degree of common lithological and lithogenic features, mainly the presence of coal seams, retain their association.

<table>
<tr><th>Reid,1944; 5a,b Baralaba Area</th><th>Derrington et al, 1959 Cracow Area</th><th>Dear et al, 1971 Monto Area</th><th colspan="3">This Paper, South-eastern Bowen Basin</th></tr>
<tr><td rowspan="2">?——?</td><td>Isla Formation</td><td rowspan="2">Rewan Formation</td><td rowspan="2" colspan="3">Rewan Group</td></tr>
<tr><td rowspan="2">Kia-Ora Fm</td></tr>
<tr><td rowspan="2">Baralaba Coal Measures</td><td>Baralaba C.M.</td><td>Rangal C.M.</td><td rowspan="2">Baralaba Sub-Gp</td><td rowspan="3">Blackwater Group</td></tr>
<tr><td rowspan="2">Gyranda Formation</td><td>Kaloola Mbr</td><td>Kaloola Fm</td></tr>
<tr><td>Calcareous Plant-bearing Beds</td><td>Gyranda Formation</td><td colspan="2">Gyranda Formation</td></tr>
</table>

Figure 3: Stratigraphic Nomenclature - South-eastern Bowen Basin Upper Permian to Lower Triassic.

ENVIRONMENT OF DEPOSITION

The dominant environment which persisted throughout deposition of the Rangal Coal Measures was paludal. These coal measures developed from an extensive long-lived peat-forming swamp interrupted intermittently by sediment bodies produced by changing distributary systems (Mallett, 1983). Much greater compression occurred in peat than in other sediments and differential compaction progressively changed the relative proportions of peat and sediment to what are seen today as split coal seams within a larger sedimentary mass. A number of localised environments were also present within the overall Rangal paludal environment, and are represented by the associated interseam sediments (refer Mallett, this volume).

DESCRIPTIVE GEOLOGY

The Rangal Coal Measures is a distinctive lithological unit which is characterised by some properties which are consistent throughout the basin and others which are variable. The major features which help characterise this formation are listed.

Stratigraphic Setting

These measures are everywhere overlain conformably by the Rewan Group and everywhere rest conformably on the 'interval of abundant tuffs'.

Colour

The grey colouration of the Rangal Coal Measures is very consistent. Some browns are present but green is rarely if ever present.

Lack of Tuffaceous Beds

An absence of tuffs, especially in the coal seams is particularly diagnostic. All other coal-bearing formations which could reasonably be confused with the Rangal Coal Measures have tuff beds within at least some seams.

Regional Lithogical Composition

Sandstones of the Rangal Coal Measures are invariably labile and generally volcano-lithic in composition. Composition is dominated by volcanic rock fragments (Boyd, 1982) with minor quartz and feldspar. Secondary calcite cement is common. Siderite is also commonly present as blebs or concretions throughout arenites, mudstones and coal seams.

Local Lithology

Because of the range of depositional environments involved in interseam sediment deposition, lithology on the local scale varies considerably in both lateral and vertical senses.

Marker Horizons

Yellow sideritic floaters on the surface derived from sideritic concretions, tonsteins within coal seams, and the underlying cherty leaf beds and Yarrabee Tuff Bed are excellent markers.

Structural Setting

The wide distribution of the Rangal Coal Measures ensures variability in structural complexity of deposits.

Coal Seams

Perhaps the most variability within the Rangal Coal Measures occurs in the coal seams. This variability is reflected in :-

- the number of seams in different areas. A range of one to twelve is known,
- the wide range of coal rank. Variation in maximum reflectivity of vitrinite in oil (Ro Max.) from 0.4% to greater than 2.7% has been recorded (Beeston, 1981)
- the generally dull nature of the seams. However variation within and between seams is characteristic. Reactive maceral content decreases upsection in both cases.
- increasing ash content upsection within and between seams.
- variable ash chemistry and mineralogy which can affect both coking and steaming properties when basicity is high. Siderite and calcite are the two major basic components.
- invariably low sulphur content resulting from minimal marine influence on environment of deposition.

SUMMARY

The Rangal Coal Measures and equivalents are distinctive lithological units which occupy a stratigraphic position between the 'interval of abundant tuffs' and the Rewan Group. They are characterised by the grey colouration of their sediments, a lack of tuffaceous beds, lithological composition and coal seam properties. They are widely distributed and the included coals encompass a wide range of rank. This diversity is unmatched by any other coal-bearing formation in Queensland and assures great flexibility for future marketing of these coals.

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DEPOSITIONAL ENVIRONMENTS IN THE RANGAL COAL MEASURES

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The Rangal Coal Measures are the most widespread and uniform coal measures within the Bowen Basin, although they are only a relatively thin sequence from 100 to 300 metres in thickness. They represent the final transition of the Bowen Basin from a marine and marginal marine to a wholly terrestrial environment, at about the end of the Permian. This was accompanied by a climatic change leading to warmer drier conditions. There is no evidence for marine influence within the Rangal Coal Measures.

Environmental model

Multiple coal seams were formed in this phase, with two main seams in the thinnest sequence in the north, and up to ten in the southernmost exposures near Theodore. Seams can be traced over large distances of up to 100 km, by typical profiles or quality characteristics. However over the distance many changes occur in the seam. Plies and splits occur frequently, when part of the seam traverses up or downsection to join the overlying or underlying seam. This results in a cross-section with an anastomosing network of coal seams, which enclose lenses of terriginous sediment. When compaction effects are removed, it can be shown that the terriginous sediments form a minor part of the original sedimentation. They represent ephemeral interruptions to virtually continuous peat accumulation.

The Rangal Coal Measures were accumulated within very extensive palludal peat swamps, with no direct marine influence, and with occasional terriginous incursions. They were deposited on the landward side of a deltaic coastal plain (upper Delta Plain), with much of the sediment bypassed through the peat in well defined distributaries, allowing thick clean peat accumulation over large areas.

Seam thickness and continuity

Controls on the sediment distribution and style related to relatively fixed fluvial source inputs, and internal localisation processes. Localisation of deposition was dependent on flow characteristics, and compaction of the peat which created depressions to accept sediment. Although the area had an extremely flat surface approximating to the water table, it was topographically high enough to be isolated from sea level change effects which dominated coal seam formation in the underlying coal measures. Localisation of thick sediment deposition was caused by compaction of peat by existing distributaries and overbank splays. This generated sediment 'sinks' which acted as a focus for sedimentation, and internally controlled the distribution of terriginous material within the organic peats. Terriginous sediment was excluded from any area which could maintain its elevation and lead to the local development of thick seams. These excessively thick peats stored up potential compaction, equivalent to the areas being progressively compacted nearby, and when eventually overtopped by a sediment influx, compacted dramatically, giving a thicker than usual sediment overburden.

This process can be seen in an analysis of the relationship between seam thickness and immediate interseam overburden within the Bowen Basin. The plot of seam versus overlying interseam thickness for representative mine areas in the Bowen Basin indicates that at a certain thickness of coal (peat) the compaction potential takes over from hydraulic factors as the dominant control of sediment localisation. For coal seams greater than 4 metres thick, overburden is either very thin (a few metres) or thick (average 35 metres). This reflects the potential compaction in the peat which formed the seams. The peat can support very light loads of muds drapes and ash falls forming thin interseam, but if any significant overbank influx occurs, it causes the peat to subside thirty to forty metres providing a localised sediment sink. The subsidence is time related, and bearing in mind that sediment would be passing through the system all the time, deposition would occur progressively with the subsidence. As the base of the pile subsides shallow sediments were rapidly buried by subsequent shallow sediments, all of which were deposited originally at the same depth.

With thinner peat accumulations that give rise to coal seams less than four metres thick the thickness of interseam sediment shows no significant relationship to seam thickness. This suggests that it is controlled by other factors such as hydraulic flow conditions in the distributory systems or sediment supply.

As sedimentation occurs rapidly to fill the sediment sinks created, each interseam usually represents a single event. An areal analysis of lithologies and structures should reflect the physiographic expression of the depositional system responsible for the sediment wedge. It has been shown that a simple plot of sand percentage for an interseam wedge will outline the basic form and style of deposition. An example from the Orion to Pollux interseam at Curragh illustrates how clearly the crow's feet pattern of distributaries within a splay is shown. In this example the incremental sediment beds are thin and widespread, with no massive thick sands developing which could/would lead to dramatic local settling of the peat. No very high angle beds dipping to underlying coal seams were formed, most dips falling in the 5 to 10 degree range. The deposit represents a fairly small system only a few square kilometres in extent, which splayed out from a nearby larger distributary. The dynamics of peat compaction in the system is illustrated in the interseam section overlying the Pollux seam. Here large curvilinear sand masses are associated with the splay tongues seen between Pollux and Orion, and represent the location of a large distributary in the sediment transport system.

Sediment deposited in the distributary is all well sorted sand, with the muds carried off by splays or bypassed through the peat swamp. The thick sands accumulated in the distributary are sufficient to cause dramatic compression of the underlying peat, and form beds steeply dipping to the underlying coal. At deposition the sandy channels were less than ten metres deep, but warping and subsidence has allowed the accumulation of over forty metres of sands now arranged in a series of overlapping lenses dipping at up to 25 degrees. This strong warping is restricted to the distributary systems.

An area at Moura located between pits 30 and 60 shows the development of a sedimentary lens which evulsed from the distributary just to the east of the existing outcrop line of the interseam. The point of evulsion remained fixed, and sediment was intermittently flushed to the west, over peat. It was mainly composed of sands with occasional silts and mud drapes, and many periods of no deposition, and some erosion. As the sands were deposited in linear strips some 8 to 15 metres thick and 200 to 400 metres wide, they caused very significant downwarping of the underlying peat, and the locus of sedimentation fanned slowly from a southwesterly to a northwesterly direction. Discontinuous sedimentation, mud drapes, subaerial weathering, occasional mudcracks and lag conglomerates all in close proximity indicate that the channelway was only intermittently activated, but that when it was, it experienced high energy flow.

Summary

The landscape of the Rangal Coal Measure time consisted of very extensive peat swamps traversed by distributaries connecting fluvial systems to the sea, with associated splay areas and lakes accepting terriginous muds. The areas of sands and silt accumulation migrated quickly through the swamps, but at any time only occupied a very small area of the peat bog. There would have been patterns to the distributary and interdistributary sediment systems, but not enough data is available to accurately build a reconstruction of the complete systems. It might be expected that the vertical superposition of interseams would represent the lateral change in terriginous sediment systems seaward to landward across the peat. No rigorous analysis of the vertical changes has yet been made, but it is common to find lacustrine silts concentrated towards the top of the sequence suggesting that lakes bordered the fluvial plain.

POST DEPOSITIONAL HISTORY

IGNEOUS INTRUSIONS IN THE BOWEN BASIN

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An estimated minimum of 5,000 million tonnes of coal have been lost from the Bowen Basin through the action of igneous intrusions. This is based on the size of outcrops shown on maps and the assumption that below each outcrop there has been a loss of 10m thickness of coal. The estimate does not include losses due to intrusions that do not form outcrops. The Bundarra Granodiorite is an exceptionally large intrusion which accounts for approximately 3,500 million tonnes of the lost coal. This intrusion lies in the heart of the northern Bowen Basin and occupies an outcrop area of about 88 km^2 and a disturbed barren area of about 250 km^2.

The intrusions range from acid to basic in composition and have a wide variety of forms. The Bowen Basin is one of the few places in the world where acid to intermediate intrusions are common in coal. They range in age from Lower Cretaceous (e.g. intermediate stocks) to Tertiary (e.g. basalt dykes and flows). The main concentration of intrusions is in the north of the basin.

Nine intrusions are recorded on the Bowen 1:250,000 Geological Sheet occupying a total area of about 26.5 km^2. The largest (8 km^2) is an irregular sill-like body of "feldspar porphyry". Virtually all seams in this region are affected by intrusions, particularly the upper seams. Spectacular outcrops occur in Rosella Creek 28 km south of Collinsville. The Mount Coolon 1:250,000 Geological Sheet records the most intrusions (16 occupying 55 km^2) and these are prevalent in the Blackwater Group. The Nebo Synclinorium contains more numerous intrusions than the Collinsville Shelf, and the larger intrusions are in the Nebo Synclinorium. Widespread Tertiary basalt associated with acid to intermediate plugs is up to 300m thick in this region. Six intrusions aggregating an area of about 21 km^2 are shown on the Mackay, Clermont and St. Lawrence 1:250,000 Geological Sheets. These are mostly of intermediate composition and range in age from Lower Cretaceous to Tertiary. Basic lavas up to 540m thick are recorded on the Clermont Sheet. Although 13 intrusions of Tertiary rhyolite and trachyte occur in widespread basalt in the Emerald 1:250,000 Geological Sheet they occupy an aggregate area of only 6 km^2. No intrusions into the coal-bearing strata of the Bowen Basin are shown on the remaining 1:250,000 Geological Sheets covering the southern portion of the basin except for one less than half a square kilometre in area on the Eddystone Sheet. Nevertheless, Tertiary dolerite sills and dykes are known to occur in the Blackwater Coalfield, in the Bluff-Yarrabee areas and in the Reids Dome beds. Cretaceous to Tertiary trachyte intrusions also occur in the Baralaba area.

Intrusions are common in structurally disturbed areas. Some intrusions are apparently aligned with basement fracture zones. They are generally post-coalification and post-tectonic but the larger intermediate intrusions occur within domed sedimentary rocks and are dominantly displacive. Small basic sills in coal tend to be dominantly replacive.

Regional coal rank variations are not obviously related to the occurrence of intrusions but subtle relationships may yet be found.

Graphite occurs in a metamorphic aureole at Jacks Creek near Collinsville, and in the metamorphic aureoles of the Bundarra Granodiorite and the Mt. Gotthardt Granodiorite. Cindered coal or natural coke, however, occurs with most other intrusions and the origin of the graphite is not fully resolved.

THE THERMAL HISTORY OF THE SOUTHERN BOWEN BASIN: AN APATITE FISSION TRACK STUDY

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The thermal history of the southern Bowen Basin has been studied by use of Apatite Fission Track Analysis (AFTA). Fission track analysis has proven to be a powerful tool for the detection of thermal events in which temperatures of around 100^{o}C have been reached (Gleadow, et al., 1983). However, unlike techniques such as vitrinite reflectance which give only an indication of the maximum paleotemperatures achieved, ATFA provides important information on paleotemperature variation through time.

APATITE FISSION TRACK ANALYSIS.

Fission tracks occur in all uranium bearing minerals and are the result of the spontaneous fission of ^{238}U. The fission decay creates a linear damage trail which can be chemically revealed by a suitable etchant. The density of spontaneous tracks in a mineral is a reflection of both the age and the uranium concentration of the mineral. The uranium content can be measured by irradiation with a known fluence of thermal neutrons in a nuclear reactor, producing a set of induced fission tracks, usually in a mica detector placed next to the mineral. The age of the mineral can then be calculated from the known neutron fluence and the ratio of spontaneous to induced tracks. Fractures and tracks intersecting the polished surface of a mineral can act as conduits for the etchant to reveal fission tracks that totally lie within the body of the mineral. Those 'confined tracks' which lie horizontally represent the full etchable track length, and the measurement of these tracks can provide unique paleotemperature information.

Apatite is the most temperature sensitive of the minerals suitable for fission track analysis. Early studies (Naeser,1981; Gleadow,1981) showed that over geological time, fission tracks in apatite show measurable annealing effects in the temperature range 60-125^{o}C, broadly coincident with the temperature range in which liquid hydrocarbons are generated.

The Otway Basin of south-eastern Victoria has been particularly useful in understanding the thermal response of fission tracks over geological time, due to the presence of the thick, uniform, volcanogenic Otway Formation, which contains abundant apatite. In a detailed investigation of apatites from selected exploration wells Gleadow et al. (1983) and Green et al. (1985) have shown that with increasing temperature, tracks shorten as the original damage is healed or 'annealed', causing a corresponding reduction in track density.

Therefore, as the degree of annealing increases, the mean confined track length and the fission track age both progressively decrease. In addition, the distribution of the confined track lengths broadens as the mean length decreases, while the distribution of single grain ages also show important differences at various degrees of annealing. The reduced ages are referred to as partial or apparent ages which have no geological relevance except that they indicate that the samples have been subjected to temperatures of 60-125°C. At temperatures greater than 125°C generally no fission tracks remain and so the ages are effectively zero.

As discussed by Green et al. (1985), because of the nature of the thermal history experienced by the apatites in the Otway Basin wells, in which temperatures have steadily increased with time, the temperature dependance of the fission track parameters identified in those wells can be applied in other basins to elucidate paleotemperature information.

SAMPLING.

Fission track ages and lengths were determined on apatites separated from outcrop samples and from samples at shallow depths (<500m) in coal, stratigraphic and petroleum wells of the upper coal measures of the Blackwater Group: the Bandanna Formation, the Baralaba Coal Measures and the Rangal Coal Measures.

On the basis of palynological data, the Baralaba Coal Measures and its basin-wide equivalents have been equated with the Chhidruan-Djulfian age, of Middle Permian age (Foster, 1983). This age corresponds to the traditional Tatarian age (248-253 Myr), to which Harland (1982) assigned the Baralaba Coal Measures. Therefore, the Baralaba Coal Measures and its basin-wide equivalents are considered to have a stratigraphic age of around 250 Myr.

Extensive vitrinite reflectance data exists for the samples investigated in this study (Beeston, 1981). Thus the fission track study will enable comparison of the response of two thermal history indicators.

RESULTS.

Figure 1 shows the distribution of apatite ages in the upper Permian Coal Measures of the southern Bowen Basin. For clarity these ages have been grouped into 40 Myr intervals and for each age interval a represenative track length distribution is shown.

The oldest apatite ages occur in the west, on the Springsure Shelf, where ages are greater than 240 Myr. The track length distributions in this region are narrow, with means of around 14um, and most tracks between 13 and 16 um, with only a few tracks of less than 10 um. In the Denison Trough area and across the Comet Ridge the apatite ages decrease to around 160 Myr. On the eastern side of the study area from Theodore to Baralaba a similar decrease in apatite age is evident, with apatite ages decreasing from around 220 Myr in the south, to ages of around 160 Myr near Baralaba. The mean track lengths of samples with ages of 240-200 Myr are between 13 and 14 um, with most tracks between 10 um and 16 um. Samples with ages between 200-160 Myr have mean track lengths between 13.5 and 12 um, also showing most tracks between 10 um and 16um, but with a more pronounced shorter component.

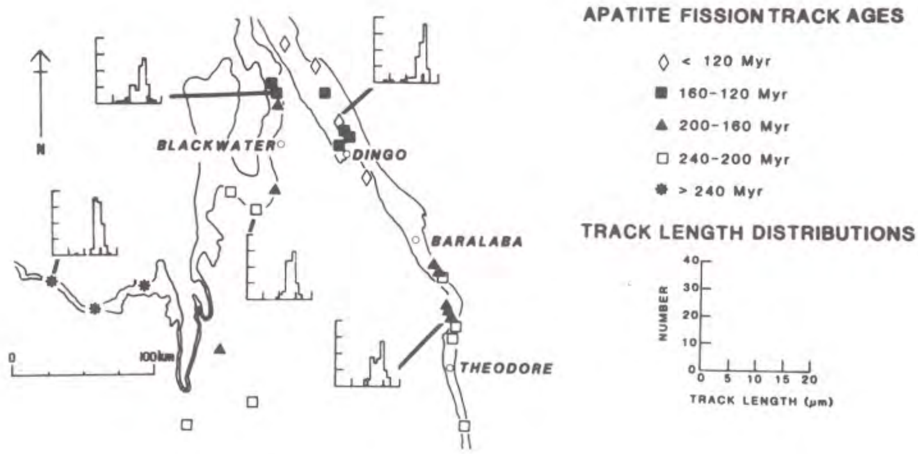


FIGURE 1: The distribution of apatite age and representative track length distributions of the upper coal measures of the Blackwater Group in the southern Bowen Basin. The typical error is 10-15 Myr.

In general, the youngest ages are found in the north of the study area near Blackwater and Dingo. The representative track length distribution of the 160-120 Myr age group shows shows a suggestion of bimodality, with a shorter component centring around 10-12 um, with the longer component between 13 and 15 um. The youngest ages of less than 120 Myr generally occur to the north of Dingo. The representative mean track length is 14.12um, with the majority of the tracks around 13 to 16um but with a few tracks of shorter lengths down to 5um.

The relationship of mean track length and the standard deviation of the track length distribution to apatite age is more clearly illustrated in Figure 2A and B. As the apatite age decreases from around 245 Myr, the mean track length is reduced, accompanied by a corresponding increase in the standard deviation. However, at ages of approximately 120 Myr the mean track length begins to increase while the standard deviation begins to decrease. At the youngest ages of around 100 to 110 Myr the mean track length reaches 13.5 to 14 um., the standard deviation is generally reduced to 1.2- 1.4 um, but with one obvious exception, where the standard deviation is 2.2 um.

Figure 2C illustrates the relationship of vitrinite reflectance (Beeston,1981) to apatite age. A clear trend is evident, with regions where $R_o$max values are low ($R_o$max < 0.5) giving apatite ages that are old, varying around 230-255 Myr. With increasing $R_o$max the apatite ages steadily decrease until $R_o$max values reach about 2.0 and the apatite ages are close to 100 Myr.

INTERPRETATION AND DISCUSSION.

Ages on the Springsure Shelf are close to the depositional age of 245 Myr and have mean lengths around 14um with standard deviations of approximately 1.0 um. As discussed by Gleadow et al. (1985), such length

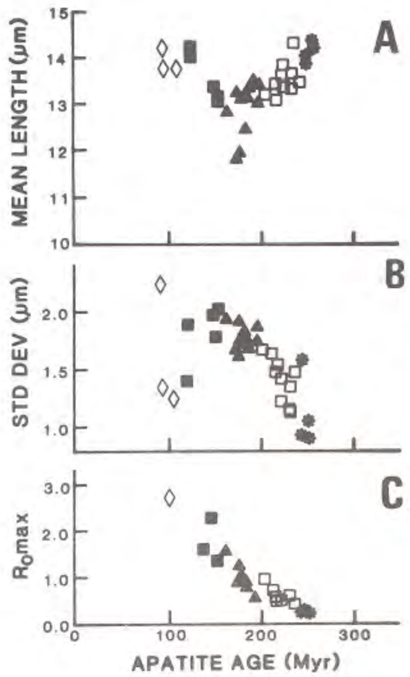
FIGURE 2:

Interrelationships between
A: mean track length

B: standard deviation of track length distribution

C: vitrinite reflectance ($R_o$max)

and apatite fission track ages for samples in the study area.



parameters are typical of rapidly cooled apatites, the age of which can be interpreted in terms of a definite "event". The samples of the Formations under study contain a significant component of volcanogenic material suggesting that the majority of the apatites were derived from contemporaneous volcanism. Both the low $R_o$max values of approximately 0.5 and the thinning of the Permian units across the Shelf reaffirm the idea that the area has not been significantly heated above, 60°C. Therefore, the apatite ages approximate to the depositional age of the Bandanna Formation in this area.

Vitrinite reflectance data suggest that the samples of the Bandanna, Rangal and Baralaba Coal Measures in other parts of the study area have experienced higher maximum paleotemperature, followed by subsequent cooling (since the samples are now at the surface). Inspection of Figures 2A and 2B suggest that as the age decreases, the data is trending towards lengths of about 14 um and standard deviations of around 1.0 um. Such length parameters would be indicative of rapid cooling from temperatures above 125°C, at a time given by the age of such apatites. Therefore, the fission track parameters now observed in outcrop samples (Figure 1 and 2) can be interpreted in terms of the admixture of two distinct components: an older shorter component which has undergone annealing at temperatures of between 60- 125°C and, a second longer component formed after subsequent cooling. As the degree of annealing in the older component increases, the mean track length and fission track age is reduced. Eventually, the number of tracks in this older component is reduced to such an extent that the younger long component becomes dominant and hence mean track length increases and the standard deviation decreases, leading to a further reduction in fission track age.

In the vicinity of Dingo and Blackwater the $R_o max$ values are greater than 2.0 which is taken to indicate that maximum paleotemperatures exceeded at least 125°C. The youngest samples with ages of around 100 Myr have mean track lengths of near 14 um but the occurrence of a few short tracks (<10um) result in widely varying standard deviations, one sample has a standard deviation of 2.2 um. Therefore, these distributions are not narrow enough to actually date an event, and the presence of these short tracks may be due to two causes. Either, the maximum paleotemperatures did not exceed 125°C so that the short tracks represent a small inherited component, or the maximum paleotemperatures were much greater than 125°C but the uplift was slow so that some tracks were accumulated at temperatures of between 60-125°C. The vitrinite reflectance data tends to support the latter hypothesis, as values above 2.0 $R_o max$ suggest paleotemperatures greater than 150°C. In this case, the thermal maximum would have been reached prior to the age of these young samples, that is in the mid-early Cretaceous.

Previous views on the history of the region have involved rapid burial followed by cooling towards the end of the Triassic, with subsequent stability, but the fission track data clearly shows widespread Cretaceous effects. At this stage it is not certain whether the thermal effects responsible for the observed fission track data result from increasing depths of burial, or an increased heat input associated with intrusive activity (known in the north of the Basin) or a combination of the two. Sampling of similiar units in the north of the Basin, particularly in relation to the Cretaceous intrusives, is underway in an attempt to resolve these issues.

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TERTIARY GEOLOGY OF THE GORDONSTONE AREA

P.J. Hanna, McElroy Bryan & Associates Pty Limited

The Gordonstone prospect, (A to P 389c), situated south of the Gregory Mine, lies near the southern extent of the German Creek Coal Measures on the Comet Ridge. Mining of the German Creek Seam at Gordonstone will be by underground methods as the coal measure sequence is covered by a thick blanket of Tertiary strata averaging about 65m and ranging up to 110m in thickness.

The lateral changes in the Tertiary rock types are irregular and complex, making correlation from borehole to borehole difficult. The Tertiary strata include the lithologies described below.

BASALTS

As many as eight (8) distinct basalt flows can be recognised in the Gordonstone area, all characteristic of undersaturated intraplate alkali basalts. The olivine phenocrysts indicate that some basalts are quite fresh while others have undergone complete alteration. Nearly all the basalts are vesicular to some extent, the vesicles ranging from less than 2mm to greater than 2cm in diameter. The vesicles may be empty or filled with calcite, chalcedony, or iron oxides.

HIGHLY WEATHERED BASALT

Irregularly interlayered with the basalts are green montmorillonitic clays. These clays are extremely weathered products of basalt flows and contain remnant magnetite crystals. They are of low to medium strength and often contain sporadic thin hard bands of cherty material.

ALTERED TUFF

It is uncertain whether the tuff is mafic or intermediate as it has been extremely altered to a cream coloured clay in most drill cores. Thin sections illustrate a flattened ignimbritic structure which has been almost obliterated by the alteration.

SILCRETE

Thin layers of silcrete (usually less than 1m thick) are found sporadically throughout the Gordonstone area. The silcrete is a product of subsurface silica concentration and is characterised by sand size fragments cemented in a siliceous matrix.

LIGNITE

Dark brown to black lignitic material occurs in some areas and can be up to 2m thick, but are not continuous laterally. The lignites often display wood and plant fragments and may have a significant kerogen content.

CLAY

Clay represents a significant proportion (about 75%) of Tertiary sediments in the Gordonstone prospect. The clay has high plasticity, is hard, fissured and has a variety of colours including grey, red, brown, orange, yellow, purple, pink and buff. In some areas the clay is interbedded with sandy clay containing up to 50% fine to coarse grained sand.

CLAYEY SAND

Beds of semi-consolidated "sandstone", usually found below the clay, represent an upward-fining sedimentary sequence in the Tertiary strata. The sand is fine to coarse grained with up to 50% matrix of high plasticity clay.

SAND AND GRAVEL

Although irregular in occurrence, unconsolidated sand and gravel often occurs at the base of the Tertiary sequence. These beds range from medium sand to pebbly grainsize and are composed of sub-angular quartz (85%) with lesser amounts of lithic and volcanic fragments. The sand and gravel beds are remnant channel deposits and their thickness can be up to 30m. The channel sands are often less than 200m wide.

Groundwater Studies of the Tertiary sequence at Gordonstone have delineated two main aquifers, which together, can produce airlift water flows of more than 25 litres/second (40,000 gals/hour). The main aquifers are the basalts and the basal sand/gravel beds. Although the columnar jointing and fracturing of the basalt flows is a source of groundwater in some areas, the more significant water flows are from brecciated zones between adjacent basalt flows. In outcrop, these brecciated zones are observed to consist of voids up to 0.3m across.

The sand and gravel beds which occur in the palaeo-valleys of the early Tertiary land surface have high porosity and permeability. These unconsolidated sands and gravels are a source of significantly high water flows. The salinity of water from the sand and gravel beds is found to be generally lower than that of the basalt aquifers.

The Tertiary sequence at Gordonstone has created drilling difficulties throughout the exploration programme. The high swelling nature of the clays and the constant caving of unconsolidated and water saturated sand and gravel has necessitated the use of steel casing in every borehole at Gordonstone. Larger diameter drill holes were affected most by the Tertiary strata and many were redrilled three or more times before steel casing could be inserted to below the base of the Tertiary, often up to 90m. The large flowing aquifers often caused loss of air and water circulation while drilling through the Tertiary. This was overcome by the use of drilling muds to "seal" the aquifers until casing could be set in the hole.

Access to the German Creek Seam by drift of shaft through the Tertiary sequence poses special problems at Gordonstone because of:

(a) the extreme variation in rock strength, from extremely hard basalt through to very weak unconsolidated sand and gravel,
(b) the instability of strata, in particular, the high swelling clays and the unconsolidated sand and gravel beds,
(c) the high groundwater flows from the basalts and the sand/gravel aquifers.

Geotechnical studies of the Tertiary strata have been carried out and more testing will be necessary to provide sufficient data for the design and construction of mine access and ventilation at Gordonstone.

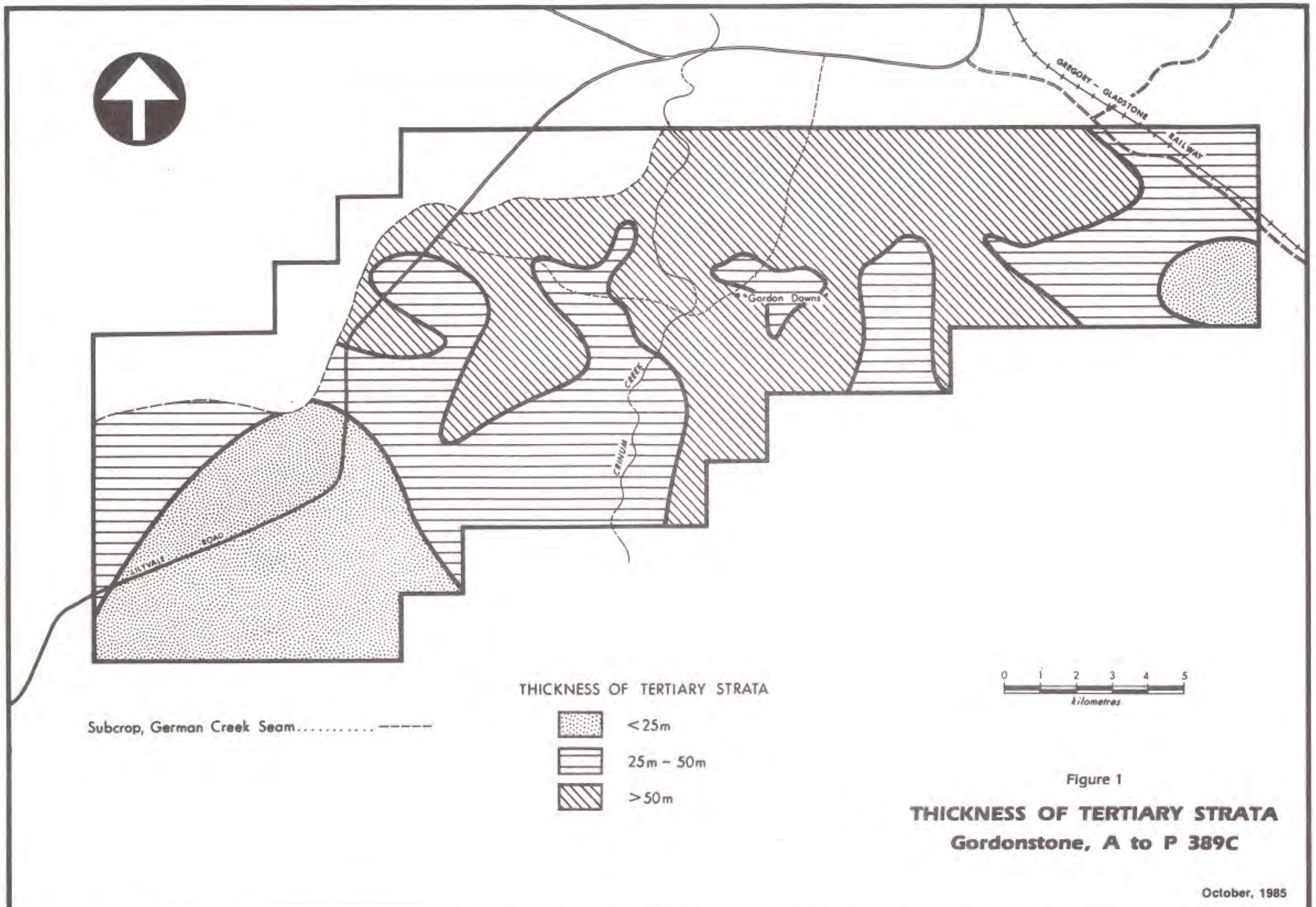

Figure 1

THICKNESS OF TERTIARY STRATA
Gordonstone, A to P 389C

October, 1985

Prepared by McElroy Bryan & Associates Pty Limited

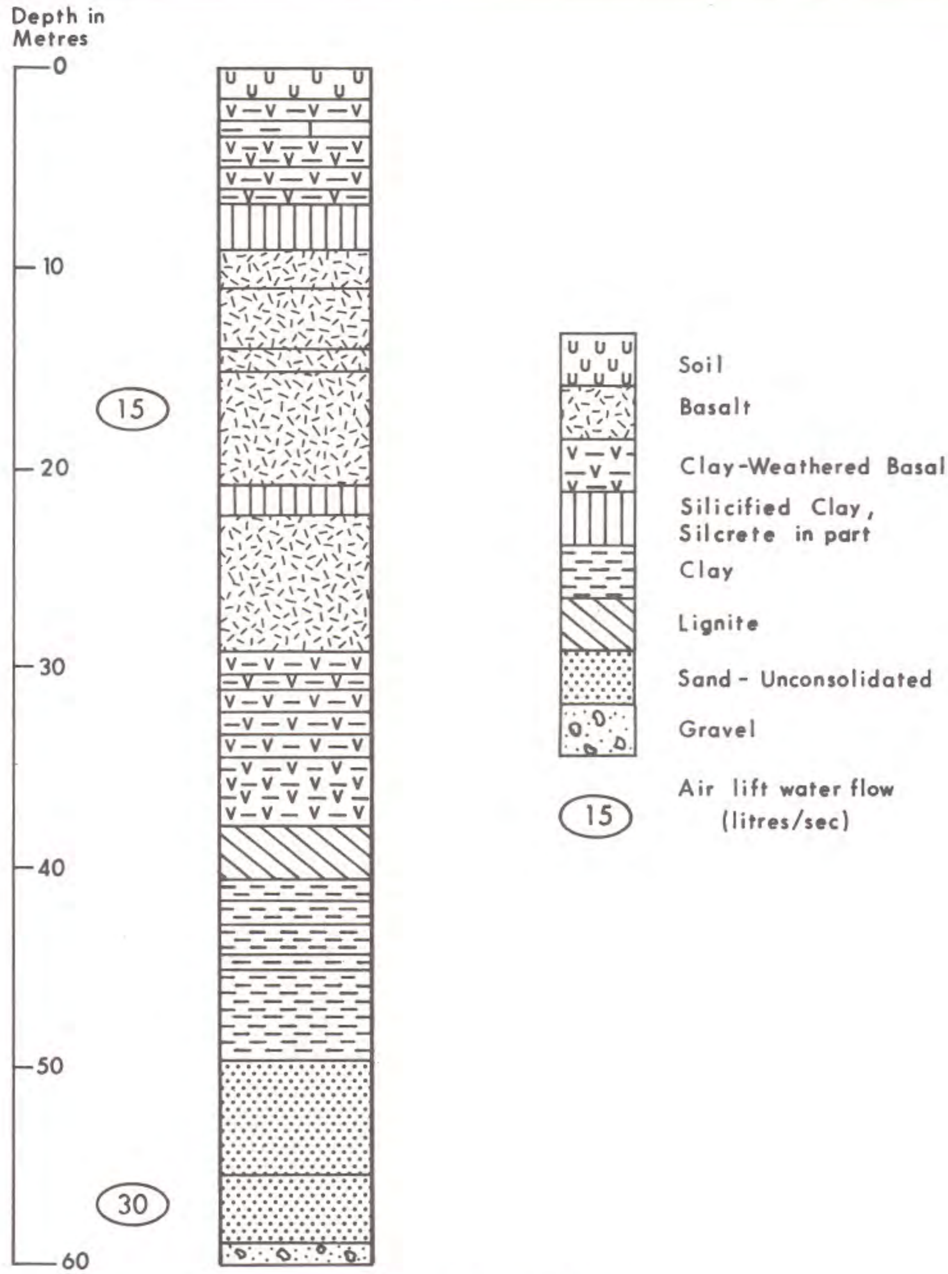

Figure 2
TYPICAL STRATIGRAPHIC SECTION TERTIARY STRATA Gordonstone, A to P 389C

October, 1985

Prepared by McElroy Bryan & Associates Pty Limited

CLAY ROCK DIAGENESIS

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In the Bowen Basin, the stability of spoil piles and highwalls is in part controlled by the behaviour of weakly lithified clay-rich rocks (clay rocks) that are often present in the interseam and overburden sequences. A better understanding of the mechanisms of clay rock behaviour and a knowledge of their distribution should allow better mine design, adoption of correct remedial measures should failures occur, and a soundly based transfer of experience from one mine to another. In this paper data gained during a study of the engineering behaviour of clay rocks is interpreted in terms of the diagenesis of clay rocks.

The following factors influence the behaviour of clay rocks during mining, especially when water is present: grain size distribution, mineralogy, cementation, texture, and exchangeable cation composition. These factors are geological functions of source materials, depositional environments, diagenesis, and weathering. Broadly speaking, the clay rocks in most of the coal measures in the basin had similar source materials and were deposited in similar depositional environments (refer other speakers, this symposium). Coal rank varies across the basin indicating different levels of diagenesis. Vitrinite reflectance data provides a useful framework to trace the diagenetic evolution of the clay rocks.

The clay-size fraction (which is typically 30-50% by weight of the rocks) is composed dominantly of kaolin, illite, quartz, and an interstratified illite/montmorillonite (I/M). The I/M has an ordered structure with a rectorite phase often present. Similar I/M is associated with the diagenetic transformation of montmorillonite to illite and the temperatures at which it is 'stable' are similar to those that can be calculated from the vitrinite data of the Bowen Basin coals. Some of the illite and the quartz may be diagenetic. The origin of the kaolin has not been established.

At Goonyella a chlorite and randomly interstratified I/M assemblage has been identified. Its occurrence is anomalous in the context of the vitrinite data. Of interest is that despite the XRD pattern, under the TEM the clay is seen to be composed of thin laths of illite. A randomly interstratified I/M is also present in the immediate floor of A seam, Moura Mine, but here its presence may be related to in situ leaching by seam waters.

The I/M is present as clay stacks that range in size up to 15-20 microns. These stacks are the result of particle alignment during compaction and growth of the clay during diagenesis. On disaggregation these stacks may break down to the laths referred to previously. These textural features of the clay have important implications to engineering behaviour.

The dominant cement in the clay rocks of the Bowen Basin is carbonate (see Johnson, this symposium). There are sufficient diagenetic sources of Ca, Mg, Fe etc. to account for this cement. Silica is also produced during diagenesis but it is yet to be identified to be an important cement. Organic matter also acts as a weak bonding agent. Assuming that pervasive cementation develops late in diagenesis after compaction, rock bulk density should give a measure of the degree of cementation. Comparing typical density profiles with vitrinite data, the low density Riverside/Goonyella sequences are anomalous. Possible interpretations include non deposition of carbonate, a diagenetic event that dissolved carbonate, or weathering.

During diagenesis the divalent cations calcium and magnesium tend to replace sodium on the exchange sites of clay. Despite this the exchangeable sodium percentage (ESP) of Bowen Basin clay rocks is typically 25-50. At sites examined so far the ESP is closely related to the composition of water from the adjacent coal seam. Except at South Blackwater, calcium is more dominant than magnesium on the exchange sites. At South Blackwater, the low ESP (5-10) and a Mg/Ca ratio greater than 1 are believed to be related to the proximity of Tertiary sequences.

CARBONATE DIAGENESIS OF COAL MEASURE SEDIMENTS

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INTRODUCTION

Carbonate cementation particularly as concretions is a widespread phenomenon in coal measures, (e.g. Taylor and Spears, 1967; Curtis, Pearson & Somogyi, 1975; Matsumoto & Iijima, 1981). The formation of coal measure carbonates can be readily understood in borad terms, even if the details their precipitation are not so well known. Appropriate cations, particularly Ca, Mg, Fe and Mn could come from groundwaters during deposition, from alteration of detrital grains such as feldspar and rock fragments, or be derived from exchangeable sites on clays during diagenesis. The carbonate component could be due to carbonate in groundwaters, but more likely is derived from CO_2 liberated by any of a large number of organic geochemical reactions. For example CO_2 could be derived by bacterial respiration, oxidation of biogenic methane, or from decarboxylation reactions during diagenesis.

Carbonate cementation in the Moranbah Coal Measures is of three types: 1) concretionary, 2) pervasive and 3) void fill. Concretionary cements generally occur in fine-grained lithologies, whereas pervasive cements generally occur in sandstone units and are associated with clays. Void fill cements (such as joint or fractures in concretions) occur in all lithofacies and their situation indicates very late formation.

CONCRETION TYPES

Five major types of concretion have been recognised:

1) Large concretions
2) Small concretions and stratal cementation
3) Displacive lenses
4) Fracture lenses
5) Mineralised stumps and logs.

Large Concretions

Large concretions are rounded, lenticular, domal or extensive stratal masses up to 1 m thick and several metres long. Macroscopic, concentric zoning is rare, and bedding is rarely obvious within the concretion unless outlined by abundant plant debris. Large concentrations are generally fractured with fracture surfaces coated by white clay or iron oxides. Bedding is severely warped around concretions, both above and below, indicating formation early in diagenesis. Mineralogy is ferroan dolomite with siderite/ferroan dolomite at the periphery.

Large concentrations occur mainly in the siltstone/sandstone and the lower parts of siltstone lithofacies. Cementation is commonly confined to siltstone beds, even with adjacent sandstone layers warped around the concretion.

Small Concretions and Stratal Cementation

Small concretions are rounded, generally elliptical masses of carbonate-cemented sediment. There is a continuous gradation from isolated concretions, to linked, sausage-like masses, to extensive stratal cementation. Typically, concretions are 10 to 15cm across and the cementation 4 to 10cm thick and extending laterally up to 100m. Small concretions are not radially zoned but bedding is commonly preserved within them. Stratal cementation may be homogenous, or faithfully preserve laminae over extensive distances, even laminae showing soft-sediment deformation. That is, some stratal cementation has occurred late in diagenesis.

Bedding wraps around concretions, and one case was seen where the concretion was surrounded by slumped laminae indicating movement of the concretions while the sediment was still soft. Small concretions clearly form early in diagenesis.

Small concretions and stratal cementation are very common in the siltstone and siltstone/sandstone lithofacies. In the siltstone lithofacies they form banded outcrops ("dolosiltstones" of Godfrey, 1978), where repeated beds 4 to 10cm thick, and only 10cm apart may extend up to 100cm along the outcrop.

Mineralogy is mainly ferroan dolomite with minor siderite, though stratal cementation may be almost completely siderite. Samples which display surrounding compaction invariably have ferroan dolomite, while siderite characterises beds without compaction. Geochemical analyses confirm a stratal pattern rather than a radial pattern of composition.

The high Fe content of certain layers may be due to higher original levels of organic material, on which Fe was complexed (Baas Becking & Moore, 1959; Rashid & Leonard, 1973). Such a conclusion is supported by the direct linear relationships between Fe and percent organics determined for the samples. Data from each type of concretion plot almost as straight lines. The different axis intercepts probably reflect differing grainsizes or types of organics which had differing amounts of complexed Fe, or reflect concretion formation at different stages during diagenesis when varying amounts of Fe had been desorbed.

Displacive Lenses

Displacive lenses are flat, lenticular bodies, which consist internally of irregular layers of ferroan colomite which split sedimentary layering apart. Laminae can be traced from an original sedimentary layer, split by carbonate and then re-joining. Individual carbonate layers are up to 2cm but most are less than 0.5cm thick.

Individual displacive lenses are 20 to 30cm thick and about 0.5m long, and it is common for several to be developed *en echelon* against each other. Surrounding compaction is normal. Displacive lenses were found only in the siltstone/sandstone lithofacies.

Fracture Lenses

Fracture lenses are flattened, lenticular bodies of similar dimensions to displacive lenses. Internally the host sediment is split by a series of curved fractures forming a "feathered" pattern. Fractures may extend outside the lens to penetrate surrounding mudstone or sandstone layers, however most fracturing is confined to the lens. Fractures are filled with cloudy ferroan dolomite/clay mixtures with a cross-vein structure. Plant debris has been thinned across the fractures and appears to have been stretched across fracture formation.

Fracture lenses show compaction above and below. They occur in the siltstone and siltstone/sandstone lithofacies within 3cm of the top of the Goonyella Middle seam. This distribution parallel to the top of the seam contrasts with the distributions of other forms of concretion which occur throughout lithofacies units.

Isotope Data and Interpretation

Carbon and oxygen stable isotope ratios of concretionary carbonates indicate low temperature, early diagenetic origins for the concretions. $\delta^{18}O$ values reflect an overprint of ^{18}O depleted meteoric waters from high palaeolatitudes and probable alpine influence. A single large concretion (1m x 5m cross-section) from sandstone/siltstone lithofacies had siderite, dolomite and minor calcite cements, all carbonates forming at depths of less than 1000m. Several small concretions (typically 15cm across) have siderite cements of early diagenetic origin and dolomite cements formed at higher temperatures and depths 900m to 1500m.

Isotopic data, particularly $\delta^{13}C$ values, suggests that two processes were active carbon dioxide sources for the concretionary carbonates, (a) bacterial fermentation of soluble degraded organic matter giving the most ^{13}C enriched primary carbonates, siderite and calcite, in a large concretion, and some siderite is small concretions and (b) thermally dependent decarboxylation of immature organic matter, most probably from the palaeo-low rank coal of the Goonyella Middle Seam, giving ^{13}C depletion to secondary dolomites and some siderite of the small concretions.

Concretion Development

Carbonate concretion development at Goonyella is a complex matter. Most cement is now ferroan dolomite and appears to have formed early in diagenesis. The origin of the cations is not known and there is a distinct possibility that the present ferroan dolomite mineralogy is not the original cement, but formed during later diagenesis, perhaps by replacement siderite or calcite. However there is circumstantial evidence that the Fe content of the cement is controlled by the amount of organic material in the sediment.

A puzzling feature of the cementation is that cements which are mineralogically the same (ferroan dolomite) occur in two distinct, but intergrading forms:

1) Incorporative - void fill and grain replacement;
2) Displacive - splitting laminae (displacive lenses) or in fractures (fracture lenses).

Both forms occur early in diagenesis as evidenced by surrounding compaction, and both can be shown to intergrade, indicating formation at much the same time. The reason for the different modes is not clear but may be due to differing rates of crystallisation from supersaturated solutions. The displacive forms could be due to faster growth which forces the sediment fabric apart while incorporative forms develop during slower, steady cementation which allows time for grain replacement.

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TECTONICS AND STRUCTURE

REGIONAL STRUCTURE OF THE NORTH DENISON TROUGH

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1. INTRODUCTION

As part of a regional study of the Denison Trough initiated by AAR Limited/OCA NL joint venture, a combined landsat, seismic structural and seismic stratigraphical analysis is underway to determine the tectonic history of this gas province. This paper summarises the results of this study to date.

The technique of seismic stratigraphy combines biostratigraphy, core and log facies analyses with seismic style and geometry to delineate successive depositional sequences and to establish the relative age and nature of their boundaries (Vail et al, 1977). This enables the style and relative chronology to be established for each tectonic regime. These depositional sequences have been designated with roman numerals (fig. 4). This designation bears no relationship to the Permian faunal zones of Dickens et al (1964).

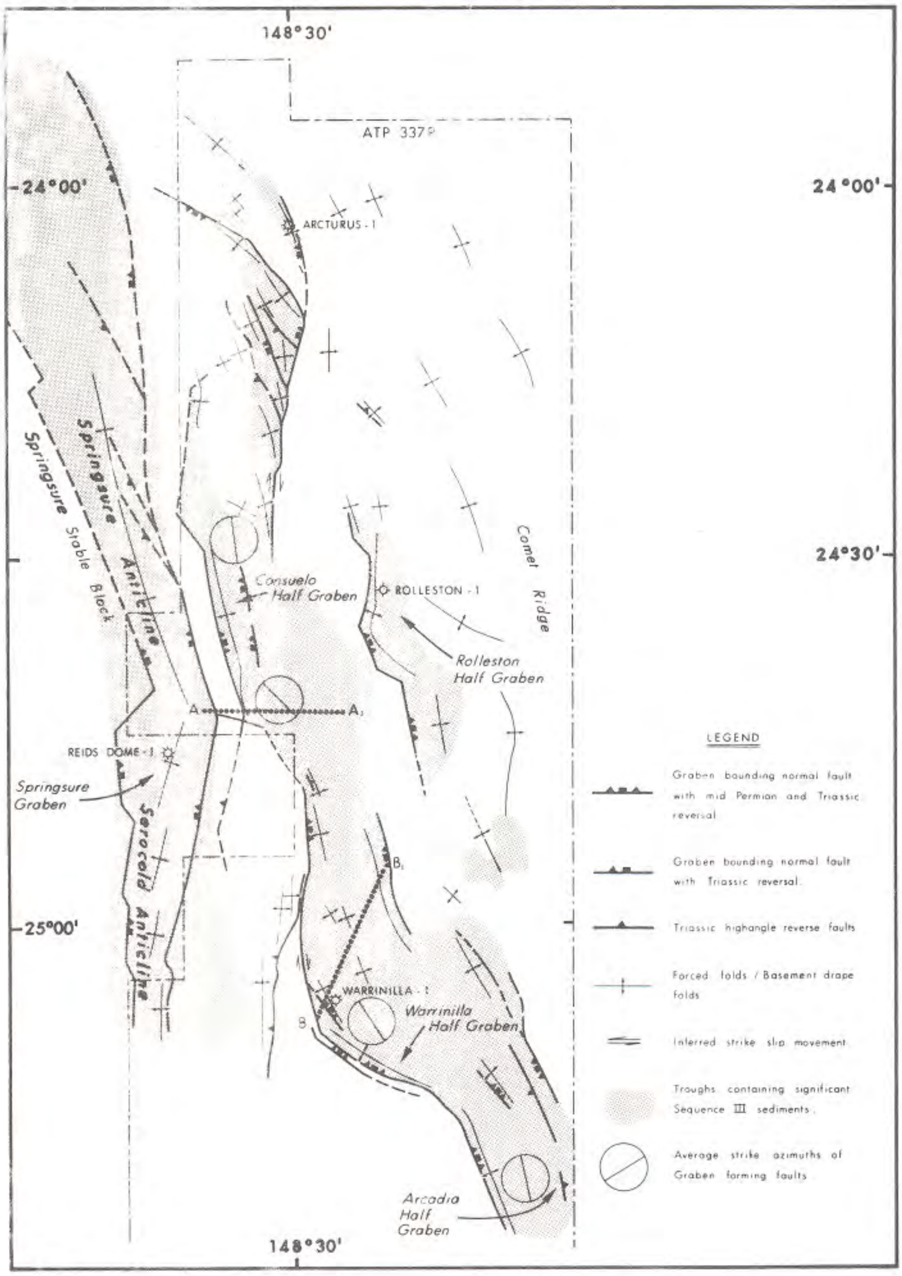
2. NORTH DENISON TROUGH STRUCTURAL ELEMENTS

The principal structural elements of the North Denison Trough are composite structures reflecting several phases of tectonism that spanned the Permo-Triassic (Figure 1).

The "Trough" consists of several north trending grabens and half grabens that formed towards the beginning of the Permian (Brown, 1977). These grabens and half grabens were subjected to a mild compression during the early to mid Permian and a more intense compression during the Late Triassic. These compressions resulted in positive inversion (Harding, 1985) by flexural folding above the axial zones of the grabens and by reverse movement of graben/half graben bounding faults with consequential assymetric force folding of the overlying sediments.

Significant mid-Permian reversal and folding was restricted to the boundary faults of the Consuelo, Warrinilla, Arcadia and Rolleston half grabens. The Triassic compression reactivated all the boundary faults as well as producing pure high angle reverse faults.

Direct evidence for strike slip movement is not present. However limited compensatory right lateral strike slip is expected along the western flank of the Warrinilla half graben to accommodate extensive



NORTHERN DENISON TROUGH

PERMO / TRIASSIC STRUCTURAL ELEMENTS

BASED ON SEISMIC & LANDSAT INTERPRETATION

0 10 20 30 40 km

AUTHOR V. Ziolkowski, R. Taylor

Figure 1

reverse movement on the southern boundary fault. Further evidence for right lateral movement occurs in the Arcturus 1 area where the principal north trending fault is associated with possible NW trending wrench or wrench enhanced anticlines. In the northeastern area a set of compressionally enhanced basement drape folds occur.

Essentially all of the extensional features indicate an east-west or northeast-southwest extensional component. Most of the compressional features suggest a compression directed from the north east.

3. STRUCTURAL HISTORY

Seismic and borehole data shows that basement in the north consists of north-south trending folded terrain of Devonian-Carboniferous sediments, metasediments and acid volcanics. This terrain may in part have formed the fold belt to the Carboniferous Drummond Basin to the west. At some stage during the late Carboniferous or earliest Permian this terrain was subjected to extensional tectonics and north south trending grabens and half grabens formed (Figures 2, 3a). The graben bounding faults utilized the basement grain, occasionally dog legging to adjacent grains (Figure 1). Synchronously with this deformation, typical early stage graben sediments of sequence III (Figure 4) filled these troughs (this sequence includes the basal part of the Reids Dome Beds). The sediments shed off bounding fault scarps, forming talus slopes and alluvial fans that impinged on restricted flood plains and lakes. Fluctuations in base level coupled with continued extensional faulting resulted in several unconformities within sequence III. Finally a major drop in base level associated with continued extensional faulting resulted in a regional angular unconformity at the top of this sequence (Figures 2, 3a).

Following the extensional phase, the North Denison Trough underwent regional (thermal(?)) sag, with normal adjustment movement along the graben bounding faults and some larger intra graben faults (Figure 3b). This was initially accompanied by deposition of flood plain/lacustral sediments of sequence IV (Figure 4) in the deeper parts of the grabens/half grabens. These terrestrial sediments gave way to marine sediments as the first major marine transgression took place (eustatic overprinting of the continuing tectonic sag). Several westerly sourced, low energy regressive pulses of restricted coastal plain to shallow marine siliciclastics were deposited onto tilted, rotationally faulted sequence III strata (Figures 2, 3b). These sequence IV sediments initially confined to the troughs, eventually spilled out onto the Comet Ridge to the east. Sequence IV includes most of the Cattle Creek Formation and lowermost Aldebaran Sandstone (Figure 4).

Apart for some local evidence of flexuring deep within sequence III, both III and IV thicken into the grabens and half grabens (Figure 2). Deposition was focused by normal faulting. At the end of deposition of sequence IV the first evidence for the onset of compression occurs. Low amplitude flexuring of the graben fill and subtle force folding above half graben boundary faults preceded deposition of sequence Va (Figure 2, 3c). This phase marks the beginning of positive inversion of the grabens/half grabens and

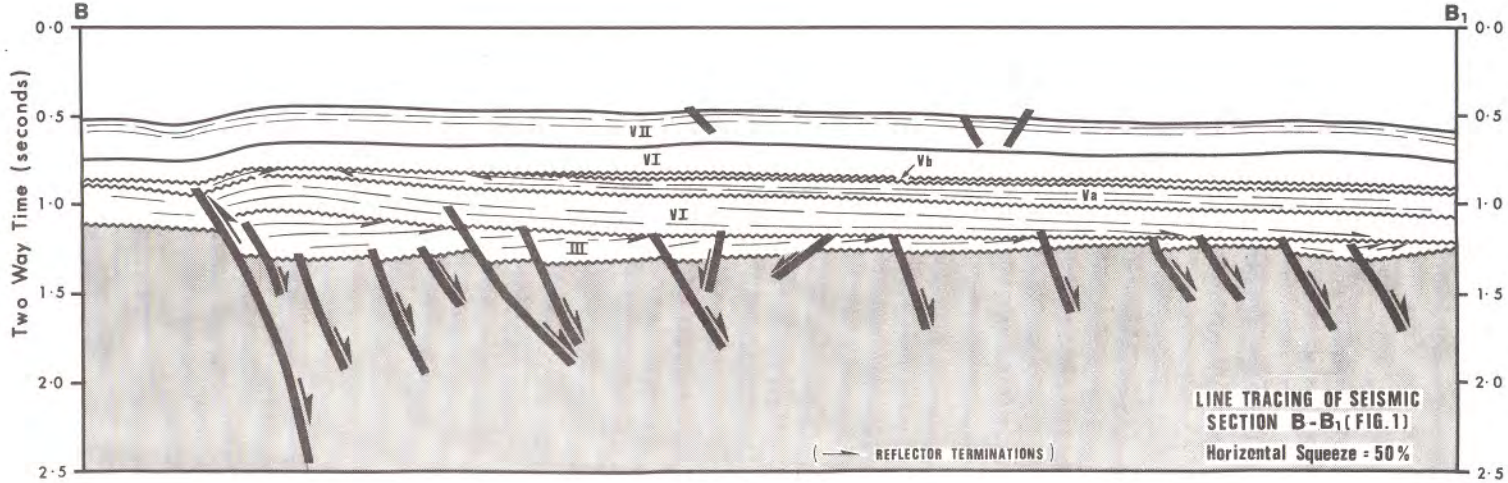


Figure 2 (a)

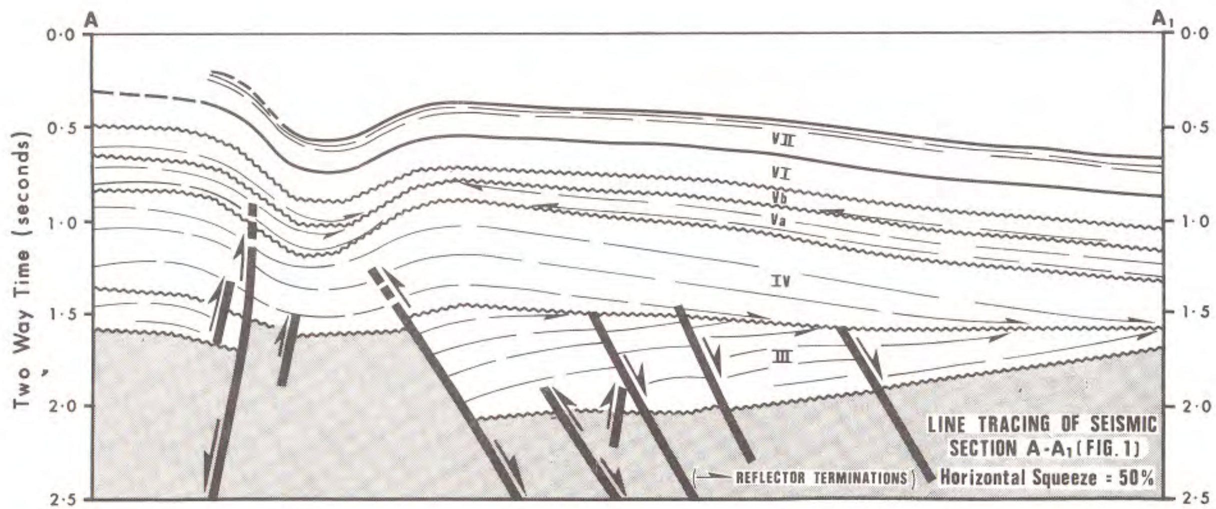
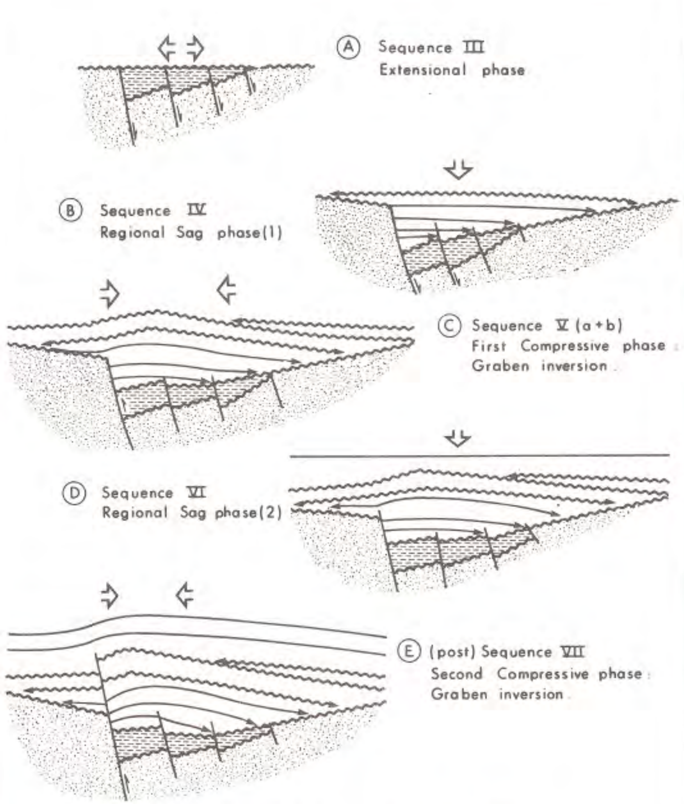


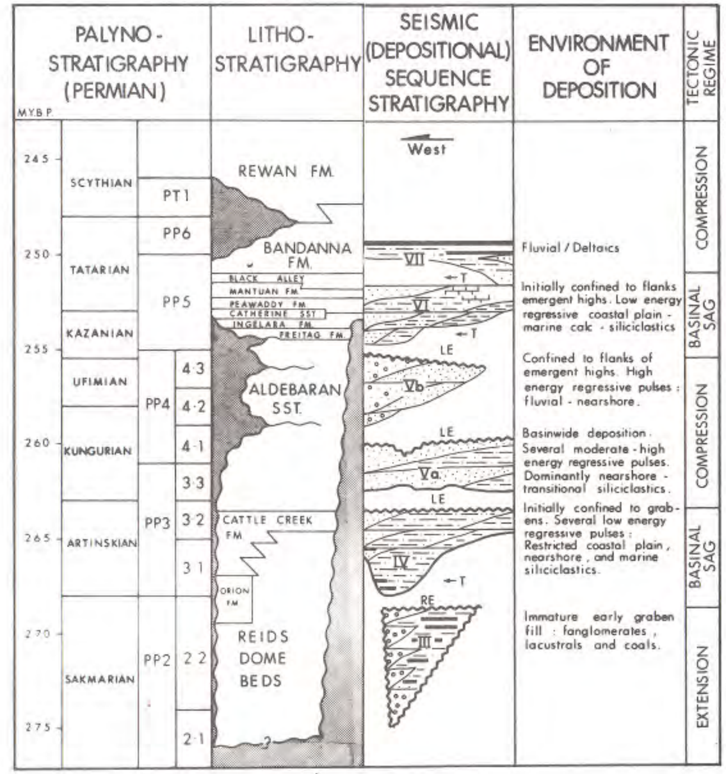
Figure 2 (b)



STRUCTURAL EVOLUTION OF THE WARRINILLA INVERTED HALF GRABEN

AUTHOR : V. Ziolkowski

Figure 3



DENISON TROUGH STRATIGRAPHY

RE = REGIONAL EROSION
←T = MAJOR TRANSGRESSIONS
LE = LOCAL EROSION OF HIGHS

AUTHOR : V. Ziolkowski
Palynostratigraphy from Price 1985

Figure 4

thickening away from the graben/half graben axes of subsequent sequences.

Sequence V (including the Aldebaran Sandstone) reflects this tectonic rejuvenation. The sediments are coarse grained, bed load dominated, transitional to shallow marine siliciclastics. The source was still predominantly from the west. Continued compression, accompanied by a major relative drop in base level, resulted in the major angular unconformity between sequence Va and Vb. Sequence Vb was deposited as a high energy fluvial-shallow marine siliciclastic wedge on the flanks of these emergent highs (Figure 2, 3c). Reverse movement along the graben/half graben bounding faults continued after deposition of sequence Va/b and extensive erosion of the emergent highs occurred (Figures 2, 3c).

Following the mid Permian compression the basin returned to relative tectonic quiescence with onset of regional sag. A major transgression occurred and sequence VI was deposited, initially on the flanks of the emergent highs but eventually blanketing the entire region (Figures 2, 3d). This sequence (including the Mantuan to Frietag Formations (Figure 4)) reflects the tectonic quiescence with low energy coastal plain-paralic-shallow marine calc-siliciclastics being deposited. In the vicinity of the North Denison Trough this set of regressive pulses were sourced from the west and northwest.

A major transgression followed deposition of sequence VI. This transgression heralded a change in basin geometry with fluvio/deltaics from the evolving foreland to the east, inundating the basin. Sequence VII (containing the Black Alley Shale and the Bandanna Formation (Figure 4)) was the first of these units. Following sequence VII deposition the basin was subjected to the most intense compressive phase with reactivation of reverse movement on the graben/half graben bounding faults (Figures 2, 3e) and with the evolution of pure high angle reverse faults and possible right lateral compensatory strike slip movement (Figure 1).

4. CONCLUSION

The elements that form the tectonic framework of the north Denison Trough are multiphase. Commencing with extension tectonics in which narrow grabens and half grabens were formed and then mid Permian and late Triassic compression in which the troughs were inverted. These structures are identical to modern structures in the peri-cratonic margins of the back-arc basins of Sumatra where Paleogene grabens have been compressed and positively inverted during the Neogene (Harding, 1985).

The authors wish to acknowledge P. Price of CSR Oil and Gas Division for the extensive palynological data without which this form of study could not be undertaken.

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STRUCTURE OF THE NORTHERN BOWEN BASIN

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STRUCTURE

Within the area outlined on the locality plan the Bowen Basin is divided, tectonically, into the stable Collinsville Shelf and the active Nebo Synclinorium. Seams to the west of the hinge line tend to be clean, continuous and moderately thick. Seams to the east of the hinge line are dirty, split, discontinuous and more numerous under the conditions of instability, rapid subsidence and rapid sedimentation. The thickness of the Moranbah Coal Measures decreases across the hinge line.

Two series of thrusts are important; the thrusts on the eastern margin of the basin, such as the Collinsville Fault and those thrusts associated with the hinge line separating the Nebo Synclinorium and the Collinsville Shelf. The strike of these features is N to NNW.

Two of these thrusts, the Burton Range thrust and the Rosella Creek thrust have a related series of strike slip faults striking S.W.

Strong E - W lineaments can be traced on Landsat photographs through basin sediments and the adjoining igneous complexes particularly in the vicinity of the Bowen River and the Newlands mine. There is strong evidence for a major uplift of Bowen Basin sediments north of the Bowen River.

Dyke swarms occupy tension fractures associated with the major thrusts. These are orientated east west in the north and south west in the south.

A line of Tertiary basalt plugs, apparently unrelated to major fault directions, bears NW in the central south of the area.

APPENDICES

1. Locality plan.
2. Structural Elements of the Newlands - Collinsville Area.
3. Cross Section A-A'.
4. Cross Section B-B'.

FIG. 1

LOCALITY PLAN

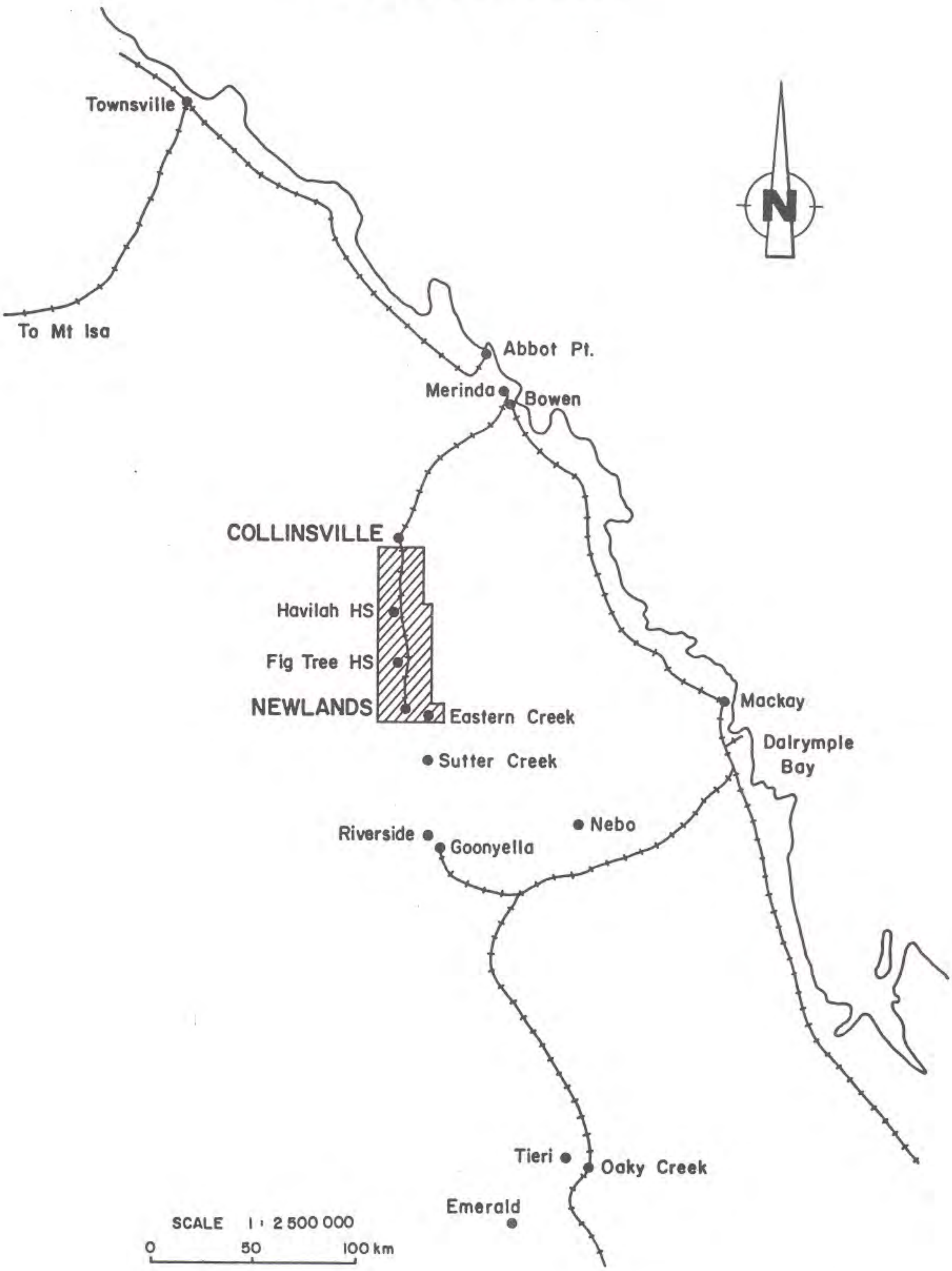


FIG. 2

STRUCTURE
COLLINSVILLE – NEWLANDS AREA

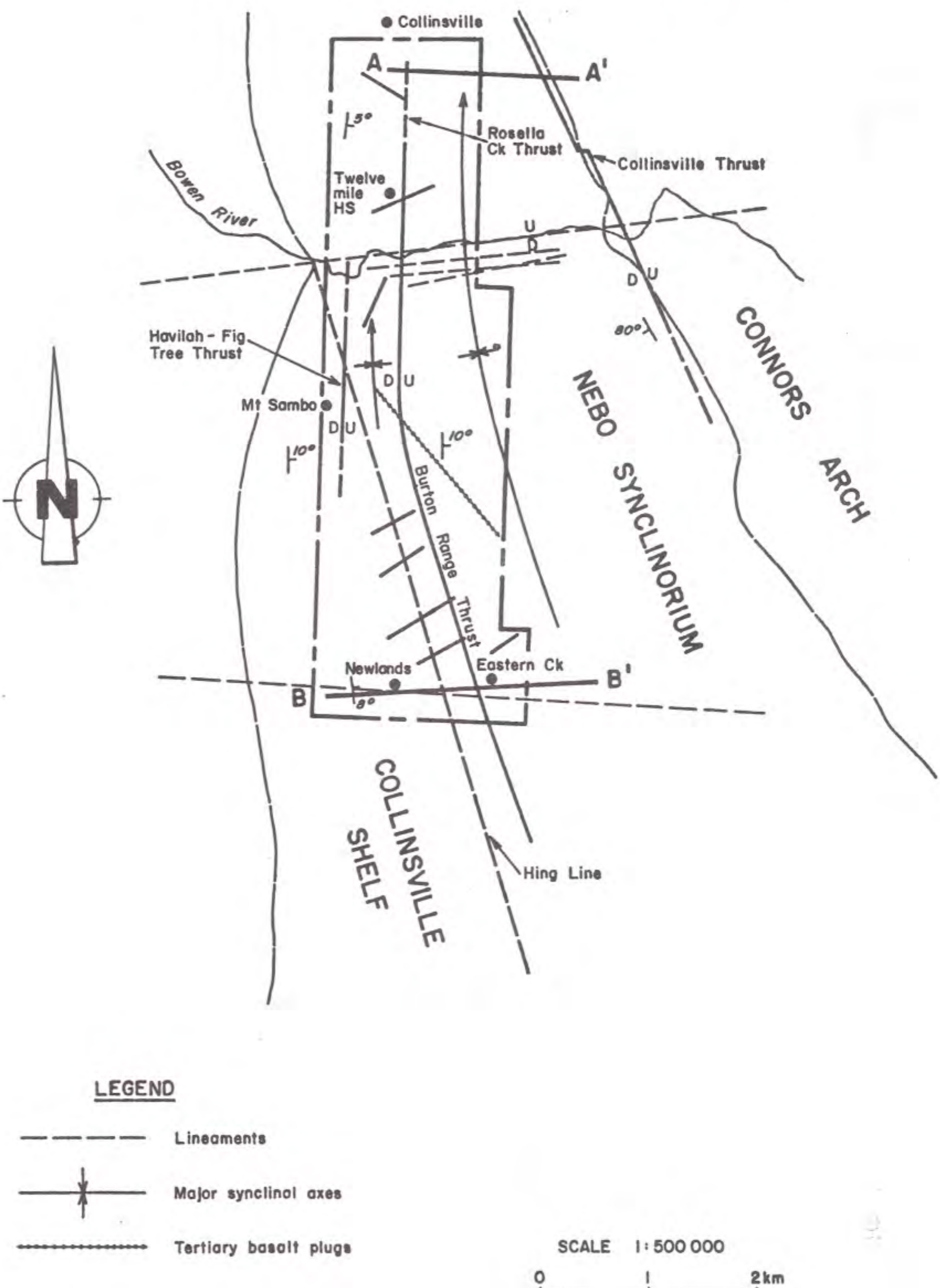


FIG. 3

CROSS SECTION A-A' THROUGH BELMORE AREA

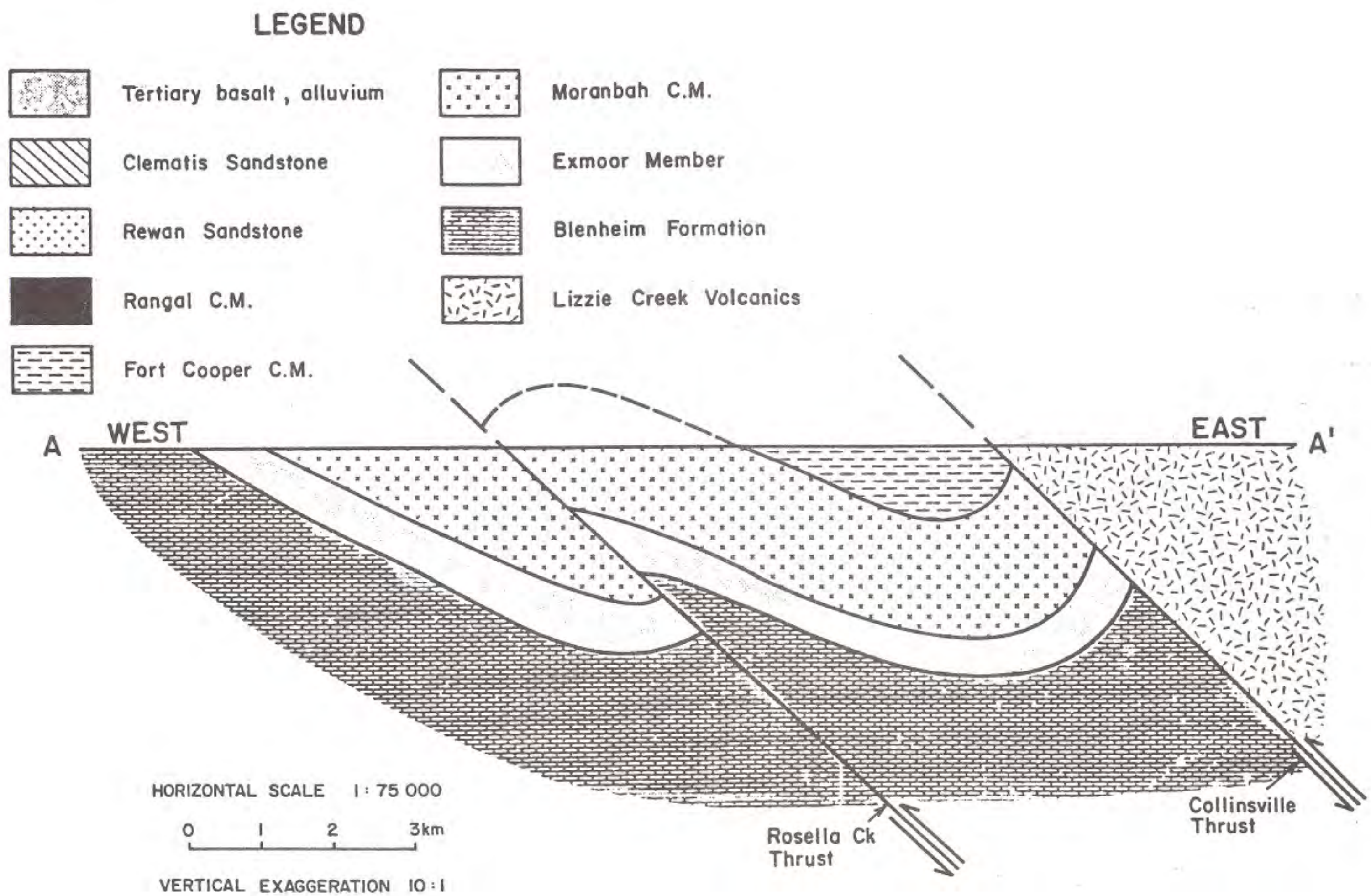
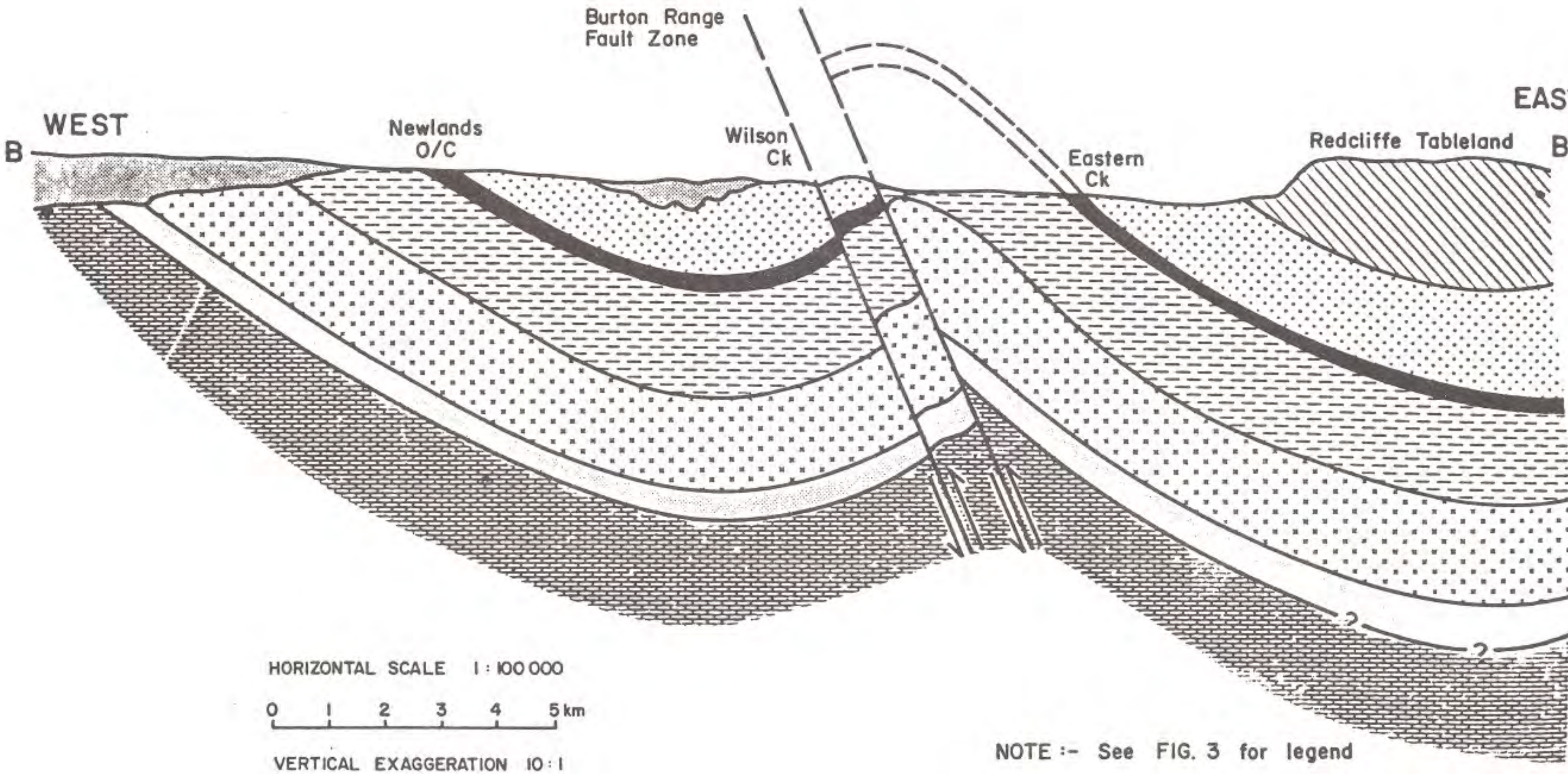


FIG. 4

CROSS SECTION B - B'
THROUGH NEWLANDS - EASTERN CK AREA



STRUCTURAL LINEAMENTS IN THE BLACKWATER AREA

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L.R. Grimstone, Lance Grimstone & Associates

J.M. Gorman, Curragh Queensland Mining Curragh Mine

The mines of the Blackwater district are located on the eastern margin of the Comet Ridge. West of the Jellinbah Fault, the coal measures dip gently to the east at 3 to 7 degrees and strike north-south. This north-south strike is displaced from 0.5 to 4 km by a series of northwest - southeast striking thrusts spaced at 5 to 10 km. Strike is also modified by north-east - south-east strike slip faults which displace the thrust zones. Normal faults and dykes are aligned in a north-east - south-west direction.

A series of thrust faults roughly parallel the Jellinbah Fault and includes the Como Fault striking through Curragh Mine, the Shotover Fault passing through Blackwater township, and other unnamed faults to the south. These thrusts are strong continuous regional features which can be traced through the Mesozoic rocks forming the Blackdown Tableland. The largest of these is the Shotover Fault which has a broad outcrop zone of structural disturbance in the coal measures. The seams are displaced by the fault approximately 4 km to the west from the southern limit of Curragh Mine to the northern extension of the strike of Blackwater Mine north of the railway line. No exposure of the fault has been made in any of the mines, but it is well documented in boreholes and seismic sections.

The Como Fault has been exposed in Curragh Mine where the overthrusting causes the displacement of seams to the west from Pits C east to Pit C. The thrust is a complex of faults with an overall dip of about 10 degrees to the north-east, with overthrusting from the north-east.

The zone of serious disturbance at the surface is about 1 km wide. The leading edge of the thrust has not been exposed, but early cuts in Pit C east were within a few hundred metres of it. At depth the thrust has little discernible effect in the drill cores, and is confined to a single plane lying in the bedding or at a very low angle. At the level of the Orion seam there is only minor disruption of the seam. In the Pollux seam, the thrusts are confined within the seam over long distances. This dramatically deforms the seam, and the overthrusting forms sheared bands, areas of thickened and thinned coal, and duplicated seams. These effects depend on the position of the thrusts within the seam. The south-east extension of the thrust can be mapped into the Curragh East area by the band of deformed Pollux seam, which in places is stripped entirely of coal for a width of 0.5 km. This gives a minimum distance of horizontal overthrusting associated with the fault. Numerous small saw tooth faults intrude floor and roof sediments into the seam.

As the thrusts move upsection they bifurcate or radiate, and steepen, giving many more faults and faulted blocks. Not only do bedding plane faults lie within the Aries Castor seam, but the seams break into many wedges and fault slices. Significant shortening and complementary thickening of the section occurs, and this effect can be used to trace fault zones. The wedges are bounded by horizontal and low angle north-east and south-west dipping thrusts. They are driven up or down depending on their orientation, as the thrust blocks react across the fault.

A block about 1 km wide at the surface to the north-east of the thrust, dips gently south-west towards the main thrust plane. The block is bounded on its north-east side by a steep fault which branches off from the main thrust at depth. It changes its dip from north-east to south-east, but during deformation the north-east side rises over the south-west side in the same sense as the main thrust. For south-west dipping sections of the fault, this generates a pseudonormal fault configuration by variations in the thrust plane orientation. The pseudonormal style is fairly common throughout the thrust zone, particularly in the radiating zone with wedge blocks. The stresses associated with movements on these curved surfaces result in the formation of bedding planes and low angle thrusts, which usually cut the pseudonormal faults. In places they divert along the steeply dipping pseudonormal faults for short distances before resuming a low angle shear orientation.

North-east - south-west trending structures are also a persistent regional feature, but they have not been well exposed in the pits. One of these structures was partially seen in Ramp 4, Curragh, and another lies in the corridor between Ramps 8 and 7, Blackwater Mine. At Curragh the structure has an apparent downthrow of 30 metres on its north side. Downdip, the thrusting of the Como Fault is displaced about 0.5 km (north side to the west), which in an easterly dipping sequence would explain the apparent downthrow to the north. Well developed clusters of low angle thrusts abut the strike slip faults on their southern side at both Curragh and Blackwater.

Normal faults are extremely rare, the only significant one occurring in Blackwater Mine Ramp 14, located approximately in the centre of a block bounded by NE-SW and NW-SE structures.

Large sandy channels and extensive sand sheets have controlled the localisation of faulting at Curragh. The thrust fault rides against and over very large sand bodies in both the Orion-Pollux and Pollux-Caster intervals. The coal and sediments beneath the sand are free from significant faulting. However around the margin of these sands deformation is concentrated.

STRUCTURAL GEOLOGY, CENTRAL BOWEN BASIN

K. Whitby, Senior Associate, McElroy Bryan and Associates Pty Limited

INTRODUCTION

The purpose of this paper is to present a summary of the results of nearly 10 years of coal exploration in the Central Bowen Basin, and in particular to provide a synthesis of structural features within that area.

In the area north-east of Emerald and south of Dysart coal exploration has been carried out by McElroy Bryan and Associates Pty Ltd at German Creek (ML 1306, ML 1908), Middlemount (A to P 315c), German Creek East - formerly Roper Creek (A to P 414c) on behalf of Capricorn Coal Management Pty Ltd, and at Gordonstone (A to P 389c) and Lake Lindsay (A to P 388c) for Denham Coal Management Pty Ltd. Additional data has been made available, for the purposes of this synthesis, by Oaky Creek Coal (ML 1315) and BHP-Utah (ML 559 and A to P209c - Gregory Mine). The co-operation and assistance of all of those companies is gratefully acknowledged. Figure 1 shows the location of the study area.

REGIONAL STRUCTURE

The structure of the Central Bowen Basin is influenced by the proximity, and the effects, of the Dawson Tectonic Zone (Folded Zone) which lies to the east of the study area. The Folded Zone is bounded on the west by the Foxleigh Fault, a major thrust fault system which extends from south of Blackwater, northwards to Winchester. Another major thrust system, the Jellinbah Fault, is subparallel to, and occurs some kilometres to the west of, the Foxleigh Fault.

The intensity and style of the structural disturbances within the Permian coal measure sediments are related to the distance from those major structures.

Variations in the style of structural deformation across the area are probably also influenced by the different lithological character of the formations. For example, the sandy sequences of the Rangal Coal Measures in the German Creek East and Lake Lindsay areas are considerably less competent than the thick sandstones of the German Creek Formation at the German Creek Mine.

Figure 2 shows the stratigraphic succession typical of the Central Bowen Basin, and Figure 3 indicates the distribution of the formations.

LOCAL STRUCTURAL FEATURES

Regional Stress Field

With the introduction of longwall underground coal mining methods imminent in Central Queensland, the accurate prediction of structural features and the role of the geologist in assisting the mine planning engineers are becoming increasingly critical factors in the successful development of these mines.

Successful delineation of major structural features is usually the result of close spaced structural drilling. However, it is the smaller scale structures, e.g. faults with throws of 2m - 5m, which are extremely difficult and costly to detect by drilling at depths in excess of 150m. Detailed structural analysis will generally enable the geologist to assess at least the most likely orientation of structures.

An integral part of structural analyses in recent times has been the use of the hydraulic fracture ('hydrofrac') technique to augment the recording of naturally occurring discontinuities in the geological environment such as rock fabric, joints, faults, cleats and dykes. Hydrofrac experiments carried out by CSIRO at German Creek and Gregory mines indicates that the existing direction of principal horizontal stress (σ_1) is aligned approximately NE - SW. At German Creek most igneous dykes have been injected along tension fractures parallel to σ_1. In addition, major fold axes and some reverse faults are aligned normal to σ_1. Major planar discontinuities in outcrops and highwalls from German Creek to Gregory are aligned in these two primary directions;

i.e. 040° - 050° magnetic,
320° - 340° magnetic.

Igneous Intrusions

Dykes in the German Creek area are mostly oriented at 050° - 070° magnetic and are usually less than 4m thick. The dykes are composed of teschenite and have been successfully delineated under relatively thin cover by high resolution magnetics.

Sills occur at various stratigraphic levels throughout the study area, and preferentially intrude coal seams. The trachyandesite has often intruded along pre-existing fault zones and has then been emplaced as sub-horizontal sills up to 30m thick, at or near the level of major coaly intervals. The sills are generally very fractured and are good aquifers. The incidence of sills intruding coal seams is highest at German Creek and decreases markedly towards the south.

Horizontal Shear Zones

High horizontal compressive stresses have led to the development of thin but widespread horizontal shear zones throughout the Central Bowen Basin. They are difficult to detect in exploration drilling as the crushed zones are rarely recovered successfully in cores, however, they are readily recognised as low sonic velocity zones on sonic geophysical logs.

Best examples of shear zones are:

(i) within the Girrah Seam; Lake Lindsay,
(ii) claystone parting; Middlemount Seam, German Creek East,
(iii) within German Creek Seam; German Creek, Gregory, Gordonstone.

Faults

Normal Faults tend to increase in frequency towards the south west, and with the exception of the major thrusts (Jellinbah Fault and Foxleigh Fault), faults with the largest displacement (e.g. Grasstree Fault - German Creek, Boundary Fault - Gordonstone) are normal faults. The throw of these faults may be up to 50m. Normal faults throughout the area are aligned both parallel to and normal to the present principal stress direction, which suggests an earlier period of tensional stress in a direction similar to the present compressive stress.

Reverse Faults are very common at Lake Lindsay and to a lesser extent at German Creek East and Middlemount. Small scale (up to 10m displacement) reverse faults occur at German Creek, but their frequency diminishes to the south west towards Gordonstone. Reverse faults are usually oriented normal to σ_1, i.e. NNW, although reverse faults with a strike slip component oriented parallel to the principal stress direction are not uncommon.

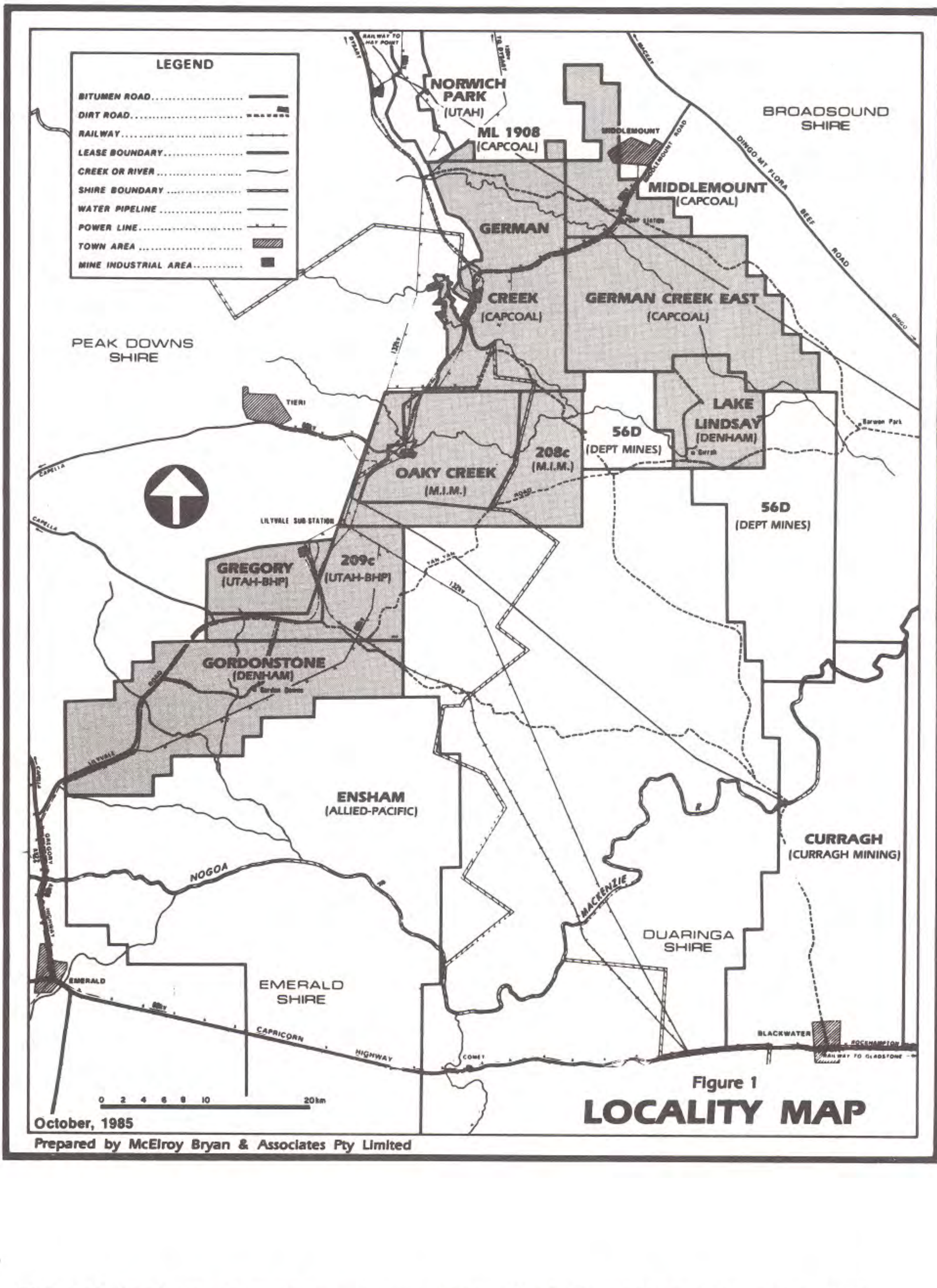

Figure 1
LOCALITY MAP

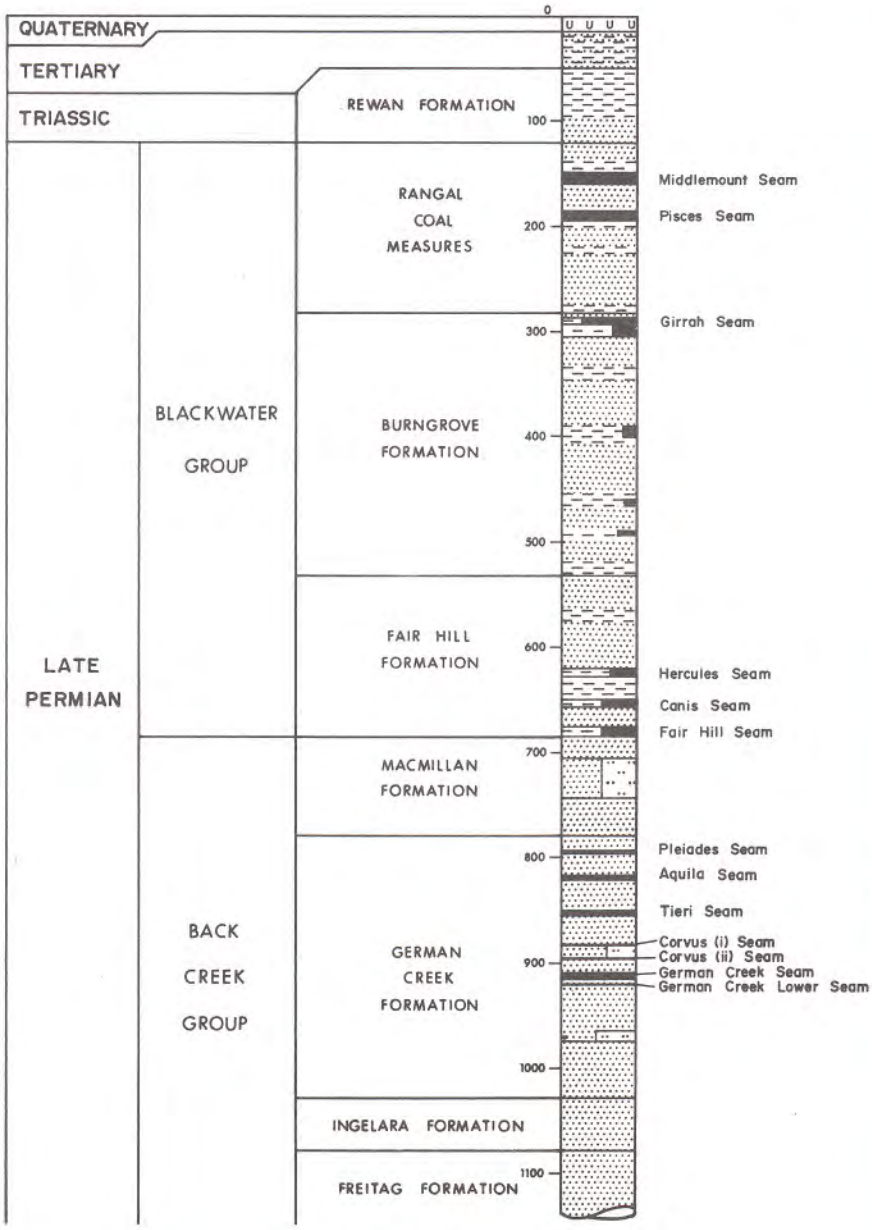

Figure 2
TYPICAL STRATIGRAPHIC SECTION
Central Bowen Basin

October, 1985

Prepared by McElroy Bryan & Associates Pty Limited

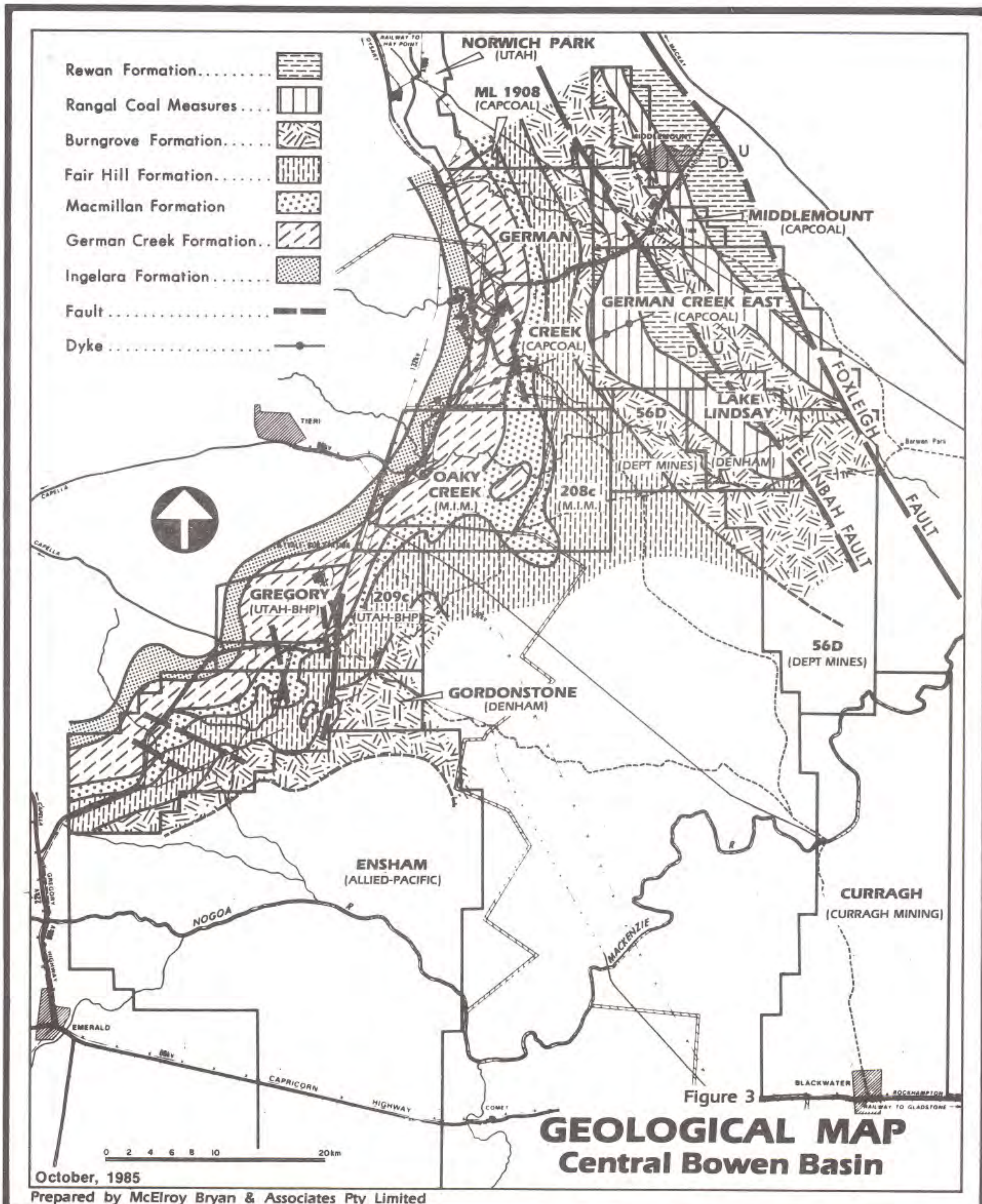

Figure 3
GEOLOGICAL MAP
Central Bowen Basin

INTERPRETATION AND ANALYSIS OF STRUCTURE IN THE BOWEN BASIN

B.E. Hobbs, CSIRO, Division of Geomechanics

The Bowen Basin is a large region of late Palaeozoic to Triassic sedimentation that occupied the tectonic position of a foreland basin to the New England orogen, lying to the east. The eastern margin of the Bowen Basin is characterized by thin-skinned thrust tectonics, a style of deformation widely developed in foreland basins throughout the world. From east to west, this tectonized margin of the Bowen Basin is characterized by five distinct zones, each with their own structural style. These zones are (1) the Gogongo Fold zone in the east, bounded on the west by the Gogongo thrust and characterized by the widespread development of a steep east dipping slaty cleavage in Greenschist facies meta sediments; (2) the Dawson Fold zone with tightly folded weakly metamorphosed sediments, lacking an axial plane cleavage for the most part and with steep axial surfaces, bounded on the west by the Yarrabee thrust; (3) the Yarrabee zone characterized by dome and basin structures in weakly metamorphosed sediments, bounded on the west by the Jellinbah thrust; (4) the Blackwater zone characterised by broad open folds and a number of flat lying thrusts such as the Curragh, Shotover and Sirius thrusts that tend to localize within coal seams but which may ramp through the section resulting in local duplication or elimination of coal seams. These thrusts produce coal mylonites and have horizontal displacements of at least 5 km; (5) the Comet zone characterized by broad dome and basin structures. All of these zones and bounding thrusts trend NNW-SSE and are cross cut by major lineaments that trend NE-SW. These lineaments are both sinistral and dextral strike-slip faults, kink-zones or fracture zones that in some instances appear to have been contemporaneous with the thrust systems. Basaltic dykes also parallel this lineament direction. Although thrusts such as the Yarrabee and Jellinbah are steeply east dipping at the surface, it appears that they flatten with depth to form a major detachment zone of which the Curragh, Shotover and Sirius thrusts are splays. The tectonic style is characteristic of thin-skinned thrust tectonics and in many aspects is reminiscent of deformation within the Appalachian coal sequences. On a local scale, within individual coal seams, the structure may appear complicated but it conforms to a pattern which is part of this overall style. Perhaps by chance, the tectonic pattern of SWW directed thrusts and steep NE-SW strike slip faults, kink zones and dykes, is compatible with the measured present day stress field which consists of a maximum principal stress horizontal and directed NNE-SSW and minimum principal stress vertical.

AN APPLICATION OF HIGH RESOLUTION MAGNETICS TO DYKE AND SILL DETECTION

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University of New England, Armidale

The northern Bowen Basin has undergone several events of volcanic intrusion since the late Permian period. Prior knowledge of the location, thickness and hardness of such intrusions can be of paramount importance to underground mine planning, and can significantly increase the efficiency of open pit extraction. It is unrealistic to expect to detect steeply dipping dykes, or the limits of silling, during a normal drilling program.

Dykes and sills down to 0.1 metre thickness have been routinely mapped in the Bowen Basin coal environment where Tertiary cover is thin. Dykes down to 1 metre thickness may be mapped beneath up to about 50 metres of Tertiary alluvium depending upon their magnetic sysceptibility.

New technology has enabled the routine detection of these thin intrusives through the development of a very fast sampling, automatic positioning and recording, caesium magnetometer system (Stanley, 1982). This system is capable of recording and plotting magnetic field measurements to 0.1 nT sensitivity, at a sample interval of 0.25 metre at a rate of up to 10 km per hour. In practice, 20 line kilometres (80,000 data measurements) can typically be surveyed on foot and plotted per day.

The first example shows data recorded at 0.5 metre intervals, 0.5 metres above ground level along eight, three kilometre lines separated by 100 metres. The data clearly shows two dykes and two sills. Note that the major sill has a thickness of only 2.4 metres and the major dyke has a thickness of 1.1 metre. The minor dyke of thickness only 0.1 metre can be traced for 700 metres. Expansion of the vertical scale revealed this dyke much more clearly than depicted in this data plot. The width of the anomaly over thin dykes may typically be only a few metres making them detectable only from closely sampled data.

The characteristics of the waveform of the magnetic profile over a sill can be mathematically predicted from a model which assumes the top surface of the intrusive to exhibit a broad band, "white" magnetic spectrum. The truncated horizontal surface of the sill is closest to the magnetic sensor. The magnetic profile over this section contains the highest frequencies and their amplitude increases with increasing thickness of the sill. Down dip from the subcrop, the sill thickness is constant but its depth below the magnetic sensor is increasing. Consequently, the high frequencies in the magnetic spectrum are progressively filtered out as depth increases. Thus the amplitude of the magnetic profile decreases down dip and the attenuation of the high frequencies in the waveform becomes obvious. Figure 2 contains all the predicted features observable in real field data. It can be shown that the distance between adjacent maxima and minima in the waveform when divided by twice the Tangent of the local magnetic Inclination gives the depth to the top of the sill. The dip of the sill can be calculated from Arctan (dl/S). If the sill is assumed to have uniform thickness then that thickness can be calculated by trigonometry from the width "W" at subcrop.

Limitations to the success of the method are determined by the composition of the intrusive rock (its magnetite content), the depth of Tertiary alluvials overlying the intrusive and in some cases the presence of near surface magnetic interference from basalt flow, magnetic alluvial gravels or mine machinery. Weathering of the intrusive near the ground surface and alteration of the intrusive on contact with the coal, reduce the magnetic detectability. Experience from surveying over 600 line kilometres in the Bowen Basin region has clearly established this method as cost effective and successful.

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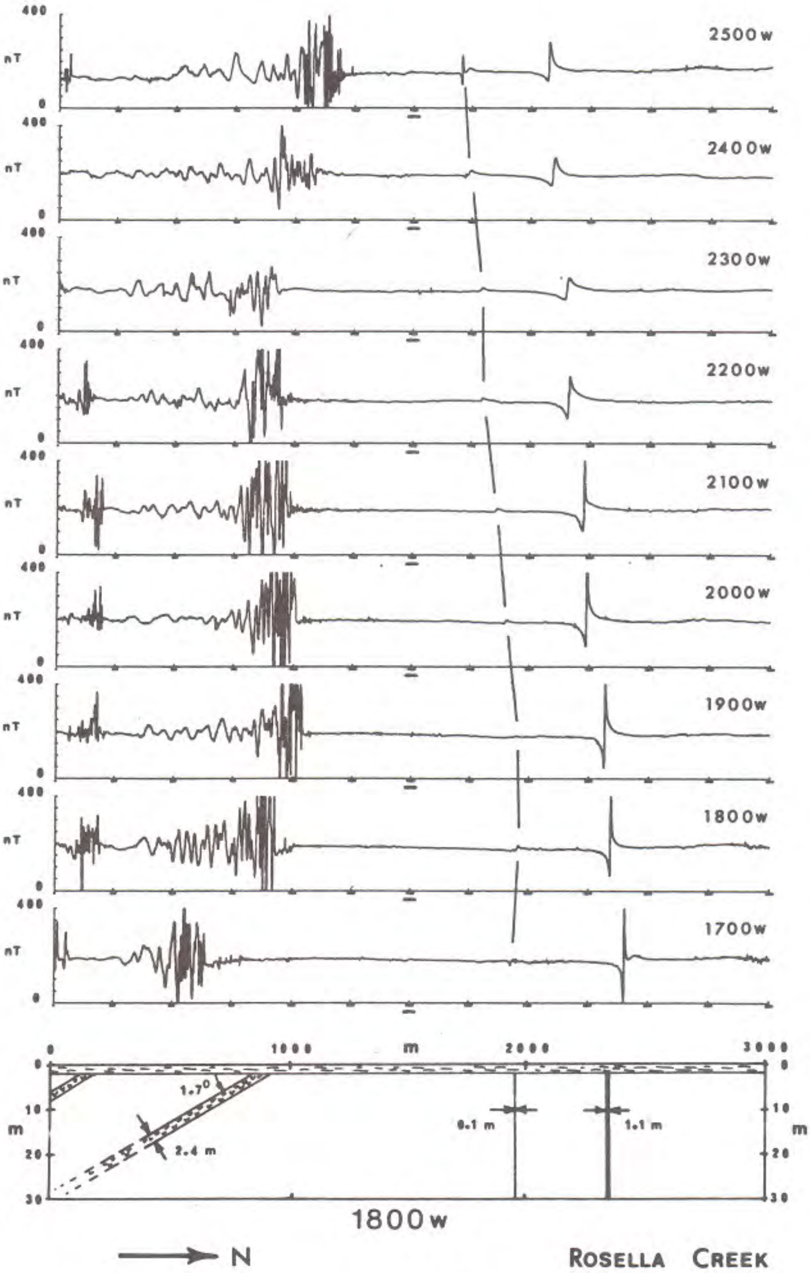

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Figure 1

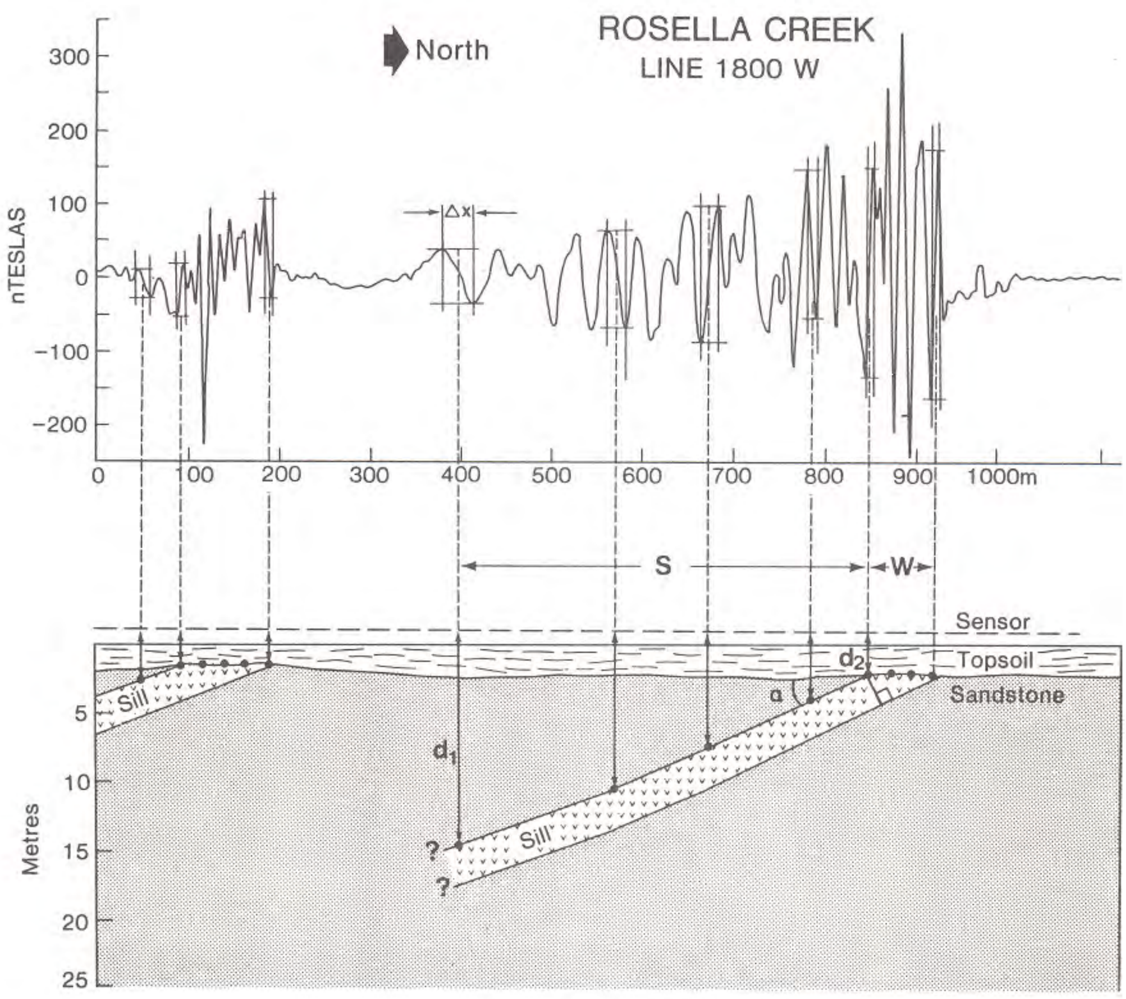
ROSELLA CREEK
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Figure 2

FACTORS AFFECTING COAL MINING

GEOLOGICAL FACTORS AFFECTING DEEP SURFACE MINING

A.L. Davies, Technical Services Department, UDCL

INTRODUCTION

Professor Tom Atkinson, the visiting fellow for the Warren Centre Project on Advanced Surface Mining Technology has summarised the challenge to future surface coal mining in Australia as follows:-

"Many of Australia's established coalfields have depleted reserves of flat dip, shallow depth coal. This will inevitably require mining companies to consider deposits in more complex geological settings, with deeper overburden, often steeper dips, more critical groundwater problems, increased geotechnical difficulties and possibly with less competent materials, e.g. Jurassic coals. This situation will require the movement of greater volumes of overburden per tonne of coal, concurrent with the need to maintain Australia's competitive position."[1]

These factors are primarily geological, and put in the simplest of terms, the Warren Centre Project findings are an outline of the plan of attack to meet these geological challenges.

To a limited extent, some of these factors are already being encountered. Bowen Basin surface coal mines which have been operating for a decade or more are now extending their operations into areas of steeper dip; greater structural disturbance; and are encountering overburden and groundwater conditions which are more adverse than in the prime areas where mining first commenced. However, in general, these are still areas of shallow depth coal. The adverse geological factors have been encountered with less severity in prior operations, and designs and operational techniques have been developed to minimise their impact on mining operations.[2,3]

The geological factors which will affect surface coal mining to depths of 90 metres and beyond are more speculative, particularly for those aspects where the introduction of new technologies are predicted. This paper considers some aspects of deep surface mining based on the preliminary findings of the Warren Centre Project; with emphasis on geological and geotechnical conditions which will influence mine design and operating procedures.

OVERBURDEN REMOVAL

Overburden Material Properties

Table 1 below, lists the rock strength categories for typical overburden materials encountered in the Bowen Basin.

TABLE 1 Overburden Strength

Strength Category*	UCS (MPa)	Overburden Materials
Soil	< 1.5	Tertiary sediments (excluding duricrusts), extremely weathered zones in Permian Coal Measures, (PCM), and Tertiary Basalt
Weak Rock	1.5 - 15	All weathered and some fresh PCM laminated lutites; highly weathered - moderately weathered PCM massive lutites and arenites, and highly weathered Tertiary Basalt
Moderately Strong Rock	15 - 50	All PCM lithologies with the exception of dolomitised beds and highly siliceous arenites. Moderately weathered Tertiary Basalt. Massive ferruginous duricrust
Strong Rock	50 - 120	PCM dolomitised beds and siliceous arenites. Moderately to slightly weathered Tertiary Basalt
Very Strong Rock	120 - 230	Fresh Tertiary basalt and siliceous duricrust (silcrete)
Extremely Strong Rock	> 230	

* IAEG recommended classification. UCS = unconfined compressive strength.

Overburden Material Properties cont.

As illustrated by Table 1, the vast majority of overburden materials are in the "Soil, Weak Rock, and Moderately Strong Rock" categories. The relative proportions of these material categories present within a particular area are dependant on the presence and extent of Tertiary Sediment cover, and the depth of weathering penetration. In the most extreme cases with deep Tertiary Sediments and deep weathering penetration, as much as 60 - 70 metres of the overburden consists of "Soil" and "Weak Rock". Conversely where Tertiary Sediments are absent and weathering is of limited penetration, "Moderately Strong Rock" can be encountered within 10 - 15 metres of the ground surface. A more typical situation would be for "Soil" constituting the surface 15 metres of overburden, underlain by "Weak Rock" to a depth of 30 metres.

Overburden Stripping to 60 metres

Current overburden stripping operations to depths of approximately 60 metres have been achieved almost exclusively by draglines (typically $45m^3$ bucket capacity, 99m boom length and boom angles of 38°). Generally the draglines operate on a bench 10 to 20 metres below ground level. The overburden is blasted, and the weak "Soil" overburden above bench level is chopped by the dragline and the overburden below bench level is dug conventionally, to a maximum digging depth of around 45 metres. When questioned by the Warren Centre working group, virtually all mines indicated satisfactory performance of draglines for overburden removal. It is unequivocal that the draglines have operated satisfactorily in almost all overburden conditions even where overburden blasting practices have been uncertain.

Deep Overburden Stripping

Rehandle is the principal factor to be considered in the continued use of draglines for overburden removal beyond 60 metres depth. A rehandle curve for a typical large dragline shows that the percent rehandle at a digging depth of 40 metres is 53%, which rises to 70% at a digging depth of 45 metres. However, the more important statistic is that the 5 metre greater depth of digging incurs an incremental increase in rehandle of 206%, so that the prime unit cost of digging is more than 3 times the dragline unit cost. Therefore alternative methods of overburden removal with unit costs up to three times that of the dragline become economically comparable with the draglines for deep stripping.

One option would be to use larger draglines. The Warren Centre Project suggests the potential for draglines with boom

Deep Overburden Stripping cont.

lengths of 183 metres capable of excavating 75 metres of overburden. This option may be followed in future new mine developments and major re-developments of existing mines, however in the majority of mines the current generation of draglines are likely to be utilised for the foreseeable future. Given their proven capacity to cope with "Moderately Strong Rock" overburden in all but the most extreme circumstances of inadequate fragmentation, their most effective application will be in the basal 45 metres of overburden, below the depth of most Tertiary Sediments and weathered rock.

Prestripping

Prestripping constitutes the removal of the uppermost overburden leaving approximately 45 metres of overburden above coal for conventional dragline stripping. Hence at the 90 metre overburden isopach the volume of prestripping will match dragline stripping. From the wide variety of earth-moving technologies available for prestripping, the Warren Centre Project emphasises the advantage of continuous excavators coupled with belt conveyors for spoil removal. The performance of the robust bucket wheel excavator and associated conveyor system in Cleanskin Pit at Goonyella Mine[4] has shown that such systems can be successfully applied to prestripping where the prestrip overburden consists of the "Soil" and "Weak Rock" categories in Table 1. However where "Moderately Strong Rock" is present within the prestrip overburden, continuous excavator systems currently available for surface mining are not capable of digging the overburden without high fragmentation blasting which reduces all insitu rock to block sizes compatible with the bucket capacity and conveyor system. As Professor Atkinson proposes, the development of "a modified bucket wheel excavator with driven precutters, e.g. disc cutters or road header type cutters, in front of each bucket" would provide a solution to this problem, and the low proportion of quartz clastics and cements in much of the Bowen Basin coal measure sediments would minimise the abrasion difficulties with such a system.

However, prior to the development of such a system, it is unlikely that continuous excavators will be applied to prestripping outside of those areas where "Soil" and "Weak Rock" overburden predominate to the maximum prestrip depth. Where "Moderately Strong Rock" predominates, prestripping is most likely to proceed using truck and shovel systems with full overburden blasting. Hybrid systems using shovels or hydraulic excavators or possibly draglines loading to an in-pit crusher which reduces the spoil to a size compatible with belt conveyor transport are also identified as future options in the Warren Centre study.

Overburden Blasting

Blasting for prestripping systems will require greater fragmentation than has been the norm for dragline stripping. In extreme cases where block sizes of more than 500mm cannot be tolerated this will almost certainly require a re-evaluation of blast design procedures and the introduction of smaller diameter overburden drill rigs. In all cases much greater geological input will be required for blast design, defining strata with large insitu-block sizes, delineating the major structure orientations, and identifying high strength beds for deck charging and weak beds for stemming. Existing technology in the form of geophysical downhole logging and performance monitoring of overburden rigs is available for these investigations, and their effective use will be a necessity for more demanding blast design requirements in the future.[5,6]

For dragline overburden the continued development of throw blasting will provide benefits in efficient use of cheap chemical energy for spoil movement and will enhance spoil stability by depositing large, more durable blocks of rock at the base of the spoil pile.

SPOIL MANAGEMENT

Dragline Spoil

With rare exception the spoil placed by dragline during deep stripping will be "Moderately Strong Rock" from below the depth of weathering. Hence the shear strength of the spoil will be higher than for the previous situation where "Soil" and "Weak Rock" overburden materials were admixed. However the fine grained lithologies within the "Moderately Strong Rock" overburden will still exhibit the propensity for slaking and reworking when saturated by water ponded at the pit-floor interface. The reasoning given by Rosengren[7] to assume the residual angle of friction and zero cohesion for the foundation material in the spoil piles remains relevant. The results of recent testing of spoil materials at Blackwater Mine[8] are summarised in Table 2.

TABLE 2 Residual Shear Strength of Overburden Spoil

Spoil Type	Residual Angle of Friction Ø'r
Weathered Overburden (mainly "Weak Rock", minor "Soil")	Range 18° - 19°*, cohesion < 10 KPa
Fresh Overburden ("Moderately Strong Rock" lutites)	Range 20° - 22.5°*, cohesion < 15 KPa
Weathered Overburden, contaminated with pit floor mud (floor dip 5.5°)	16.2°** assumed cohesion = 0
Fresh Overburden (floor dip 11.3°) ("Moderately Strong Rock" lutites and arenites)	23.6°** assumed cohesion = 0

* Test Method:- remoulded, consolidated, saturated direct-shear tests, drained conditions (sheared at 0.007 mm/min), 3 stage at 300, 600, 900 KPa Normal Stress.

** Back analysis of Spoil pile failures. (Bulk spoil strength Ø = 30° C = 0).

The results shown in Table 2 illustrate that when considering the residual shear strength there is only a slight increase in strength accompanying the change to "Moderately Strong Rock". Also even where this more competent overburden is placed on a properly prepared and cleaned pit floor, spoil failure can occur in adverse conditions (such as floor dips greater than 10°), and back-analysis indicates shear strength of the spoil base comparable with residual shear strength test results. However the most important feature is that even small amounts of pit floor mud left by incomplete floor preparation will greatly increase the potential for spoil pile instability, irrespective of the quality of the spoil materials.

Prestrip Spoil (Second Generation Spoil Dumps)

The placement of prestrip spoil as a surcharge on dragline spoil will require close attention to overall spoil slope geometrics, to avoid major spoil failures involving much larger spoil volumes than previously encountered.[9,10] Also it must be recognised that the increase in spoil pile height for second generation spoil piles will result in normal stresses of the order of 2 - 3 MPa at the pit floor/spoil interface, whereas most experience and testing of spoil shear strength has been for normal stresses up to 1 MPa (as per Table 2 footnote). As indicated by Denby et al,[11] consideration must be given to the probable curved shear failure envelopes for spoil materials in determining appropriate shear strength for design purposes.

Prestrip Spoil (Second Generation Spoil Dumps) cont.

The placement of prestrip spoil will also exacerbate the limiting effect on spoil storage room of coal haulage ramps. The Warren Centre Project identifies the advantages of replacing the ramps with underspoil conveyor tunnels, pipeline transport of run-of-mine coal, over the highwall high angle conveyors, over the low-wall steep angle conveyors. All of these options will require close geotechnical evaluation to establish their feasibility.

GROUNDWATER CONSIDERATIONS

Although groundwater adversely affects pit slope stability and adds to pit drainage requirements the major impact on strip mining operations has undoubtedly been on overburden blasting. Even low rates of groundwater inflow in blast holes are sufficient to require the use of more expensive water-gel explosives in place of ANFO

Generally there are two aquifer systems. Unconfined aquifers at a depth of 5 to 20 metres in the more sandy Tertiary Sediments, which are perched above the impermeable clays at the Tertiary - Permian unconfirmity; and the coal seams, which are confined aquifers, typically with a piezometric surface at a depth of about 40 metres.

The permeability of the aquifers in both these systems is low (ie $K \nless 10^{-3}$ cm/sec) as indicated by the results of borehole permeability tests as follows:

Tertiary Sediments	-	$K = (1.0 \text{ to } 5.0) \times 10^{-4}$ cm/sec
Coal Seams	-	$K = 1.5 \times 10^{-5}$ to 2.0×10^{-4} cm/sec

The few instances of published pump test results for coal seam aquifers indicate somewhat higher permeabilities than those derived from borehole testing (eg $K = 2.6$ to 4.0×10^{-4} cm/sec for the Pollux and Aries-Castor seams at Curragh[12]).

Detailed studies of groundwater effects on overburden blasting at Yura Pit, Peak Downs Mine indicate that the perched aquifers are the major cause of wet overburden blasting conditions. Unaided drainage of the coal seams exposed in the pit has proven sufficient to lower the piezometric surface to the vicinity of the coal seam top for at least the extent of the next strip, provided that drainage is not impeded by pit flooding or spoil cover of the seam exposure.

Prestripping of the Tertiary Sediments for future deep surface mining will eliminate the adverse effect of the perched aquifers. However as the pit depths increase, so will the piezometric head at the exposed coal face with the eventual result that unaided drainage will be inadequate to maintain dry overburden blasting conditions. It is doubtful if dewatering by pumped wells in the low permeability coal seams will be cost-effective unless accompanied by permeability

GROUNDWATER CONSIDERATIONS (cont)

enhancement (eg by presplit blasting as practised in some South African strip coal mines[13]).

Commencement of mining in deep, previously unexposed (and hence undrained) coal seams will present special cases of high piezometric heads in the boxcut. Even where such seams are not mined but are separated by thinner parting from the main seams, the increasing uplift pressures accompanying deeper stripping will adversely effect pit floor stability and in severe cases, depressurisation wells may be required.

INSITU STRESS AND PITWALL STABILITY

Stratified coal measure sequences exhibiting large differences in mechanical properties between adjacent strata are particularly difficult cases for stress analysis. Additionally the stress conditions in near surface strata are only now starting to be investigated. Hence, in the absence of definitive data only a broad consideration of insitu stress conditions can be attempted. Some insight is provided by the results of insitu stress measurements by CSIRO mainly at underground mine sites in the Bowen Basin. At depths of around 200 metres, their tests have shown that the principal stress direction is horizontal, oriented generally NE-SW, and at least twice the vertical stress (C. Mallett pers.comm.)

In deep surface mining these high, horizontal, residual stresses can be anticipated to increase excavation deformations, particularly causing dilatancy in the highwall crest area and promoting shear and resultant "move-out" along weak beds in the vicinity of the highwall toe. Prestripping followed by dragline stripping will result in a benched highwall configuration which will tend to alleviate the worst of these effects. However, the existence of more competent rock in the lower 45 metres of overburden is likely to promote the adoption of steep highwall slopes below the dragline working level. Steep slopes, accompanied by dilation along joint surfaces and "move-out" at the highwall toe provide a recipe for slope failure by the block toppling mode. Although these failures rarely involve large volumes of overburden, they occur much more rapidly than the more commonplace translational failures and present a greater hazard to personnel and equipment.

High stress concentration due to unloading of the pit floor can also cause the preferential development of floor-parallel cracks in underlying strata. This disruption of floor strata integrity could readily progress to buckling failure of the floor and uncovered coal, and promotion of spoil pile failures, particularly in steeper floor dip areas, and where the floor strata are weak laminated lithologies and/or are subject to uplift pressures from underlying aquifers.

CONCLUSIONS

As mentioned in the introduction, this paper is an attempt to speculate on the geological factors which will influence the surface mining of coal in the Bowen Basin as the mining depths increase beyond the current maximum of around 60 metres.

Attention has been given to the influence of overburden properties on the selection of overburden removal systems; consideration of the handling of overburden spoil; and the effects of groundwater and insitu stresses on progressively deeper excavations.

This paper commenced with a quotation from Professor Atkinson and it is perhaps appropriate to also allow him the last word, quoting from his assessment of the role to be played by geologists and geotechnical specialists in future surface coal mining operations.

"Geotechnical problems, even when not serious, often interrupt production and are time-consuming for management. It will be essential to adopt new attitudes to this subject as problems increase due to increasing overburden depths. For remedial work to be cost-effective it is necessary to have a knowledge of the history of the operations and of similar geological settings, involving routine compilation of information regardless of whether conditions are stable or not. The replies to the Warren Centre questionnaire showed a general lack of awareness by mine operators of the geotechnical problems associated with deep overburden. Increased awareness must be a feature of future mine design and operations".

ACKNOWLEDGEMENTS

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GEOLOGICAL HAZARDS TO UNDERGROUND COAL MINING IN THE BOWEN BASIN - AN ASSESSMENT

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Although the extent of underground mining in the Bowen Basin is considerably less than in the Sydney Basin, the effect of geological hazards has been disproportionally high. At Leichhardt Colliery, more than a decade of intensive geological analysis, related gas and rock mechanics studies and perserverance in mining, failed to overcome the extensive problems of high seam gas emissions, outbursting and roadway instability (Wood and Hanes, 1982). All this in an environment of high fault intensity (Table 1) led to the colliery's closure in 1982.

At Collinsville, down-dip development has been repeatedly terminated by high seam gas emissions and outbursting since the occurrence of the first recorded outburst in 1954. In a regional evaluation of outburst proneness, the maximum desorbable gas contents were found to be amongst the highest in Australia (Williams et al., 1984).

Although Leichhardt Colliery (because of its severity) and Collinsville (because of its long mining history) account for the majority of geological hazards, no geographic area is free of significant mining problems. Geological hazards of widespread distribution are thrust faulting, high seam gassiness and related outbursting, thick seams, weak coal and high fault intensity (Table 1).

In todays economic climate, the viability of underground mining increasingly requires the adoption of high volume production methods. Longwall mining is well established in the northern, southern and western coalfields of the Sydney Basin and is about to be introduced into the Bowen Basin. Its introduction has considerably heightened the need to predict and effectively account for geological hazards. An assessment of the geological problems confronting longwall mining in the Sydney Basin provides an insight into the type of problems to be addressed in the Bowen Basin.

TABLE 1 - GEOGRAPHIC OCCURRENCE OF THE MAJOR GEOLOGICAL HAZARDS

Locality/ Colliery	Collinsville	Cook	Leichhardt	Moura	Laleham	German Creek	Harrow Creek
Geological Hazard/ Control							
Thrust Faulting	X		X	X	X	X	
High Fault Intensity		X	X	X	X		
Normal/ Strike Slip Faulting	X			X	X		X
Differential Compaction Fault		X	X		X		
High Seam Gassiness	X		X	X		X[1]	
Outbursts	X	(X)	X	(X)			
Thick Seam (> 4 m)	X		X				X
Weak Coal	X		X			X	X
High Stress			X				
Igneous Intrusions	X					X	

( ) denotes relatively minor occurrence
1 anticipated

In the early days of longwall mining, difficult face conditions resulted from the underdesign of powered supports in accepting the loads generated by massive strata. Face related problems are now essentially overcome with resulting increased daily outputs averaging up to 7000 tonnes. This high productivity has placed an increasing demand upon the need for rapid entry development. A common occurrence is the difficulty in keeping gateroad and panel development rates up to the pace of longwall extraction. In essence, the technology employed is unable to cope with the prevailing geological conditions. The main problems are roadway deterioration associated with weak strata and high lateral stresses, and inadvertent intersection of faults and dykes and related fracture zones. There is also a strong trend toward narrow roadway (4.5 - 5 m), propless drivage in which rib support becomes an integral part of the roadway support system. This places a heightened need to account for the strength and deformation characteristics of the coal seam and particularly, the intensity and direction of cleating.

Gateroad deterioration under longwall face abutment loads is creating considerable difficulties. New secondary support techniques of strata stabilisation are being implemented and extensive on-going research is taking place directed toward roof, rib and floor stabilisation. The geological contributions are weak roof and floor strata, unfavourable cleat orientation and structural discontinuities.

The problems of seam gas emission and outbursting are heightened in the case of entry developments for longwall mining. In an increasing number of collieries, the control of ribside gas emissions has necessitated the use of in-seam gas pre-drainage. Post-drainage is similarly used to control the gas-make along longwall faces associated with goafing and strata relaxation.

Similar problems can be expected for longwall mining in the Bowen Basin, with modifications to account for local geological effects. The importance of defining geological structures cannot be too highly stressed, especially in an outbursting or longwall mining environment. Any mining company contemplating a longwall installation must be prepared to support investigations aimed at producing the best possible definition. Losses incurred in striking unforeseen geological structures can run into millions of dollars. In addition to aerial photo interpretation and structural analyses of borecore, high resolution surface seismic and magnetometer surveys should be implemented unless good technical reasons exist to indicate a low likelihood of success. The information gained should be adequate for general planning purposes. For detailed design, in-seam investigations are necessary. In-seam seismic surveys (Richmond et al., 1985) are being increasingly applied throughout the industry and are capable of providing much greater resolution of structures than surface based techniques. Long-hole, in-seam drilling has been employed in seam gas drainage trials and boreholes up to 800 m have been drilled in Australia (Williams et al., 1985). The potential for accurately defining geological structures is high, especially if used in conjunction with in-seam seismic methods. Research in both methods is continuing. Maintenance of awareness of research developments is strongly urged as these are the only available techniques to define structures according to the accuracy required in mining.

For areas of seam continuity, it remains to define the reaction of the strata to both development and extraction and for multiseam mining where applicable. Seam dips of around 1 in 10 are relatively common in the current mining areas (Collinsville, Harrow Creek, German Creek and Moura). A rapidly increasing depth of cover will increase the likelihood of stress related problems. The problems of mining in a thick seam or soft coal will increase. Rib stability problems being experienced at Harrow Creek (Shepherd et al., 1984) are due to the increasing cover loads acting on a high rib of soft fractured coal. Special consideration for longwall face stabilisation will be required. The orientation of roadways and face line with respect to cleating will be important.

Mathematical modelling methods have undergone continual refinement and have the capability of modelling a wide range of geological and mining situations. Meaningful interpretations depend upon how well the important geological parameters are modelled and a good appreciation of the actual deformational processes underground. The company geologist should make an important contribution to the determination of modelling input and the most appropriate interpretation of results. Similarly, detailed knowledge of roadway strata geology forms an integral part to the custom design of support systems.

It is particularly significant that high gas and outbursting conditions have been widely experienced and at relatively shallow depths. An outburst was recorded at only 135 m depth at Moura (Souvan, 1984). Large outbursts (500 tonne) have occurred at Collinsville from 220 m depth (Williams and Rogis, 1980). The general increase in seam depth away from outcrop will generally lead to increasing gas emission problems.

Company geologists are in a good position to collect basic data for use in evaluation of seam gas emissions and outburst potential. The most important information is the gas content and gas composition which is fundamental to all calculations of gas emission and the design of appropriate ventilation and gas drainage requirements. For longwall emission predictions, it is important to define the gas content and composition for all coal seams in the stratigraphic sequence, regardless of their economic significance.

Although underground mining in the Bowen Basin is currently on a relatively small scale, the diverse geological hazards encountered have created serious problems and limitations for underground mining. The adverse effects of geological hazards will increase with the introduction of longwall mining. A concerted effort involving company geologists and engineers and research/consulting organisations is justified if the current and future problems created by geological hazards are to be overcome.

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A GEOLOGICAL BASIS FOR STRATA CONTROL DESIGN IN UNDERGROUND MINES IN THE BOWEN BASIN

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Underground mining in the Bowen Basin has consisted of small mechanised mines using bord and pillar development and numerous variants of pillar extraction. Many of these mines have utilised the flexibility of the bord and pillar system to negotiate seam dislocations, igneous intrusions and areas of seam thinning. Zones of roof instability have created hazardous face conditions, generally in localised areas, but the flexibility of the bord and pillar system has allowed relatively rapid relocation, usually with minimal losses of production. Regrettably, some of these "localised instabilities" have resulted in serious injury or fatalities to the mining workforce. A number of mines in the basin have closed after protracted efforts to operate economically in more difficult ground conditions.

The planned installation of longwall mining in Central Colliery, at German Creek (Galt and Jones, 1985), and the feasibility studies of longwall mining undertaken at many other minesites, heralds a new era of ungerground mining for the Bowen Basin. Longwall mining is a much safer and more effective coal recovery method, but it is relatively inflexible, particularly where "geological surprises" are present. The economic success of longwall depends on continuous production and generally predictable ground conditions. The question arises as to whether sufficient mining, geological and strata control experience has been gained to minimise the technical risk associated with investment in longwall equipment in the strata of the Bowen Basin.

A number of data sets can be accessed to provide the information required for this value judgement:

I Current and past underground operating experience with bord and pillar mining in the Bowen Basin;

II Exploration programs and subsequent sedimentological and structural interpretation in current and proposed mining areas;

III Regional sedimentological and structural compilations in the Bowen Basin;

IV Laboratory and field strata control investigations and research;

V Strata control experience with longwall mining in the Sydney Basin.

The paper will examine each of the above categories, with examples from the Bowen Basin, and will consider the relative importance that should be placed on each aspect during the selection process for mining methods to fit the predicted ground conditions. Aspects of strata control, which must be considered in the context of Bowen Basin geology, include longwall geometry and orientation, chain pillar design, gateroad stability, criteria for hydraulic support selection, face and rib coal stabilisation, subsidence behaviour and panel interaction.

Successful applications of longwall mining in the Bowen Basin in seams of "normal" working height will spawn the need to further address the greatest strata control challenge facing underground mining in the region. The large underground reserves of coal in seams, with thicknesses greater than four metres, have yet to be effectively recovered by underground methods in the Bowen Basin. The challenge lies in maximising recoveries from thick seams and maintaining safe, high production rates in variable geotechnical conditions (Enever and Rawlings, 1980). This issue will become exacerbated when the opencut mines reach uneconomic overburden to coal ratios and replacement underground tonnage is required. The geological basis for the prediction of rock mass behaviour under such mining conditions will be an important consideration for equipment selection and successful operations.

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HYDROLOGICAL ASPECTS OF COAL MINING

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1.0 HYDROLOGICAL FACTORS

During mine design, operation and maintenance surface and underground hydrological features which have to be taken into account are:

- supply of water for mine use
- excess water from storm runoff or pit inflows or underground mining
- environmental effects of mining
- stability of pit walls and spoil piles
- dewatering ahead of mining for economic reasons (occurrence of wet blast holes).

Supplies of water are required for dust suppression, coal washing plants, bath houses, clean down areas, fire fighting and associated townships. The quality of water required varies with the use.

Excess water may be from quite small local area runoff or major river diversions. These excess flows if not separated from certain areas of the mine may lead to pollution downstream.

The quality of water for pre and post mining therefore needs to be sampled, tested and monitored. Bowen Basin mines are not generally regarded as being "wet", with water inflows usually controlled by sumps with only limited pumping required. The main aquifers are generally the coal seams with saturated alluvium of basalt having the potential for providing inflows as mining progresses in some existing mines. Several of the mines currently undergoing pre feasibility studies also have the potential for quite high water inflows from considerable thicknesses of saturated basalt or mining through extensive deposits of saturated alluvium of high permeability.

This paper briefly outlines the information required to assess surface and underground water and the sources and methods used in obtaining this information.

2.0 INFORMATION REQUIRED

Information required to assess both surface and underground aspects is:

- climatic principally rainfall, evaporation, streamflow of runoff volumes
- water quality.

Information of particular relevance to underground water is:

- aquifer charasteristics (transmissibility/storativity)
- existing water levels
- adjacent water users of that aquifer.

Information particularly applicable to surface water is:

- intensity-duration of rainfall
- peak runoff volumes
- surface topography for either storage sites or necessity for river diversions
- existing and potential users.

3.0 INFORMATION SOURCES

The major source of existing hydrological information is the Queensland Water Resources Commission, both local offices and Brisbane offices. The Commission maintains stream gauging station, often has records of boreholes and yields from boreholes, results of pump tests. The Bureau of Meteorology does publish rainfall intensity curves and will generate information for a particular area. Adjacent mines are also a source of information.

Collation of exploration borehole data is also a prime information source.

Other potential sources of information for climatic data are local CSIRO, Soil Conservation or Department of Primary Industry research centres. Care should be exercised in adopting any one particular source of data as the station may not have been consistently read. The Bureau of Meteorology has in fact stopped using a number of sources because of unreliable data.

Pan evaporation data may be prone to these inaccuracies (Reference Watts and Hancock).

Methods Used to Collect Information

Information which can be collected with the resources available for surface water estimation is limited.

Some mines have established complete weather stations including pluviographs (to measure rainfall intensities). While after an extended period (several years) the data may become of use, the effort involved in maintaining a consistent record often means the data will end up not being collected or analysed. In any event, individual stations are no longer used by the Bureau of Meteorology (Australian Rainfall and Runoff Preview Workshop).

Therefore collection of data should be kept simple and consistent. Rainfall data seems to fit into this category.

Water samples must be collected and analysed on a regular basis from the outset to establish water quality information. The information is used in deciding potential uses and/or methods of treatment but particularly for environmental monitoring purposes.

The published and established government information sources often prove to be the most appropriate information for estimation of surface water although it is very useful to obtain knowledge of flood heights and frequency from local landholders.

Underground water estimation does require information to be collected. Due to the large size of the Bowen Basin coal mines it has been necessary to use several "index texts" to determine overall hydrogeological trends that exist in the large areas under consideration. Any problem areas that are detected can then be looked at in more detail by undertaking additional testing, for example pumping tests. The idea of the index testing is to ensure that the more expensive testing (pump tests) are representative of the site as a whole or that they are investigating particular problem area(s).

Index tests used include:

- water level measurements (of simplified system)
- air lift pump tests
- rising/falling head hydraulic conductivity tests.

Depending on the sites hydrological characteristics various combinations of these index tests are used along with (if appropriate):

- collation of exploration borehole data
- terrain evaluation (eg. for defing alluvial or basaltic areas, drainage patterns, watersheds)
- piezometel installation
- pump testing.

Several of the above techniques are described in more detail belcw.

Water Level Data

To obtain an appreciation of the extent of saturated material to be mined standing water levels should be measured in all available open boreholes and, for this reason, collar casing and capping of boreholes during exploration is recommended. This gives a simplified hydrostatic distribution of water pressure and it may be necessary to install piezometers at various horizons in selected boreholes to define any zones of higher or lower pressure (eg. to define the potential for floor heave due to the pressure of an aquifer in the floor).

The water levels can be plotted and contoured to provide information on the direction of groundwater flow and flow gradients. A comparison with the potential mining floor levels will indicate when water flows could be expected during mining.

Air Lift Pump Tests

Air lift pump tests can be carried out during exploration programs with rotary air flush drilling rigs. The flow of water from a borehole at various depths is measured by a V notch weir and the distribution of water flow with depth provides information on the relative permeabilities (and variations across the deposit) of the strata.

Rising Falling Head Tests

Rising/falling head hydraulic conductivity tests are often carried out in association with air lift pumping tests. Where sudden increases of water flow occur the drilling is stopped, soils withdrawn and a test carried out. In some instances it is more convenient to conduct a rising head test. This is particularly the case where air is used as the drilling medium and a quantity of water has been removed from the borehole. Considerable care should be exercised when interpreting these results.

Collation of Exploration Borehold Data

It is difficult to make quantitative statements about water gains or losses encountered during drilling as the amount gained or lost depends on the depth at which the aquifer is encountered and the pressure of the air or water in the hole compared to the groundwater pressure in the aquifer. Also drillers reports may not be consistently made or recorded.

The observations may, in a semi quantitative way, provide some information on the main sources of water and an estimate of quantities. The plotting of this information may define areas that could require additional testing programs.

It is advisable to obtain groundwater quality analyses during the exploration program, from the aquifers defined (eg. coal seam(s), alluvium, basalt), and also from surface waters. These data provide background data for future environmental use and indicate the potential for groundwater usage/disposal.

General

Another method which may be used for specific situations includes a borehole packer test, in which a section of the borehole is isolated with inflatable packers and the rate in intake to the section under a given pressure head (constant head), rate of head gain (rising head), or the rate of head loss (falling head test) is determined.

Results from the semi-quantitative tests outlined above can be used to select the most representative sites for full scale pumping tests (if required). Often it is desirable to delay pumping tests until definative mining studies have been completed, thus ensuring that the pump tests are carried within proposed mining areas.

As well as these tests appropriate to the determination of the underground hydrology aspects, water quality tests should be undertaken from the outset of exploration. Samples should be collected and analysed on a regular basis to establish base information for environmental monitoring during the operation of the mine and beyond.

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FACTORS AFFECTING COAL QUALITY

COAL RANK AND TYPE VARIATION IN THE BOWEN BASIN, AND THE INFLUENCE ON COAL QUALITY

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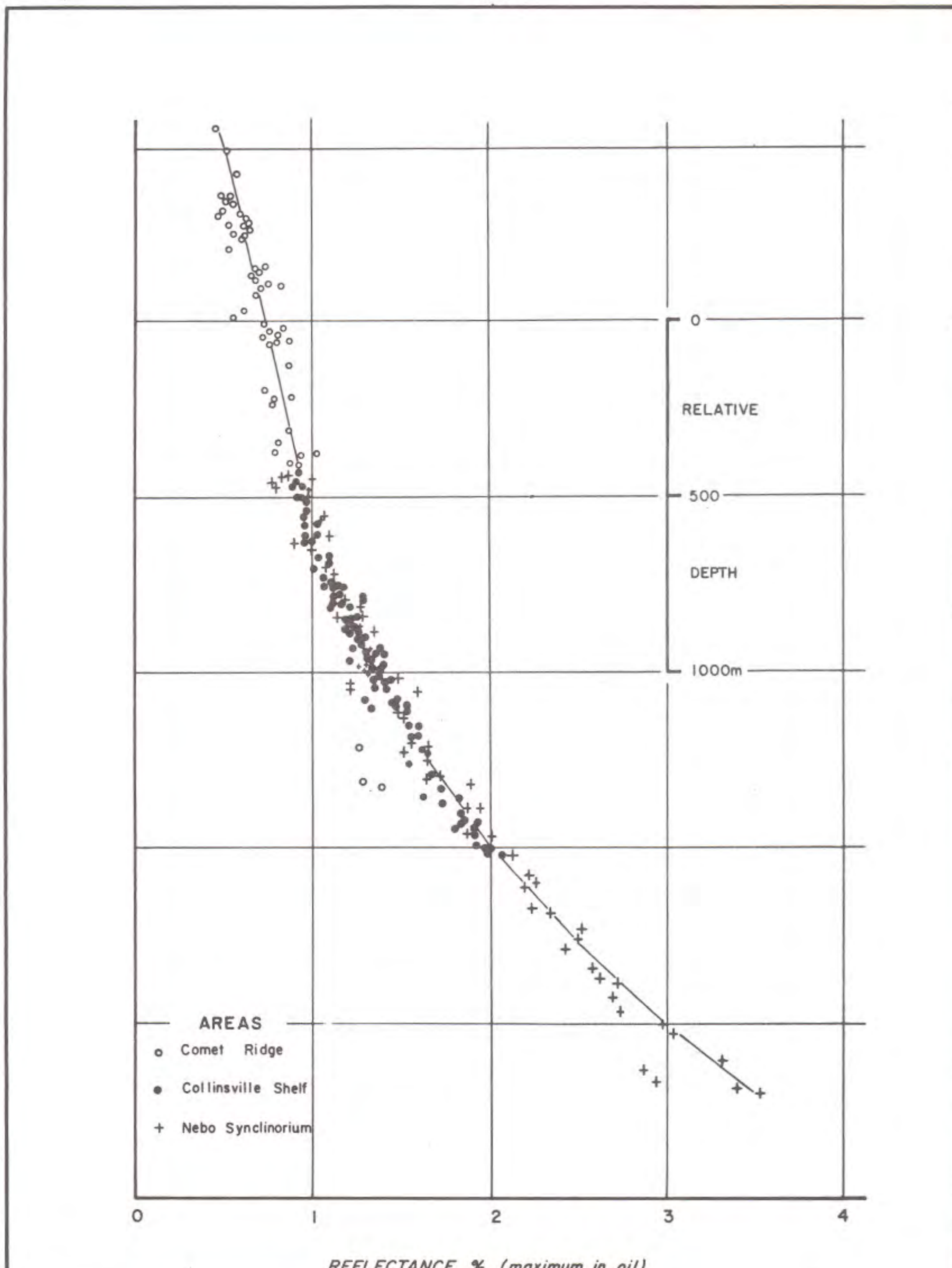
The Bowen Basin consists of a thick sequence of Permian and Triassic sediments deposited between the Thomson and New England Orogenic regions, and containing several coal-rich sequences. Coalification in the Basin was due to burial, and hence the highest rank coals occur in the centre of the north-south trending Taroom Trough. High geothermal gradients during the Permo-Triassic resulted in the metamorphism of Bowen Basin coal seams over the range sub-bituminous to meta-anthracitic (0.4% to 3.7% vitrinite reflectance) (Figure 1).

Subsequent earth movements during the Mesozoic caused medium-high rank coking coal to be exposed at the surface in the north of the Basin, while deposition of sediments in the Jura-Cretaceous Surat Basin covered the south of the Basin (Beeston, 1981; Beeston and Smith, 1984). Deposition of the Surat Basin had little effect on the coalification of the underlying Permian coals, as geothermal gradients during the Jura-Cretaceous were considerably less than those during the Permo-Triassic (Figure 2) (Beeston, 1981).

Coals that have reached optimum rank for coking, form strips around the axis of the central Trough, broken only where erosion, faulting and intrusion have disturbed the strata (Figure 3) (Beeston, 1983). The optimum rank range for high fluidity coals occurs between 1.0% and 1.4% vitrinite reflectance (Figure 4). Coals in this reflectance range occur near the surface at Gregory, Oaky Creek, German Creek, Moranbah, Goonyella and south of Collinsville in the German Creek Formation/Moranbah Coal Measures interval and at Hail Creek, Nebo, Burton Downs, Poitrel, Winchester South, Lake Vermont, Roper Creek, Lake Lindsay, Curragh, Blackwater, Blackwater South and Moura in the Rangal Coal Measures/Baralaba Coal Measures interval (Figure 3).

The relationship between rank and fluidity, however, is complicated by coal type, with decreasing vitrinite content corresponding with decreasing fluidity. Regular trends can be seen in coals from the German Creek Formation (Moranbah Creek Measures interval (Figure 4). However, results from coals in the Rangal Coal Measures/Baralaba Coal Measures interval do not correlate with these trends. Table 1 shows a lack of correlation between fluidity



- FIGURE 1. Average depth-reflectance profile, Bowen Basin (Beeston, 1981).

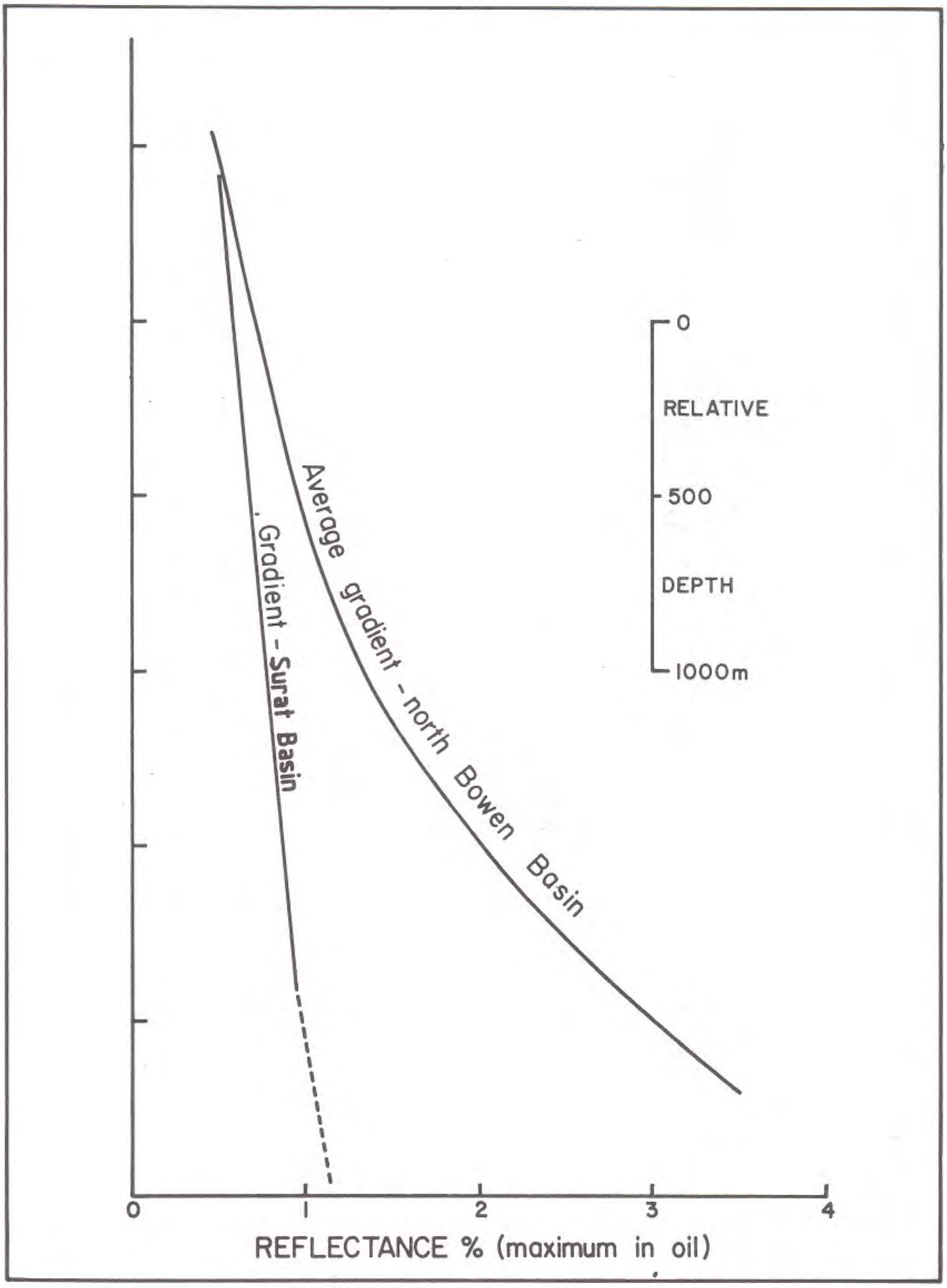


FIGURE 2. Depth-reflectance profiles, north Bowen Basin VS Surat Basin (Cabawin 1) (Beeston, 1981).

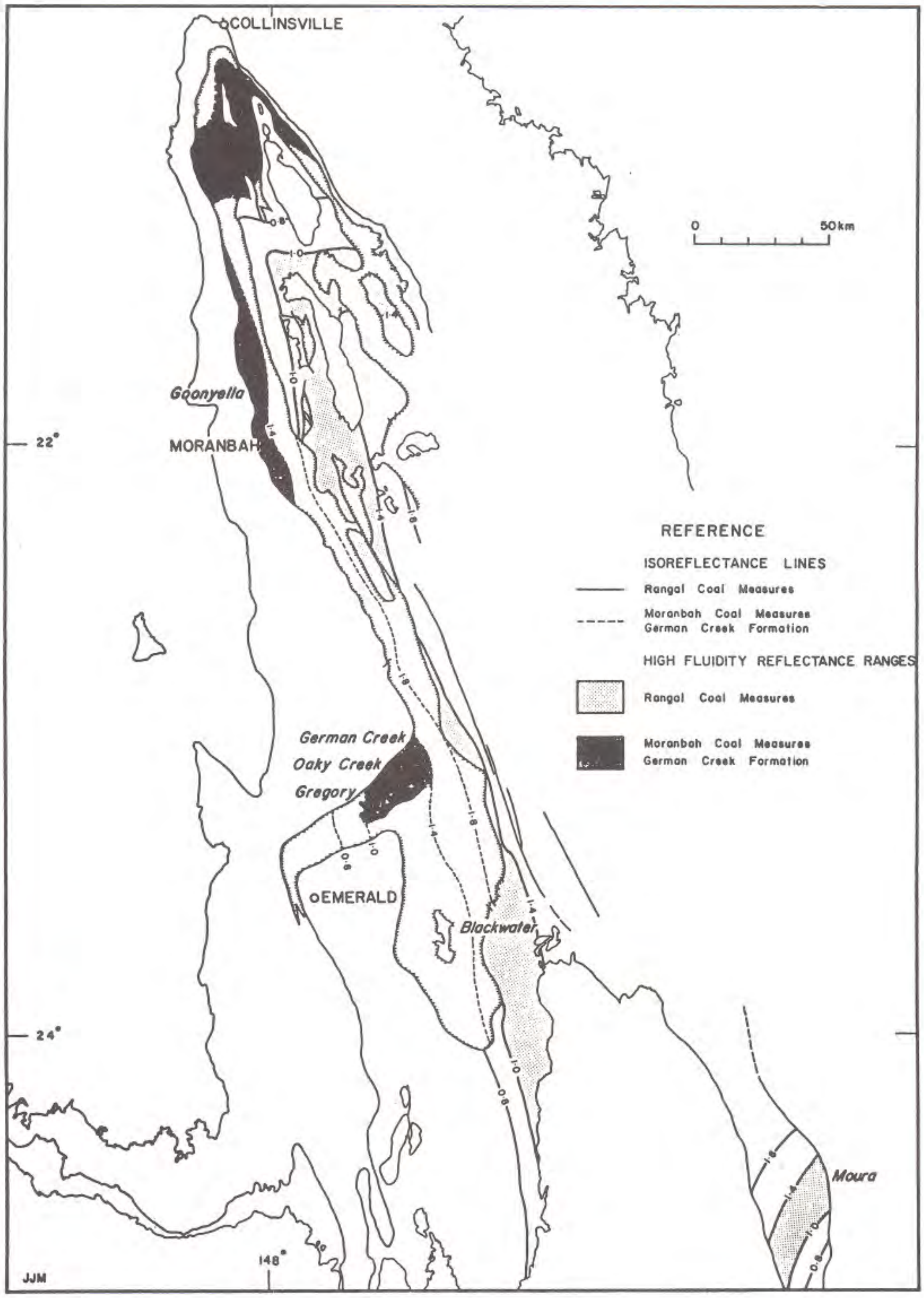


FIGURE 3. Isoreflectance map of the northern Bowen Basin showing the distribution of coal within the high fluidity reflectance range in the Rangal Coal Measures and the Moranbah Coal Measures/German Creek Formation, (Beeston, 1983).

measurements for coals of similar reflectance and total vitrinite content.

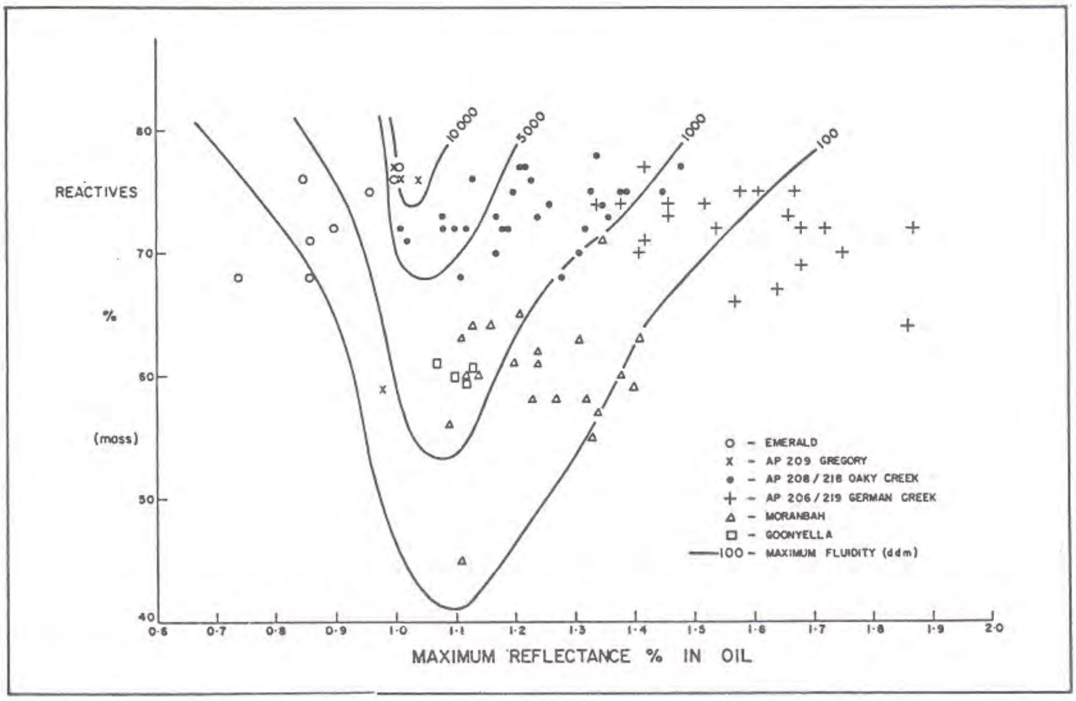


FIGURE 4. Variation in Gieseler Plastometer maximum fluidity (dial divisions per minute) with coal rank (as depicted by mean maximum reflectance of vitrinite) and coal type (as depicted by vitrinite and exinite percent), of various coals within the German Creek Formation and the Moranbah Coal Measures, Central Queensland (Beeston, 1983).

Table 1 : Selected petrographic and chemical analyses of some coals in the Bowen Basin
(Values from Queensland Coal Board, 1978)

Mine	Formation	R° max. %	Reactives (mass %)	Fluidity (ddm)	Ultimate H_2 (d.a.f.)%
Goonyella	Moranbah C.M.	1.13	61	2 200	5.2
Moura	Rangal C.M.	1.07	62	250	5.1
Blackwater	Baralaba C.M.	1.09	60	60	5.0

(From Beeston, 1982)

Detailed examination of the maceral content of these coals, showed major differences in vitrinite type (Table 2).

Table 2 : Detailed vitrinite analyses of some coals in the Bowen Basin

Mine	Total Reactives %	Telo-collinite %	Phyllo-vitrinite %	Desmo-collinite %	Exinite %
Goonyella	63	17	1	45	tr
Moura	63	23	3	30	4
Blackwater	62	25	1	31	3

(From Beeston, 1982)

The types and percentages of vitrinite macerals are partly related to the types of coal-forming plants, and the depositional environments of the peat swamps in which they accumulated. Considerable work needs to be done in the Bowen Basin to establish the various organic matter facies and lithofacies present in the coal measures, and their relationships with coal quality parameters. Such work would assist in the determination and understanding of trends in the quality of coal seams and could be used as an aid to mine planning and development.

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COMMERCIAL IMPLICATIONS OF COAL PROPERTIES

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The Bowen Basin is a coal region which geographically must rank among the largest in the world. The coal measures stretch from Collinsville in the north to Rolleston in the South with rank variations from graphite to sub-bituminous. The seams exhibit a full range of properties for both coking and combustion related tests and these properties could range within limits between very good and poor. Obviously, the analytical properties have a very significant impact on the commercial aspects of marketing the product coal. The impact occurs in regard to both pricing and saleability.

Perhaps, however, before covering the particular properties of coals which may be of interest, I should go to some words on grass-roots exploration philosophy. I would suggest that an exploration program should attempt to achieve the following goals.

1. Define the deposit in terms of geological structure (i.e. faults, dykes, seam definition, etc.)

2. Determine reserves in-situ.

3. Obtain information concerning overburden (opencut) or roof and floor (underground) conditions which will impact on mining operations.

4. Determine coal preparation characteristics suitable for plant design calculations.

5. Determine those quality parameters which are necessary to enable decisions concerning marketing to be made effectively.

The first two items are those dear to a geologist's heart and, consequently, are normally covered adequately by the exploration program. The other three items are, however, equally necessary for the deposit to become a successful operating mine. Consequently, these must be treated with the same degree of enthusiasm and diligence as the collection of the geological information. Then you will have provided the basis for the successful operation. Whilst I cannot guarantee that the information will be effectively used I can guarantee that without it the operation will not be able to function as planned.

To return to the original subject of commercial exploitation I should perhaps treat the Bowen Basin coals in terms of the two major coal measures. These are the Rangal/Baralaba and below them the Moranbah/German Creek coal measures. In general, the Moranbah/German Creek coal measures are coking coal and the Rangal/Baralaba coal measures are exploited both as coking and steam coal.

The coals of the Bowen Basin show wide range of rank. In reflectance terms the range is from 0.6 in the far south of the Basin through to 2.5 in the Yarrabee area. There are major deposits throughout the Basin which cover virtually all values between these limits. These ranges occur in the Rangal/Baralaba measures. The Moranbah/German Creek measures are limited to a narrower range in those areas where exploitation occurs or is planned for the near future.

The coal rank is the major controlling factor in the use of the coal. Generally, steam coals will fall within the range 0.6 to 1.2 reflectance and coking coals 0.75 to 1.7 reflectance. Outside of these ranges some properties will be considered undesirable and make the coal difficult to market. The properties of coals within the ranges, with the exception of ash properties, are controlled by the petrographic composition. This controls the caking and coking properties, the combustion characteristics, volatile matter and carbon content. The ash properties control ash fusion characteristics, electrostatic precipitation properties, blast furnace fluxing requirements and, to a lesser extent, the reaction rates of coke in the blast furnace.

Coals from the Bowen Basin have traditionally been looked upon as prime coking coals. However, over the past few years the range of applications has widened and now covers virtually all coal types, with the exception perhaps of the low rank bituminous steam coals such as those produced in the Hunter Valley in New South Wales. There are deposits of this type of coal but, at this stage, there are no mines operating.

Rank Effects

The term "rank" for coal is one of these nebulous terms which is very difficult to define. For the purpose of this paper I will discuss rank in terms of the mean maximum reflectance of vitrinite of the coal rather than the other methods commonly used, namely dry ash free volatile matter or dry ash free carbon content.

The rank controls many of the properties exhibited by a coal and is probably the single most important parameter which controls the final end use. In general terms coals which are used for steam raising applications are of a lower rank than those which are used as coking coal. There is, however, a considerable overlap in the ranges which means that there are many mines producing two products for different applications. The Bowen Basin has traditionally been looked upon as a source of medium to high rank coking coals and virtually all of the export mines of the Bowen Basin were developed with the coking coal market in mind. The obvious exception to this is the Newlands Mine which has recently been developed as a steam coal mine. The early export coking coal mines were developed to supply the Japanese Steel market and as such they were chosen to fit in to the requirements of the Steel Mills at the time. They were also chosen for their compatability with low rank Japanese coking coals which, in the early development of the Japanese steel industry, was a substantial part of the coal source to the steel mills. The effect of this was to place emphasis during the early 1970's upon the development of high rank coking coal deposits. This emphasis was further strengthened by the low price of oil which was used in part for process heating throughout the steel industry. However, the decline of the Japanese coal industry due to depth and diminishing reserves has led to a move towards higher volatile coals than was expected during the early 1970's. The dramatic increase in oil prices which occurred in the 1970's have further emphasised this movement as the steel industry is attempting to supply all of the process heating requirements from coke oven gas generated during the coke making process. In the mid 1970's this goal of energy self-sufficiency from coal sources would have been extremely difficult to attain.

More recently, however, there have been major changes to coke making technology which have enabled the average volatile matter of the coking blend to be increased. The use of charge preheating, briquetting, longer coking times plus an improved understanding of the coking process have allowed coke qualities to be maintained at higher coal volatile matter levels. The resultant use of increased proportions of soft coking coals and high volatile briquetting coals have increased the available coke oven gas for process heating. The effect of this in the terms of the coals industry has been to reduce the need for prime hard coking coals of high rank (or low volatile matter). Consequently, these higher rank coals which were in short supply in the mid 1970's are now in an oversupply situation.

The overall result now is that a coke oven blend will have a mean maximum reflectance of less than 1.1 whereas previously it was in the order 1.25. This has been achieved without reducing thecoke strengths necessary to feed the jumbo blast furnaces used by the Japanese industry. In fact, the average size of blast furnace employed by the steel mill industry in Japan has increased over the last few years with the recession in the steel industry. This has been achieved by the shutdown of the small, uneconomic blast furnaces.

Consequently, the changing pattern of coal usage in the past five years at least has been a change in emphasis, a reduced order book for high rank coals and a gradually increasing demand for lower rank coals combined with a dramatic increase in the demand for low rank coals which have marginal coking properties.

As the demand for the Japanese steel industry has changed and over the past few years marginally decreased or at least stabilised, there has been the development of new markets in Asia, Europe and the Middle East. Korea, Taiwan and India have emerged as major purchasers of coking coal and Eygpt and Turkey in the Middle East are developing as growing markets. The European markets of United Kingdom, France, Holland, Italy, Spain, and Portugal have shown an increased accessibility to Australian coking coals. This increased accessibility for Europe and the Middle East is largely due to the depressed level of freight rates which allows Australian coals to compete effectively against United States coals in these markets. The depressed level of the Australian Dollar has further improved the Australian competitive position and the Australian coal industry is now obtaining a significant share of these markets.

These developing markets are proving to be substantially more discerning in the quality requirements than the Japanese market. This is due to the need for Australian coals to be compatible with coals being produced in those countries and also to effectively fit into a blend of coals where it will form a substantial portion of that coal blend. This is very different to the Japanese market where no one coal was so important. As they generally formed only a relatively small proportion of the blend it could be effectively manipulated by coke oven engineers to produce a consistent result. However, in the markets outside of Japan, particularly where there is a substantial indigenous coal industry, the imported coal has to fill a particular role. This role would be either increase or decrease of volatile matter, the improvement of rank, reduction in ash, reduction in sulphur or perhaps a combination of several of these. To achieve this particular role means that the properties of the coal to be supplied has to fall within a relatively restricted range and hence the markets become significantly more discerning.

Coking Coal

There are a number of laboratory tests which are commonly used to define the coking ability of a coal. These tests were developed in Europe and the United States based upon established procedures and qualities of the coals in these areas. European and American coals of carboniferous age have substantially different properties when compared with many Australian coals of Permian age. Consequently, substantial difficulties are encountered when marketing coals into areas which have traditionally used northern hemisphere carboniferous coals as the source of coke oven blends.

Each of the Australian coal measures exhibit different coking properties, as measured by the laboratory tests, when compared with each other and dramatically different coking properties to those exhibited by a good quality coking coal from the United States or Europe. However, there are a number of coking tests available to us which may be used to define our coals even though the values of comparable coals may be different. The use of the laboratory parameter lies in its ability to define a certain quality for a given coal measure. The marketing of the Moranbah/German Creek coal measures is a much simpler proposition than the marketing of the Rangal coal measures. The Moranbah/German Creek coal measures exhibit properties which are similar to those demonstrated by northern hemisphere coals. This has the effect of those coals being immediately accepted as good quality coking coals whereas the Rangal coal measures have much lower levels of the measurable properties and considerable difficulty is encountered in convincing potential purchasers that the coals from the Rangal coal measures are capable of producing good quality coke.

Without going into a lot of detail regarding actual coking tests, there are three tests which are commonly used to indicate coking properties on a routine basis. These tests are Crucible Swelling Number, Gieseler Plastometer and Audibert Arnu (or Rurh) Dilatometer. These tests measure the ability of a coal to melt, become fluid and dilate as volatile matter is liberated by the destructive distillation of the coal on heating. Whilst each of these tests are indicative of cokemaking potential the differences between coal measures and different ranks of coal does not allow any of the three to be used as an accurate predictive method. They may be used, however, to provide a specification minimum or maximum limit beyond or below which coking results may be reasonably expected to deteriorate. They may also be used in conjunction with other data to provide a more accurate evaluation of coking capabilities.

Petrographic evaluation of coal has become very important in recent years. A method was developed in the USA in the early 1960's which was very accurate in predicting coke strengths from petrographic and rank tests. These tests are able to predict the coke strengths generated by Moranbah/German Creek coal measure coals with reasonable accuracy. They are, however, completely unsuitable for use with the Rangal/Baralaba coal measures. This is due to the high proportion of reactive macerals which are classified as semi-fusinite. Semi-fusinite occurs in a substantially different form in US coals and is largely inert. This effectively means that the methods used to predict coke strength seriously underrate the quality of coke produced from Australian coals from the Rangal/Baralaba coal measures.

Consequently, in general terms, Australian coking coals are seriously underrated by the world coal markets on the basis of their laboratory derived properties. However, when used in actual production situations the performance of most Australian coals is equal to that of US coals which would apparently have significantly superior properties.

These poor correlations with established Northern Hemisphere practice cause considerable problems when marketing Australian coals. The degree of the difficulty of course depends upon the actual level of the laboratory values to be guaranteed by the supplier. Obviously the Moranbah/German Creek coal measure producers have less problems in this regard than producers from the Rangal/Baralaba measures.

Obviously coking properties of the coals are not the only factors involved in the assessment of coking coals. There are well documented methods of assessing the cost/value implications of coal in regard to ash, sulphur, phosphorus and ash composition. These factors vary from one deposit to another and apply equally for coals from all coal measures and all geographic locations nationally or internationally.

Steam Coal

The evaluation of steaming coals is a much more straightforward proposition than that of coking coals. There appear to be less peculiarities and anomalies in the evaluation of steam coals and the exercise is therefore more straightforward. Whilst Australian experience, and in particular Queensland experience, suggests that sensitivity to such properties as ash fusion and volatile matter is much lower than believed by many overseas users, there is no doubt that the problems perceived by potential users with coals having low ash fusion and volatile matter do exist. Once again, as with the case of coking coals, the effects of various properties are very well documented and consequently I do not propose here to discuss the individual properties in any great detail but rather would only cover in general those which are somewhat anomalous in the Australian context.

Coals with low ash fusion properties may be unsuitable for many existing power stations. The problem of boiler tube fouling will arise where the temperature of the gases passing boiler tubes is higher than the initial deformation temperature of the ash so that ash will come in contact with the tubes whilst in a softened condition. This results in ash adhering to the tubes and creating a covering which insulates the tubes and hence reduces the heat transfer efficiency. In the Australian context where power stations are cycled daily between high and low load situations, the thermal shock is normally sufficient to cause ash buildup on tubes to crack and fall off and hence clean the tubes. However, in an overseas situation where in many cases base load stations operate at 100% capacity for long periods of time, this would not occur and power stations using low ash fusion coal would need to be specifically designed to handle that range of ash fusion. In the case of volatile matter the perceived ranges necessary to maintain flame stability usually lean towards the higher levels so that the user can feel sure that they are not going to encounter flame stability problems. In most cases power stations which use high or medium volatile coals are quite capable of using significantly lower volatile matter levels than they currently use without encountering problems. It is also a relatively simple proposition to make changes to burner design cheaply to enable a much wider range of volatile matter coals to be used. In general coals which have volatile matters down to a lower limit of approximately 18% dry basis may be used in conventional pulverised fuel boilers with appropriate high swirl burner design without problems. Once the 18% limit has been passed then major furnace redesign may be necessary. This normally takes the form of the use of downward firing burners as opposed to the more conventional side firing burners.

The other area where there are often problems is that of grinding capacity for the coal. The measurement of grinding capacity using the Hardgrove Index method is of doubtful validity and there are many cases where significant problems have arisen due to poorer grinding performance than expected from a grinding system. Unfortunately this problem commonly arises with some medium volatile Australian coals which have relatively high Hardgrove Index but demonstrate a toughness which gives relatively low unit grinding capacity. Research into exactly why this occurs is currently being carried out and the new grinding mill incorporated with the combustion test facility at ACIRL in Ipswich will be capable of accurately defining the grinding characteristics. Grinding capacity is also significantly impacted by mill availability, which is normally controlled by two major factors. The first is the size distribution of the coal where it has been found in many cases that specialised design requirements are needed to ensure adequate flow to grinding mills. The second factor is the abrasion characteristics of the coal. These, as measured by the abrasion index, indicate the life of the grinding components of the mill and are capable of indicating to a coal purchaser the likely availability of the mill. Where a coal exhibits high abrasion index values, the availability of the grinding plant of a power station or other coal user facility may be so significantly reduced. This may mean that the availability is too low to effectively provide a reliable supply of pulverised coal. In this context, raw coals generally have a much higher abrasion index than washed coals.

One other factor which is not commonly addressed in early exploration efforts is that of spontaneous combustion characteristics of the coal. These, like most other properties of a coal, are controlled by coal rank. The lower rank coals exhibit a much higher likelihood of catching fire during storage than do high rank coals and for this reason most low rank coals, in particular sub bituminous and lignite type coals, are not used significant distances from their minesites. Coals which are of low rank and have an obvious high chance of catching fire during storage need specialised storage precautions both in terms of plant design and handling procedures to ensure that the stockpiling systems do not add to the inherent capacity for the coal to catch fire. Well designed systems however are capable of reducing the likelihood of spontaneous combustion to a very low level.

Conclusions

A wide variety of properties as measured in the laboratory will significantly impact upon the saleability, and to a lesser extent the price, of any particular coal. The common properties such as ash, total sulphur, total moisture, phosphorus, various forms of contamination, etc. all may be considered to be either positive or negative elements in a particular coal. However, I believe that the ultimate marketability of any coal is controlled to a very large extent by the rank of that coal. The rank controls the volatile matter, the energy levels of steam coal, the potential for coke strength either in its own right or for improvement in a coke blend, the likelihood of spontaneous combustion and consequently may be held to be responsible for the nature of the coal. So when we view the various coal deposits which form the Bowen Basin and we look at the multiplicity of uses to which these coals will be put, we must realise that the reason for the different uses are largely due to changes in rank from one area to another. The differentiation between coking and steaming coals to a large extent are a result of depositional factors and consequently we have significant differences between coal measures which occurred at different times and hence under different weather conditions. The effective marketing of a coal needs an understanding of the role of that coal. This is particularly important in coking coal sales where individual coal use is unusual. All coal companies should attempt to effectively determine the suitability of the coal in the role to be filled. This requires a detailed knowledge of other coals in a coking blend and a knowledge of coking practice. To this must be added a detailed knowledge of the properties, both laboratory and industrial of the coal. Only at this stage may the suitability of the coal be judged.

Steam coal usage is simpler as the coal is often burned alone and so properties may be assessed individually.

POSTER PAPERS

THE WINCHESTER SOUTH COAL DEPOSIT

J.C. Anderson, BP Coal Australia

The Winchester South area is held under Authority to Prospect 352C and is jointly owned by BP Australia Ltd. 50%, and 25% each to Drayton Mining Development Pty. Ltd. and Westfield Ltd. It is located some 5 km east of the CQCA Peak Downs Mining Lease.

Coal is contained in the Rangal and the Fort Cooper Coal Measures. Two coal seams occur in the Rangal Coal Measures. They are named the Leichardt and the Vermont Upper, and are separated by about 30 m. Below the Vermont Upper is the Vermont Lower seam, which belongs to the Fott Cooper Coal Measures. The Yarrabee Tuff Bed separates the two parts of the Vermont Seam, and is about 1 m thick.

Structurally the deposit is contained in a syncline, the Winchester South Syncline, the axis striking north-northwesterly and plunging to the south. A zone of thrust faulting, the Isaac Fault, traverses the western side of the syncline and repeats the strike of the Rangal Coal Measures farther west (the Western Block). Scattered additional faulting exists within the syncline and along its eastern edge.

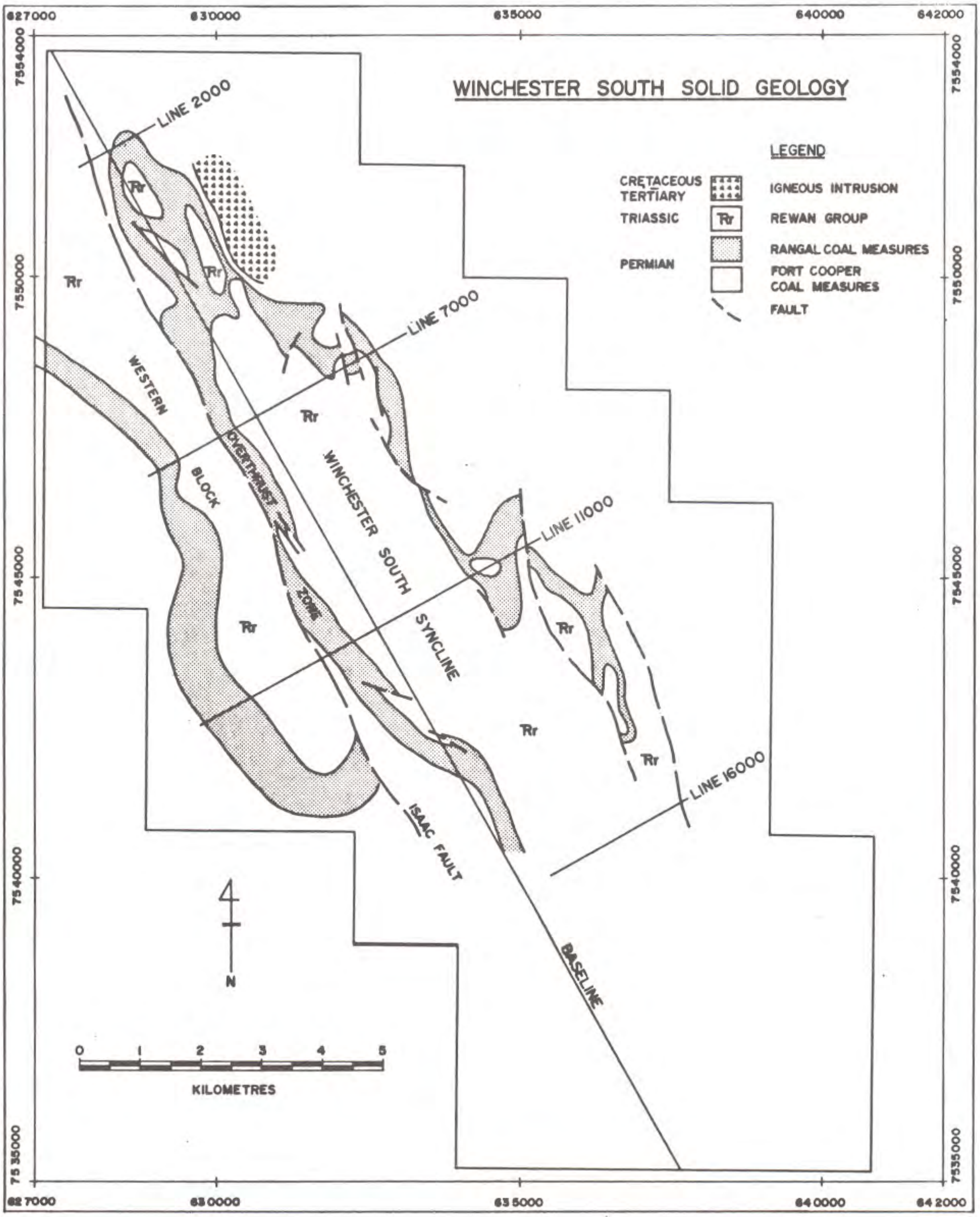
Within the Syncline, the Leichardt seam is mostly between 4 and 5 m thick, it thins and splits to the south, and is thin and split throughout the Western Block. Lithotype profile is dull with few bright bands. Average raw coal analyses for the Leichardt area are: Inherent Moisture 2.7%, Ash Content 21%, Volatile Matter 21%, Specific Energy 27 MJ/kg, and weak coking properties.

The Vermont Upper seam is mostly about 1.5 m thick, both in the Syncline and in the Western Block, and has a lithotype profile very similar to the Leichardt. Average are coal analyses for the seam are: Inherent Moisture 2.3%, Ash Content 28.5%, Volatile Matter 19.3%, Specific Energy 23.7 MJ/kg, and weak coking properties.

The Vermont Upper seam is composed of interbanded coal and tuffaceous claystone. Within the Syncline it is typically 2.5 to 5 m total thickness, but in the Western Block reaches 12 m or more due to joining with a lower seam. The coal plies are mostly dull. Average raw coal analyses for the seam are: Inherent Moisture 3.0%, Ash Content 48.2%, Volatile Matter 16.6% and Specific Energy 15.7% MJ/kg.

In situ reserves of coal within the Winchester South Syncline, excluding the Isaac Fault overthrust zone, at depth of overburden less than 60 m, are estimated as: Leichardt seam 78 million tonnes, Vermont Upper seam 48 million tonnes, and Vermont Lower seam 103 million tonnes. For an overburden depth of 80 m, the tonnages are 104 million, 57 million and 121 million respectively.

Coal from the three Winchester South seams is suitable for power generation, and can be washed to prepare an export quality or domestic quality product.



WINCHESTER SOUTH SOLID GEOLOGY
LEGEND
CRETACEOUS TERTIARY
IGNEOUS INTRUSION
TRIASSIC
REWAN GROUP
PERMIAN
RANGAL COAL MEASURES
FORT COOPER COAL MEASURES
FAULT
LINE 2000
LINE 7000
LINE 11000
LINE 16000
WESTERN BLOCK
OVERTHRUST ZONE
WINCHESTER SOUTH SYNCLINE
ISAAC FAULT
BASELINE
KILOMETRES
N

TERTIARY BASALTS AT GREGORY

R.J. BANKS, Geologist, Gregory Mine UDCL

GENERAL

Basalts of Tertiary age (34 - 22 ma?) occur on Gregory lease as discrete, valley fill deposits which were extruded onto a dissected Permian topography. The main focus of volcanic activity was in the Peak Ranges, 25km to the north. The ages quoted are for the so called "Clermont Province" of Sutherland et al 1977.

In contrast to Oakey and German Creek mines, to date no intrusives have been exposed in highwalls at Gregory although operations have been in progress since June, 1979. There is some indication of cindering of coal in two small and one large area, leased on drill hole data and surface outcrop information. Aerial magnetometry and shallow seismic refraction methods have been utilised to define the limits and thickness of basalt. Figures 1 and 2.

The fresh basalt at Gregory exhibits clearly defined flow boundaries with distinctive vesicular caps. Plates 3 and 6. Large excavations have been made in basalt in two adjacent areas of the lease. The earliest was a quarry operated to supply ballast for the German Creek-Gregory-Blackwater spur rail line. A byproduct of slightly lower quality was stockpiled for use as topcourse on haulroads and ramp surfaces. The other excavation was for the diversion of Crinum Creek around a future mining block.

BLASTING

Problems with blasting were anticipated and a series of holes along the diversion centreline were geophysically logged in order to identify bands that would require decking of the explosive column. Figure 3. One example log indicating flow tops of lower density and tendencies to cave when being drilled, appears as Figure 3. Random wet holes in blast patterns were traced back to the regularity of vertical cooling cracks which act as an aquifer. The dry holes of a pattern were considered to have been drilled within the polygons formed by the cooling crack patterns.

In weathered areas large "floating" boulders were drilled through but, because they were close to the surface, were in the area of stemmed hole. No fragmentation occurred and one large boulder (Plate 1) had to be pushed from the excavation by bulldozer.

SLOPE STABILITY

Basalt derived montmorillonitic clays in one mining block lead to selective spoiling strategies being adopted (Plate 2). Ten metres of clays were stripped off underlying Tertiary kaolinitic sands, silcrete and free running sands. The clays exhibited 21% linear shrinkage and Atterberg Limits of 56% and 29% for liquid and plastic limits respectively. One large ($200,000m^3$) failure occurred in spoil even though the clays were placed at the top of spoil. This was contributed to by the bulk properties of the spoil, derived from back analysis, being zero for apparent cohesion and a Ø of 31.5°. The spoil was placed with a Ø of 35° expected.

UNDERGROUND MINING

Potential difficulties, apart from driveage or shaft sinking through massive basalt, exist with respect to water content. Exploration drill holes that encountered more than 40 metres of basalt also experienced high water flows, e.g. 110,000 lph in bore 5008. Goafing under areas of thin intervening Permian strata will need careful consideration. Table 1 is a listing of the pertinent properties of the massive basalt.

TABLE 1

UCS MPa	Apparent Cohesion C KPa	Friction Angle Ø degrees	Unit Weight KN/m^3
241	50,000	45	27.45

Tensile Strength Brazilian MPa	Tensile Strain at Failure	Density	Porosity
10	2350 μE	$2.78t/m^3$	0.02%

Poission's Ratio	Elastic Modulus	Bulk Modulus	Sonic Velocity
0.29	30,600 MPa	24,300 MPa	6060 ± 20m/sec

Figure 1 is a plan of basalt thicknesses interpreted from aerial magnetometry, and has been borne out by drilling.

MINERALOGY AND PETROLOGY

The basalt has been described as a "glassy basalt with quartz tholeiite affinities". No olivine is visible in hand specimens examined by hand lens. Extensive vugh filling by secondary minerals occurs, especially immediately below the vesicular caps of flows. Minerals commonly encountered include quartz, chalcedony, ankerite, aragonite, chlorite, and an unnamed zeolite, as well as the glassy differentiate referred to in Plate 7.

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Journal Geol. Soc. Aust. Vol. 24, Pt. 8, pp 447-460, December, 1977.

FIGURE AND PLATE CAPTIONS

(Note: Figures and Plates are presented on the poster display).

FIGURES

Figure 1	1:20,000 Basalt Isopach Map (interpreted from airborne magnetic survey).
Figure 2	A representative shallow refraction seismic survey along the Crinum Creek Diversion to assess rippability.
Figure 3	Geophysical Log, Hole 181, in basalt overburden.

PLATES

Plate 1	Large "floater". Boulder near surface that had a hole drilled through it but was not fragmented as explosive column was in underlying weathered basalt and Permian sediments. Crinum Creek diversion south.
Plate 2	Prestripping of ∿ 10m montmorillonitic weathering residue after Tertiary basalt. Ramp 7 area. J north-east.

Plate 3	Low batter angles at unconformity between weathered Permian and Tertiary basalt. Broad channel to provide (velocity) drop structure. Crinum Creek Diversion south.
Plate 4	1:1 Batters in hard basalt. Channel narrows heading north. Crinum Creek Diversion. C Block West.
Plate 5	Dragline placing topsoil over freshly dug basalt just north of the unconformity in Plate 3. Breakages of teeth and adaptors, as well as frequent replacement of hardfacing was an accepted part of this operation.
Plates 6 - 12	Basalt Quarry.
Plate 6	North east trending Face. Looking South East. Bar 5 metres. Note well developed columnar jointing and pronounced vesicular flow top.
Plate 7	Joint infilled by devitrified late stage glassy differentiate. Scale bar 2 metres. Note offsetting of vein by horizontal bands. Same location as Plate 6.
Plate 8	Enlargement of Plate 7. Note particularly the vesicular nature of the horizontal "veins".
Plate 9	En Echelon shears developed just prior to crystallisation. Localised pressure drop appears to have promoted degassing to produce vesicles.
Plate 10	North West Face with what is interpreted as being a lava tunnel. The orange horizontal bands are considered to be the highly weathered, devitrified glassy tops of successive flows as pulses of lava flowed, cooled, and flowed until the tunnel ultimately became blocked.
Plate 11	Enlargement of Plate 10.
Plate 12	South Western Face. Columns ∿ 16 metres high, 2.1 - 2.5m across. Bench is established on vesicular flow top.
Plate 13	North Western Face. Curved cooling cracks. Just discernable vesicular lower flow top at bottom centre of photo.
Plate 14	Aragonite crystals growing in a cavity. Aragonite, opaline silica, ankerite, and zeolites are common secondary minerals.

THE ROLE OF METHANE IN BLEACHING COAL MEASURE SEDIMENTS

J.W. Beeston, Geological Survey of Queensland

White/grey-white sediments, often associated with and used as a guide to shallow coal deposits, may be due to the reducing effect of methane emanating from the coal during coalification.

White/grey-white sediments overlying coal have been known in many areas of Queensland for a considerable time (Jensen, 1968) and documentation of their surface occurrence and use in coal exploration occurs in some confidential company reports. The best known white sediments occur above the thick seam in the Blair Athol Basin, Central Queensland (Osman, 1971; Osman and Wilson, 1975). Although it had been suggested for some time that these strata, known commonly as the 'White Section', were Tertiary in age, the discovery of included plant fossils (Beeston, 1978) provided evidence for a Permian age. It was then suggested that the white colouration was a result of a downward leaching of the coal measures *in situ*, resulting in the formation of a weathering 'front' with the underlying, unaltered sediments.

An alternative process which may have predated and extended to greater depths than normal weathering has been suggested by geologist Mr Don King (personal communication) to account for exposures of "creamy white coal measure sandstone" which he observed while mapping and defining areas proposed for drilling in the Theodore, Blackwater and Goonyella coalfields. These distinctive sandstones were found to be important markers which invariably lay above concealed coal, particularly in the case of thick seams. King's explanation involves exposure of the sediments to the reducing action of methane generated and gradually released during the long term processes of coalification causing bleaching effects to coloured minerals as it migrates through the overlying strata.

Although the literature on sediment bleaching is sparse, various lines of argument can be advanced, both for and against the proposal. It is well known that methane is emitted from coal, particularly at high rank levels, through the devolatilisation process. Evidence for bleaching of geological strata by migrating hydrocarbons is available, although hydrogen sulphide rather than methane is often suggested as the possible agent (Moulton, 1926). Others give evidence for the reducing effect of methane in sandstone-type ore deposits (Shockey, 1970). Field observation of the above by D. King (personal communication) led to the comparison with white sediments common in coal measure strata in the Bowen Basin at localities such as Kianga, Moura, Blackwater and Goonyella. He further observed that they commonly immediately overlay coal, such that they were then used as surface indication of the presence of shallow coal seams. It is of particular interest to note that the most obvious bleaching in the Bowen Basin occurs at Blair Athol above a coal seam which is of the order of 30 metres thick, and which has been covered, during part of the Tertiary, by a thick basalt caprock.

Little is known of the continuation of bleached sections at depth, although discontinuation would not necessarily preclude methane alteration, but merely invoke a surface catalyst.

X-ray diffraction analysis of material from the 'White Section' revealed the clay component to be mainly kaolinite with trace mixed-layer clays (D. Carmichael, personal communication), and Fourier Transform Infrared Spectrography could not detect the presence of hydrocarbons (D. Fredericks, personal communication).

The observation of surface occurrences of bleached sediments associated with shallow coal seams has aided in coal exploration. Further studies of this phenomenon may enhance coal exploration, as well as provide information for the understanding of the genesis of, and exploration for, petroleum.

ACKNOWLEDGEMENT

Thanks are due to Dr P. Fredericks, BHP Central Research Laboratories, Shorthand, NSW, who carried out the infra-red spectroscopy.

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OAKY CREEK COAL PTY LTD

R. Clare, M.I.M. Holdings Limited - Coal Technical Services

LOCATION/TITLE

The Oaky Creek open cut coal mine is in the Bowen Basin area of Central Queensland with Blackwater being 67km to the south east, and Capella, 50km to the west.

The total project area covers approximately 270 square kilometres of which the Mining Lease No. 1315 covers an area of 127 square kilometres. The remainder is covered by Authority to Prospect 408C.

STRATIGRAPHY

The Upper Permian German Creek Formation has been divided into two members, the barren Lower German Creek member and the coal bearing Upper German Creek member. The lower barren member averages 110 metres in thickness and is devoid of economic coal seams. The upper member is approximately 160 metres thick and contains the economic metallurgical grade coal in the Oaky Creek property.

In descending order, the coal seams present in the upper member are the Pleiades 1, 2 and 3, the Aquila, the Tieri 1 and 2, the Corvus 1, Middle and 2, the German Creek and the German Creek Split.

STRUCTURE

The Bowen Basin has been divided into separate tectonic units based on the type and severity of deformation. The region in which Oaky Creek is located is known as the Comet Ridge. This area is characterised by gentle synclines and anticlines, with dips averaging less than 5 degrees.

The region is dominated by a NNW striking thrust fault system and a lesser SW system of strike slip faults. The latter system is manifested, in the SE of the A to P, by a series of SW striking airphoto lineaments.

Within the Oaky Creek lease there are two dominant fault directions, one parallel to the major thrust system and the other striking NNE. Both systems primarily consist of normal faults.

COAL QUALITY

Oaky Creek coal is a prime grade metallurgical coking coal which has excellent coking properties, exhibiting both high fluidity and high dilatation.

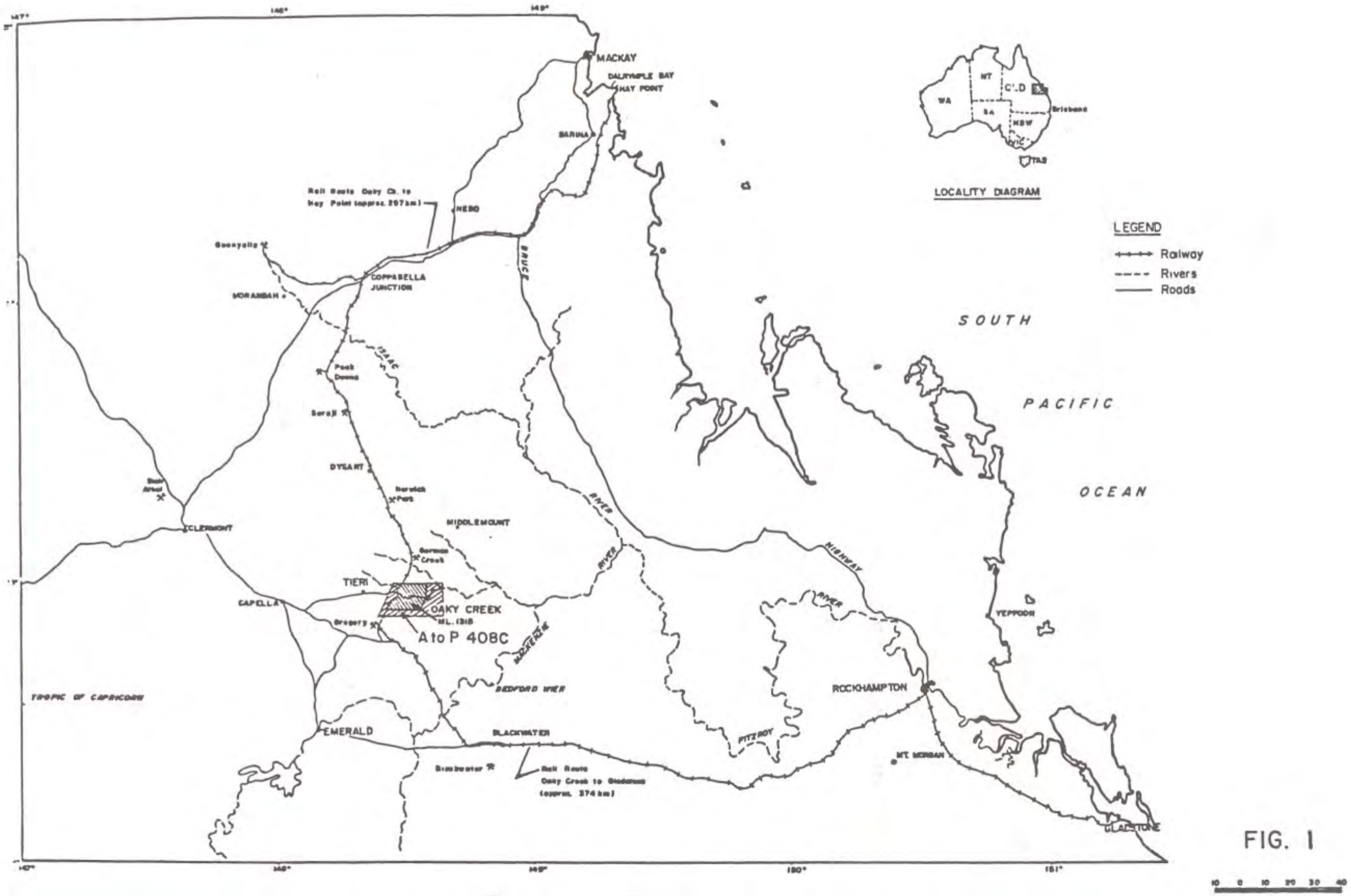
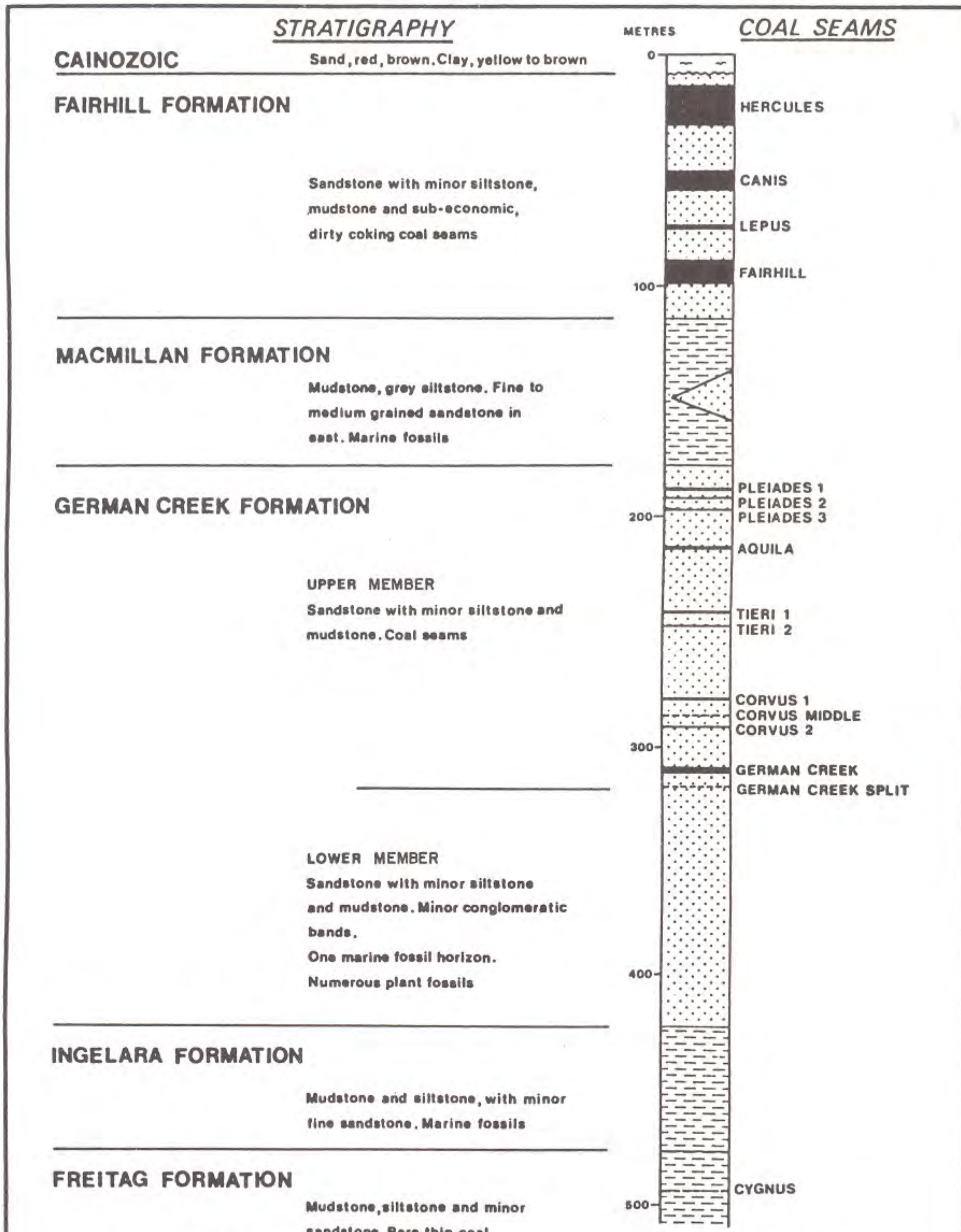


FIG. 1

OAKY CREEK COAL
JOINT VENTURE

LOCATION PLAN

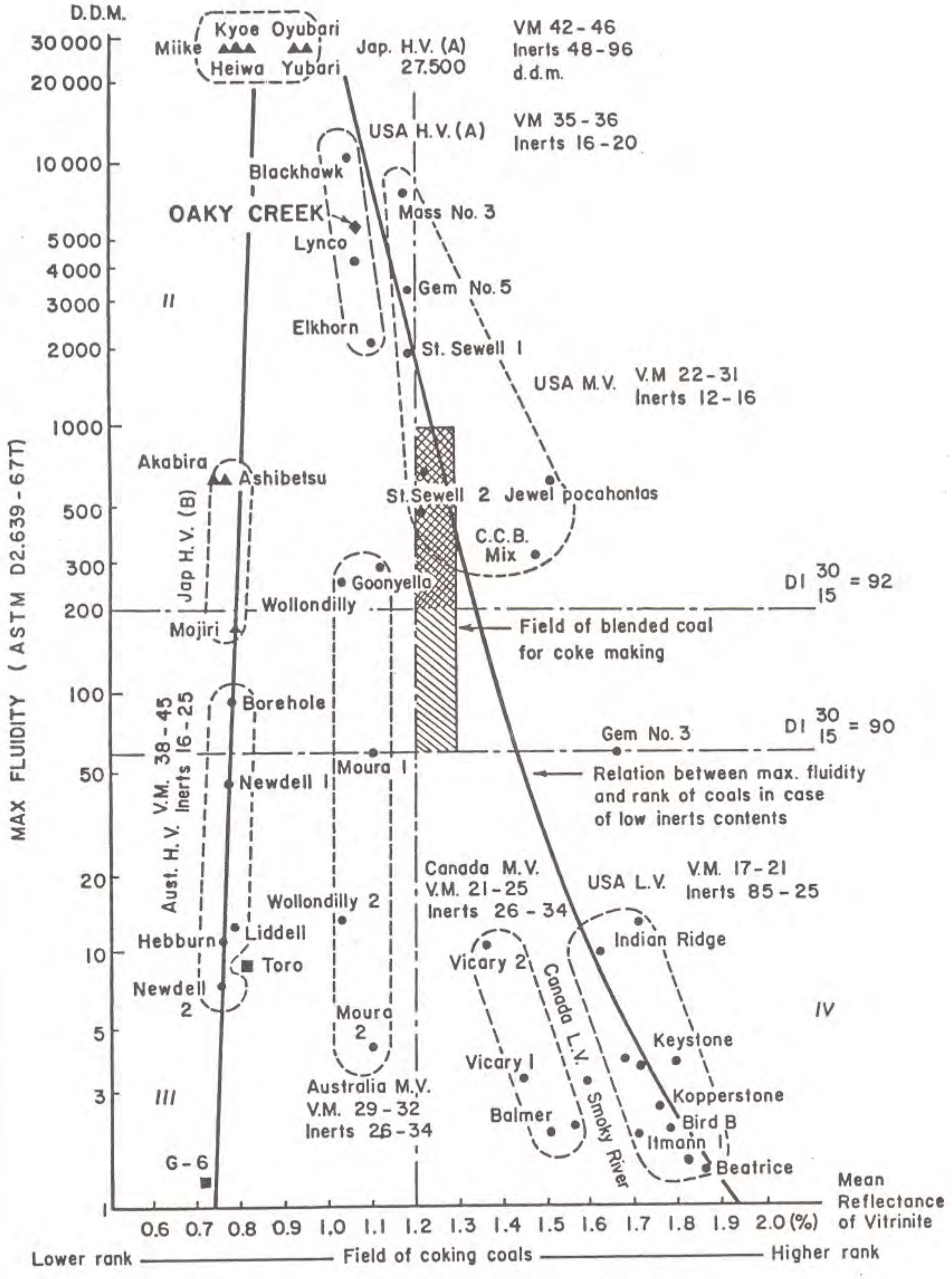


OAKY CREEK COAL JOINT VENTURE

OAKY CREEK AtoP 408C

IDEALIZED STRATIGRAPHIC PROFILE SHOWING COAL SEAMS

FIG. 2



Note: V.M. contents are shown as percent on dry ash-free basis. Inert contents are shown as volume per cent.

RELATION BETWEEN MAXIMUM FLUIDITY & RANK OF COALS

FIG. 3

DEVELOPMENT OF THE BOWEN BASIN AS REVEALED BY BASIN ANALYSIS TECHNIQUES

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INTRODUCTION

The Bowen Basin, a significant structural element within the eastern part of the Tasman Orogenic Zone, is a south-plunging synclinal structure with an exposed length of 550 km, a maximum width of 250 km, covering an area of approximately 65,000 sq. km. On its western boundary its sediments onlap the cratonic Clermont Block whereas to the east it partly interfingers and partly onlaps the latest Carboniferous-early Permian calc-alkaline volcanics of the Camboon Arc. The Basin continues in the subsurface below the unconformable contact with the Great Artesian Basin.

The geology, structure and tectonic setting of the Basin have been discussed in several recent publications (Day and others, 1983; Flood, 1983; Hobbs, this Symposium; Murray, 1983 and this Symposium). Details of the regional stratigraphy established by the joint effort of the Queensland Geological Survey and the Bureau of Mineral Resources is contained in Dickins and Malone (1973). The Basin may be divided into a western area (Springsure Shelf and Denison Trough) in which the depositional and tectonic style is typical of a foreland basin and an eastern area (Taroom Trough) which is more characteristic of a back-arc basin. These contrasting areas are separated by the Collinsville and Comet Shelves (Fig. 1).

DEVELOPMENT OF THE BASIN

It is now recognised that the stratigraphy erected by Dickins and Malone (1973) requires substantial modification (see McClung, 1981; Flood, Jell and Waterhouse, 1981; Flood, 1983; Waterhouse, 1983; Waterhouse and Jell, 1983; Waterhouse, Briggs and Parfrey, 1983). Nevertheless, a first order understanding of the sequence of development within the basin may be obtained using the basic principles of basin analysis (see Miall, 1984) and the isopach data contained in Dickins and Malone (1973).

The three dimensional geometry of each time-stratigraphic unit (formations or subgroups) illustrates the degree and mode of subsidence of the sedimentary basin during its evolution. Thickness data on successive units allow the derivation of the following

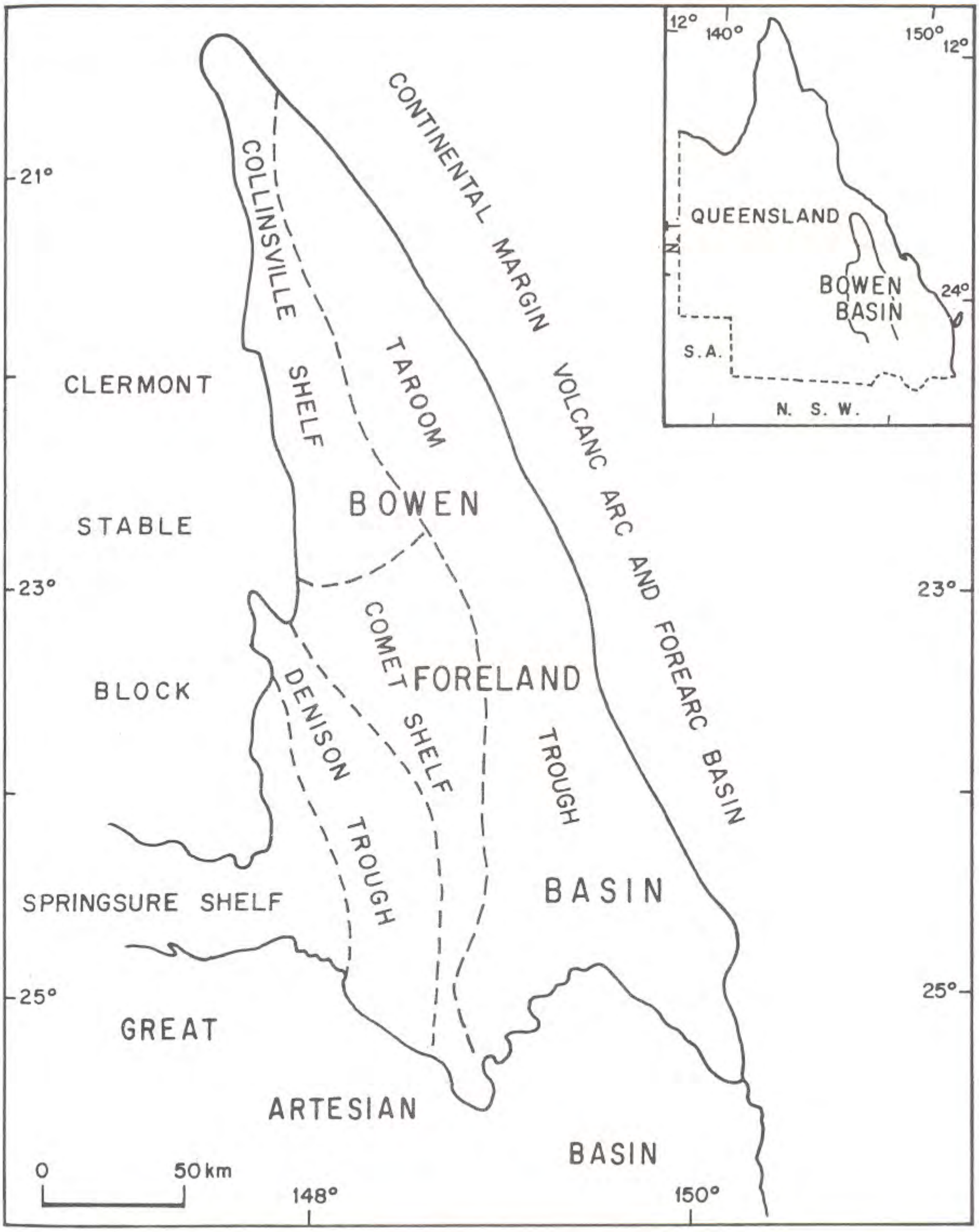

Fig. 1. Location and subdivisions of the Bowen Basin.

geometric parameters (see Sloss and Scheer, 1975): (1) position of hinge line (locus of maximum rate of change of thickness), (2) basin slope at the hinge line, and (3) basin dimensions and shape as defined by the length of the principal elliptical axes at the hinge line. Each parameter may be monitored with respect to time. Of the parameters listed above, only the location of the basin centre (the position of maximum thickness) and the maximum thickness can be read directly from the isopach map without subjective evaluation.

The spatial distribution of hinge-line positions throughout time are shown in Figure 2. According to data based on Dickins and Malone (1973), early Permian sedimentation commenced in three sub basins or depocentres, one in the southwest (Denison Trough), one in the north of the Basin, and it is now clear that marine deposition also occurred in the south-east near Cracow (see Waterhouse, 1983). Sedimentation was basin wide during the early Middle Permian, the time of deposition of the Blenheim Subgroup. The site of maximum sedimentation during the late Permian and Triassic was in the south-east in the Taroom Trough. Temporal plots of basin dimension and the maximum thickness of sediment are shown in Figure 3. A reconstruction of a west-east cross-section is shown in Figure 4. Estimates of the maximum rate of sedimentation is as follows: Permian - 280m/million years and Triassic - 140m/million years.

The most significant feature revealed by the basin analysis is that in the depocentres rotated perhaps counterclockwise in the early Permian, starting in the south-east, followed by a clockwise movement in the late Permian and Triassic from the southwest, to the north and then to the southeast of the Basin during its development. Hence the difficulty of attempts by researchers to develop a basin-wide stratigraphy. There is no excuse for the continued use of the layer cake view of stratigraphy within the Bowen Basin.

Details of the sedimentology, sedimentary facies, transgressions and regressions, the influence of Permian sea-level oscillations, and the effect of continental drift during the Permian-Triassic still await investigation. Any comparison with the geological processes operating at modern convergent plate margins which display similar arrangements of morpho-tectonic units as existed along eastern Australia in the late Carboniferous to early Triassic should help in understanding the tectonic setting and development of the Bowen Basin.

Acknowledgements

This study has been funded by a NERDDC grant (79/9127). Thanks to Bruce Waterhouse, Jack Jell, Graham McClung and Mac Dickins for stimulating discussions concerning the geology of the Bowen Basin.

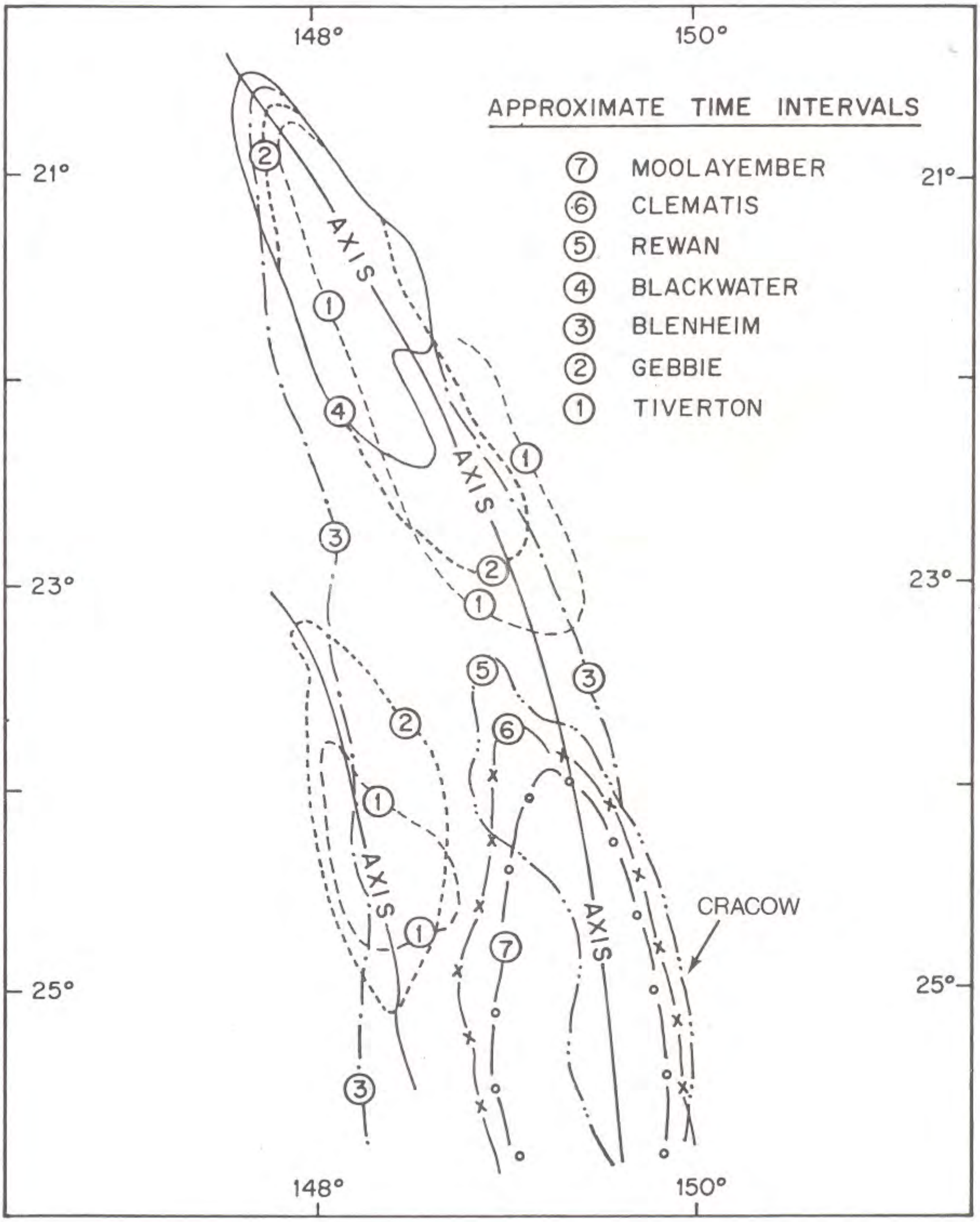

Fig. 2. Position of basin axis and hinge line for time intervals 1 to 7 (after Flood, 1983).

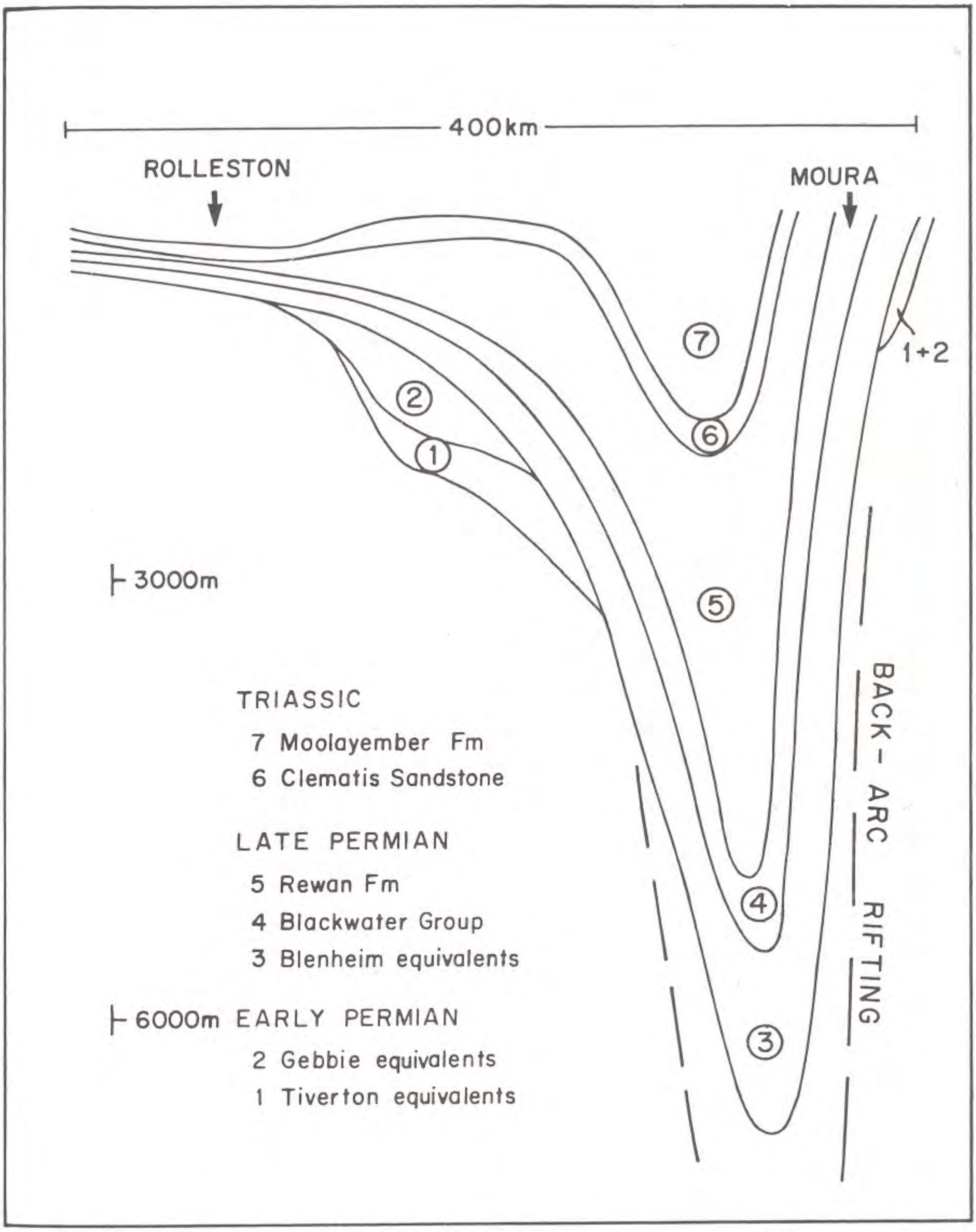

Fig. 3. Simplified cross section from Rolleston to Moura showing the major phases of subsidence and sedimentation during intervals 5 and 7 (after Flood, 1983).

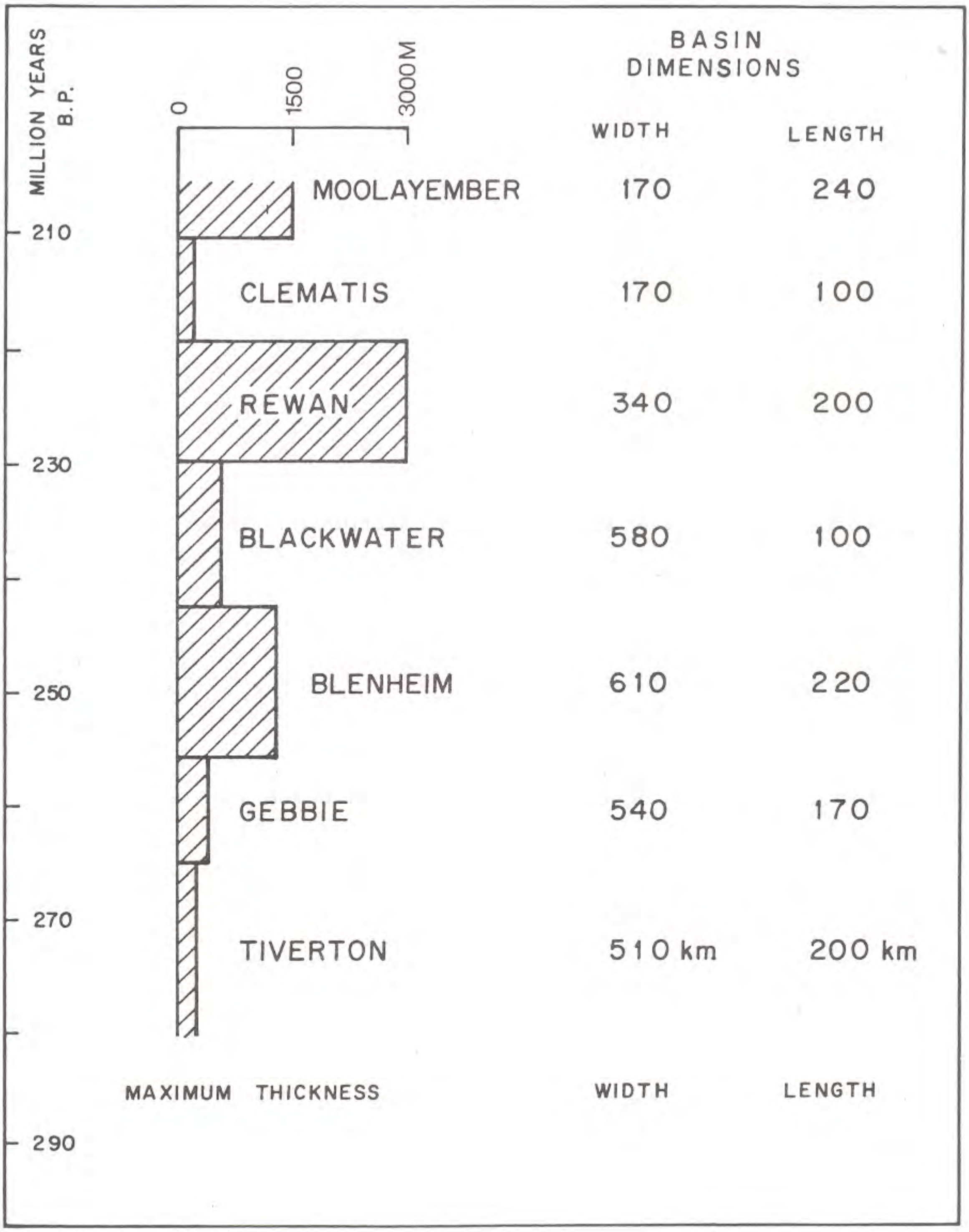

Fig. 4. Temporal plot of Basin parameters, maximum thickness, width and length (after Flood, 1983).

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FORMATION OF LARGE-SCALE INCLINED STRATA IN THE LATE PERMIAN COAL MEASURES, BOWEN BASIN, QLD

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INTRODUCTION

Theories proposed for the formation of large-scale inclined crossbeds fall into two categories. The first explanation requires that the large-scale inclined crossbeds were originally deposited near-horizontally and that they subsequently achieve their high-angle attitude as the result of variable compaction of the underlying coal seam. The second suggests that the crossbeds formed as primary depositional features and that compaction of the peat has little or no influence on their final attitude.

VARIABLE COMPACTION MODELS

Models that include variable compaction as the major factor in the formation of large-scale crossbeds have been proposed by Britten (1983) who studied the Coal Measures at Foybrook in the Upper Hunter Valley of New South Wales; Burgis (1975) who studied the Rangal Coal Measures at Blackwater in the Central Bowen Basin of Queensland, and Mallett (1983) and Mallett et al. (1983) who studied the Baralaba Coal Measures at the Moura-Kianga Coal Mine in the southeastern Bowen Basin.

The model proposed by Burgis is essentially similar to that of Britten whilst the model proposed by Mallett and co-workers is fundamentally different and will be discussed separately.

Compaction-induced depositional entity

Britten (1983) introduced the term *cide* to identify a body of rock whose attitude is the result of the differences in the differential compaction of coal and sediment. The seam splits may enclose sediments that assume bedding angles up to 45^0 to the main seams. Britten suggested that because coal forms essentially in a swamp environment then it has to be assumed that each of the coal beds including the transition split were deposited horizontally. The large-scale inclined strata are interpreted as initiating as fluvial deposits in horizontal to concave-up beds which sag at their centre depressing the peat. Mobile differential compaction results and horizontal beds are distorted and bent. Subsequently peat deposition may cover the upper surface of the channel sediments.

Channel automigration

Mallett and co-workers (Mallett, 1983; Mallett et al., 1983) suggested that the existence of sediment-infilled linear channels adjacent to a peat swamp tends to depress and compact the underlying peat whilst the immediately adjacent peat is gradually depressed and so assist the flow within the channel to migrate and occupy the position between the margin of the previous channel and the area of uncompacted peat. Immediately following deposition originally horizontal beds become twisted into sinusoidal shapes. The sequence of deposition can be deduced from the order of superposition of lensoidal units. When units are analysed in order of deposition, the steady progression of deposition in one direction is seen. As the channel migrates laterally into the peat, it leaves behind a trailing edge of sediment. This is encroached over by further plant growth as the regional water table and other controls of peat formation are not influenced by local effects around the channel. Slow settlement, after the main channel has moved on, can allow the accumulation of flat-lying swamp or lacustrine muds, or overwash sands, on the top of the, by then, steeply dipping units.

PRIMARY DEPOSITIONAL MODELS

Gilbert-type deltas, hydroponic peat islands and deep lakes

The large-scale inclined crossbeds have been interpreted in a markedly different way by Conaghan (1981). He suggests that the high-angle crossbeds are primary depositional features little modified by any secondary compaction. He envisages that the inclined strata are the forest beds of a Gilbert-type delta prograding into very deep lakes. The minimum water depths in which the coal-generated vegetal accumulations formed were typically in the range of 10-50m, commensurate with the range of primary depositional relief exhibited by the giant delta crossbeds. Conaghan suggested that the coals originated from hypautochthonous or hydroponic peat which accumulated via a rain of organic debris from floating vegetation basinward of the prograding deltas.

Crevasse splays

Flood and Brady (1985) describe a process which involves the gradual subsidence of an interdistributary swamp, development of a lake, and subsequent infilling of the lake by crevasse splays deposits. Detailed geological data in support of the crevasse sub-delta model is provided from the Late Permian coal measures in the Moura-Kianga Coal Mine in the southeastern Bowen Basin. Also, Galloway and Hobday (1983) have interpreted the high angle inclined crossbeds at Moura (Fig. 12-27) as the product of primary deposition within a deltaic system.

DISCUSSION

The recognition of genetic units within the coal measure sequences is an important aspect of an approach which is referred to as process sedimentology (see Flood 1983, for discussion). If one critically examines the published descriptions of the high angle inclined strata then the occurrences at Blackwater (Burgis 1975, Figs. 9B-12B) are best explained as crevasse splay deposits. Also Flood (1983) and Johnson (1984) both interpret the high angle inclined strata at Goonyella as splay deposits. Although the exposure in Ramp 4 at Goonyella can be explained using Britten's *cide* model, the sediments are not channel deposits; they are crevasse splay deposits and the highwall exposes a section perpendicular to the splay axis. The author's inspection of examples of the high angle crossbeds within the Moranbah Coal Measures at Goonyella, the Rangal Coal Measures at Blackwater, and the Baralaba Coal Measures at Moura suggests that they are splay deposits which accumulated within a floodplain/peat mire adjacent to major river systems on an upper deltaic plain (sense of Fielding, 1985).

Acknowledgements

This study has been funded by a NERDDC grant (79/9127). Thanks to Peter Ledger (Moura), Nigel Godfrey (Goonyella) and Cliff Mallett (CSIRO) for stimulating discussion concerning the origin of the spectacular zig-zag splits within the Permian coal measures of Gondwanaland.

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GEOTECHNICAL BEHAVIOUR OF WEATHERED PERMIAN AND QUATERNARY SEDIMENTS, SARAJI MINE

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James Cook University of North Queensland

The Permo-Triassic sequences of the Bowen Basin were uplifted and deeply incised, and then overlain by Cainozoic basalts and unconsolidated fluvial sediment. The Cainozoic sequences have been affected by several phases of deep tropical weathering, in part with lateritic duricrust development. Thus all open cut mines in the Bowen Basin have overburden composed of deeply weathered Permian bedrock, or of weathered Cainozoic sequences. The unconsolidated nature of the Cainozoic sediments, combined with weathering, forms very low strength materials in the overburden, leading to both highwall and spoil pile instability. Generally the Cainozoic sequence in the Bowen Basin has been regarded by mine operators as a single mass of low strength material despite recognition that there are lithologic discontinuities and variations in clay type within the sequence. The Cainozoic is difficult to work with since it commonly exhibits rapid lateral variations in lithology and because unit boundaries are blurred by later weathering.

The major results of this study are:

1) The Cainozoic sequence can be divided into five major mappable units. Four of the units represent phases of alluvial deposition, and the fifth, soil development on the contemporary land surface.
2) The Permian bedrock suffered deep tropical weathering before erosion and deposition of the alluvial units.
3) Two further episodes of deep tropical weathering separate later phases of alluvial deposition.
4) Weathered Permian bedrock consistently becomes more kaolinised upwards, but weathered Cainozoic units show variability of clay composition.

Weathered Permian sediments are characterised by very low smectite contents and co-dominant kaolinite and illite. Kaolinite content increases from unweathered to weathered Permian sediment. All other units show considerable variability in clay content compared to the consistent trend in the Permian sediment. There are differences between units developed in different pits. For examples at Saraji, illites dominate Bauhinia Pit whereas smectites dominate Acacia Pit.

Replicate samples were analysed for particle size distribution, moisture content and plasticity indices. In addition the survey utilised the Godfrey Slake Test, an index test, to assess spoil behaviour on a seven point scale during immersion in water. Values of 2 or less indicate slake resistant materials. Values in the range 3-5 indicate significant slake breakdown, and values of 6 and 7 indicate very rapid slaking and dispersion of spoil. Rapid slaking can lead to very weak materials, and consequent spoil failure if they are located near the base of spoil piles. The geotechnical test results confirmed the nature of the field lithologic profiles and showed clay contents were generally around 40%, with a range 15-78%. Furthermore nearly all materials had clay activities greater than 50%, and ranged up to 150%. Thus all these materials will take up free water readily forming low shear strength overburden or spoil. All samples had Godfrey Slake Test grades of 4 or greater, with most samples recording the masimum value of 7. Thus all samples will slake and disperse rapidly. Considering their high clay activities it is clear the weathered Cainozoic and Permian sediments will rapidly breakdown in the presence of water forming saturated, clayey very low shear strength materials.

Within the highwall however, *in situ* moisture contents are generally low, and all are less than the relevant plastic limit. The samples were taken after digging back at least 30cm into the wall but all values should be regarded as minima. Much of the highwall is characterised by deep fissures and smaller scale desiccation cracking. The deep fissures probably originate as desiccation cracks but are extended by stress redistribution and blasting during the mining operation so that they now generally parallel strip alignment. In summary most of the highwall exists in an undersaturated state with deep fissures which allow transfer of rain and groundwater down through the overburden.

However perched water tables are present at the Permian-Cainozoic unconformity and to a lesser extent at the contacts between individual Cainozoic units. Commonly at these locations sandy or gravelly sediments overly impermeable clayey sediments at the top of the underlying unit. Such perched water tables, particularly the Permian-Cainozoic unconformity, have higher *in situ* moisture contents and water can commonly be observed draining from the highwall at these contacts. Small failures are also common at these contacts, and most larger failures occur at the Permian-Cainozoic interface, especially where these are depressions in this contact. It should be noted that the weathered Permian bedrock is dominantly kaolinitic and contains minor amounts of deleterious smectitic clays. Despite more stable clay (indices 4-5) and lower slaking tendency failures occur at this contact because of the high saturation just below the perched water table.

Highwall failures in unconsolidated overburden are common at Saraji mine. Most failures are approximately 100m across and 10 to 25m high. Basal failure planes are generally on top of or just above coal, but others are localised on the Permian-Cainozoic unconformity, on Cainozoic unit interfaces, or Permian bedding and fault plane intersection. Highwall failures may be of circular or two wedge style.

Although weathered overburden is composed of deleterious materials with swelling clays, high clay activities and high slaking and dispersing tendencies, failure is generally avoided due to the undersaturated nature of the highwall. Since failures are localised on perched water tables where saturated clays, fail due to shearing, the natures of the Permian-Cainozoic unconformity and of significant lithologic discontinuities within the Cainozoic sequence are the most important features which need to be understood.

The Saraji study shows Cainozoic units may vary markedly in their particle size distributions and clay types. Thus it is important to know which material will eventually be placed at the base of spoil piles, where saturated conditions normally occur. Deleterious clays which did not affect highwall stability may well influence spoil pile stability.

LINEAMENT STUDIES FROM SATELLITE IMAGERY OF THE BOWEN BASIN, CENTRAL QUEENSLAND

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DATA SOURCES

Data were obtained from both the NOAA-AVHRR and Landsat MSS instruments, and these images were processed to obtain lineament maps of the basin. These two data sources were used in different modes. The small scale NOAA-AVHRR imagery was used to construct lineament maps of the whole basin, while the Landsat MSS data were used to map a more detailed study area. This detailed study area was in the Blackwater region, covering portions of the Emerald and Duaringa 1:250,000 sheets.

Both the visable and thermal infra-red channels of the NOAA-AVHRR data were examined separately. This was done in order to determine the differing thermal responses of the structures identified in the imagery. This differing thermal response may be of critical importance in determining the significance of any given structure to planned or current mining operations.

As well as being recorded on lineament maps, the structures were tabulated with a designated number, their bearing, and the length of the feature mapped. The bearings were taken after the images had been rectified to a transverse mercator grid and were always taken east of north and from the southernmost point of the mapped feature. This means that no bearings were recorded in the segment from 90 to 270 degrees since these are represented by the complementary back bearing. These data were used to construct half-rose diagrams, both for the basin as a whole and for various portions of the study areas (see Figure One).

NOAA-AVHRR

The examination of the NOAA-AVHRR data confirms previous geological studies in that it identifies two major structural directions, one roughly north east - south west and the other north west - south east. These images also show very clearly the change in deformation style between the metamorphosed rocks of the Rockhampton region and the coal sequence rocks to the west. The major structure which separates these two regions is a prominent feature on all of these images.

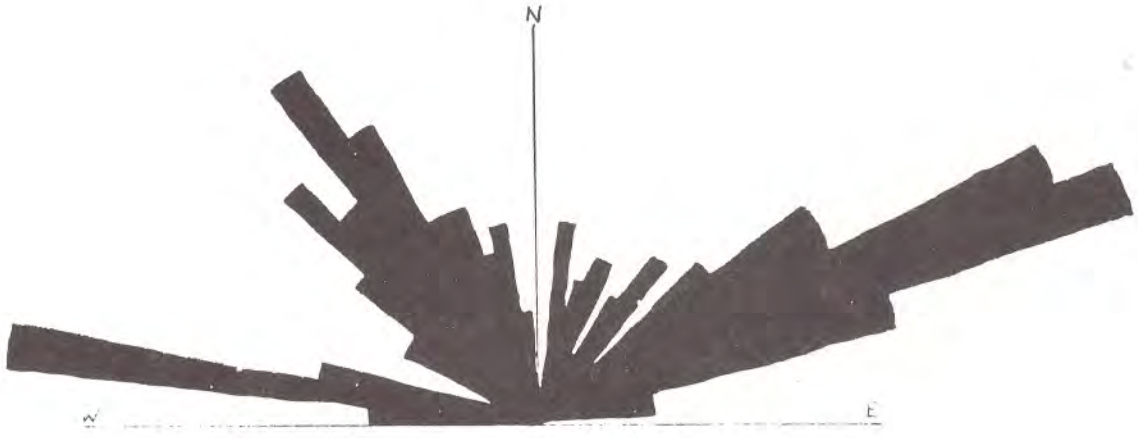

FIGURE ONE: Half-rose diagram showing the lineament distribution in the Landsat MSS study area.

An examination of the thermal infra-red data shows a clear distinction between the thermal response of the two structural directions. The north east - south west direction shows far more clearly on the thermal imagery than it does in the visual bands while the north west - south east direction has a very diffuse thermal signature. Indeed it is mainly distinguished by the change in thermal properties of the lithological types on either side of the structure, rather than by any thermal feature along the structure itself.

The ability of these data to display the whole of the basin as well as its surrounds on one image, provides an ideal synoptic viewpoint for determining the large scale structure of the basin and relating this to the surrounding geology. It can also show the large scale structural framework of any given area within the basin.

LANDSAT MSS

A) Lineament distribution

Lineaments occurred fairly uniformly throughout the study area with mapped features normally being between 2 and 40 kms long. Two regions of the study area, however, showed a relatively low lineament concentration. These regions were around Emerald and Yarrabee. In both of these locations there are extensive surficial deposits consisting of both Tertiary basalt flows and thick Quarternary soil cover. At the scale of this investigation, these effectively masked all but the major structural directions.

The study area contained four major lineament direction groups. These were, in order of prominence, a group bearing between 50 and 75 degrees east of north, a group bearing between 305 and 340 degrees, a group bearing between 275 and 285 degrees, and a very diffuse group between 5 and 40 degrees.

B. Lineament orientation

The most prominent lineament group, bearing between 50 and 75 degrees, shows a skewed unimodal distribution with the most frequently occurring direction being between 65 and 70 degrees. This group contains the greatest number of lineaments, 75 lineaments fall into this group, although the larger numbers may be a result of the visual clarity of the lineaments in this direction. This clarity is certainly greater than in the other direction groups and may have led to their detection in circumstances where the more subtle directions could not be discerned. This group has a remarkably uniform occurrence across the whole of the study area. It is aligned parallel to the principle stress direction in the basin (Enever, pers. comm.).

The second most prominent lineament direction, between 305 and 340 degrees, is a more diffuse bimodal group. The two modes are centred around 310 and 325 degrees. This bimodality decreases across the basin from west to east, with the lineaments centred around the 325 degree direction becoming more important. The more commonly occurring direction for this direction group over the study area as a whole lies between 320 and 325 degrees. However, in the western portion of the basin, the more common direction lies between 310 and 315 degrees. This latter direction group corresponds to the direction of the major thrusts in the Bowen Basin (Mallett, pers. comm.) and occurs at right angles to the principle stress direction as measured by Enever et al. (Enever, pers. comm.). Major geological structures which can be identified with lineaments from this direction group include the Springsure Fault, faults associated with the Shotover Anticline, the major fault structure through the Curragh Mine, the Jellinbah Fault, and the Yarrabee Fault. This direction group also contained the bedding directions within the folded zone in the study area. However, since these formed a special group of structures, they were not included in the lineament statistics.

The third lineament direction group, bearing between 270 and 280 degrees, is a strongly unimodal group. It is of relatively minor importance over most of the study area. However, it represents an important series of structures along the southern margin of the Blackdown Tableland and in the area around Dingo. Studies using the NOAA-AVHRR suggest that major structures with this orientation also occur elsewhere in the basin.

The fourth lineament direction group is a very variable collection of minor and/or highly localised occurrences. The group covers the segment betwen 5 and 40 degrees. There are three main modes: one between 5 and 10 degrees, one between 15 and 25 degrees, and one between 30 and 40 degrees. The 5 to 10 degree direction is mainly represented along the Dawson Range and may be related to the Mimosa Syncline. The 15 to 25 degree direction is heavily localised in the Ensham region. The third mode, from 30 to 40 degrees, occurs as a minor direction across the study area, although there is some concentration in the region to the west and south west of the Blackwater Mine.

CONCLUSION

While the relationship between the lineaments observed on the satellite imagery and mapped geological structure remains somewhat ambiguous in detail, it is clear that major structural trends can be mapped accurately at a variety of scales using these data. The images also show a number of structures which have not previously been mapped. The identification and characterisation of these features could be of major importance in understanding the geological and structural evolution of the Bowen Basin.

COAL EXPLORATION IN THE RUGBY AREA

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INTRODUCTION

The Rugby area lies some 30 km southeast of Moranbah, in central Queensland (Fig. 1).

Previous water bore and company drilling by Clutha Development Pty Ltd and CRA Exploration Pty Ltd indicated a coal seam approximately 9 m in thickness between depths of 107 and 109 m in a formation considered to be the equivalent of the Collinsville Coal Measures.

A total of 12 cored holes have now been drilled by the Geological Survey of Queensland in current exploration and further holes are proposed in the immediate future (Fig. 2).

STRATIGRAPHY

The basement rocks consist of hard crystalline acid volcanics of the Silver Hills Volcanics. They were intersected in four holes.

Overlying these volcanics is a sequence of volcanic conglomerates which are generally lithic-rich with numerous rounded volcanic clasts set in a clayey, tuffaceous matrix. The thickness of this sequence is only 5 m in one drillhole but is generally greater than 15 m and may be more than 37 m. Whether this conglomerate is part of the Upper Devonian Mt Rankin Beds or is of a similar age to the coal bearing sequence is unclear.

The coal bearing sequence is considered to be an equivalent of the Blair Athol Coal Measures and the Collinsville Coal Measures, both of which have a basal conglomerate. The sequence comprises coal and sandstone with minor mudstone and siltstone beds in some holes. Generally the coal seam lies only 2-5 m above the conglomerate but in one hole a 37 m interval of mudstone and siltstone separates the seam and the conglomerate.

Equivalents of the Blenheim Formation overlie the coal seam. This sequence of rocks is dominated by sandstone which is dominantly quartzose with numerous lithic fragments and volcanic clasts. Thin conglomerate bands are present and minor dark siltstone bands may occur, particularly in the lower part of the sequence. Bioturbation and worm burrowing are common throughout especially in the lower half of the sequence.

Fragmented shells and shell fossils commonly occur throughout the sequence. In GR 194 a 17 m interval of mudstone and coquinite, especially rich in shell fossils in the lowest 3 m approximately 175 m above the coal seam may represent the "clarkei bed".

Overlying this thickness of marine sandstone, is a clay sequence of likely Tertiary age. Owing to the thickness of weathering, which ranges from 62 to 96 m, the boundary between the two units is difficult to define accurately. The thickness of this highly weathered claystone sequence appears to vary from 15 to 63 m, averaging approximately 63 m. The sequence appears to thin to the north-east and in one hole may be absent altogether.

COAL SEAM GEOMETRY

In the northwest of the Rugby area the coal seam is 9.01 to 10.4 m thick, but decreases to the southeast to between 6.1 and 6.5 m. Towards the northeast the seam is split into three; two thin seams, 0.45 to 1.15 m were intersected, while the main seam is 4.0 to 5.0 m thick. In the far east of the area only two thin seams less than 0.70 m thick were interesected.

Basin geometry is unclear but the depth to the coal seam clearly increases in the southeast where the apparent dip is 3-5°. The coal seam forming environment was limited to the northwest and southwest probably by irregular basement topography. In GR 192 a significant sequence of sandstone was intersected but there is only a thin carbonaceous interval immediately above the conglomerate. This may represent the limit of coal deposition in that area. Further drilling is requred to define the northern limits of coal deposition and to determine the type of geological boundary at those limits.

A coal seam was intersected in one CRA hole some 12 km to the south-southeast of the main Rugby area but the seam is only 1.5 m thick. Other holes drilled further to the east of the Rugby area penetrated considerable thickness of sediment; coal seams are therefore likely to be at great depths, if they formed in this area.

Numerous holes drilled by CRA in the Logan Downs area on the Peak Downs highway 28 km southeast of Rugby intersected a number of thin coal seams but none were of significant economic interest.

COAL QUALITY

The coal seam in the Rugby area is a dull non-coking coal which is high in sulphur. It has an average reflectance of 0.93 with a generally low vitrinite content.

The coal seam generally has a higher ash content in the bottom third; for example, sections of 9-10 m thickness may have a raw ash content of up to 39% in the bottom 3 m, while sections 6 to 6.5 m thick may have a raw ash content of up to 25% in the bottom 2 to 2.5 m. Average raw ash content for the upper plies ranges from 12 to 14%.

The average raw ash for the whole seam is 17.0%. A floats product at RD 1.60 has an average yield of 80%, which could be significantly increased if the dirtier bottom section was excluded. Sulphur content of the F1.60 product averages 1.8%, most of which is in organic form.

Only limited Stage II analysis has been conducted at present, but ash fusibility temperatures are high, that is generally greater than 1600°C. Hardgrove Grindability is low - about 53 (46). Specific energy is about 35.2 MJ/kg (d.m.m.f.) and volatile matter approximately 29.7% (d.a.f.) for the F1.60 fraction.

CONCLUSIONS

The Rugby area contains an important coal resource in an unusual and isolated coal-forming environment. The 6-10 m thick seam has potential as a steaming coal if the problems of high sulphur can be overcome.

While the geological boundaries of the coal basin have yet to be fully defined, potential *in situ* reserves to 250 m depth could reach 100 million tonnes. Owing to weathering and irregular basement topography, reserves to 100 m depth are likely to be approximately 20% of this figure, which suggests underground mining would be the more favourable method of extraction.

Exploration is continuing and a full report on the area will be produced at a later date.

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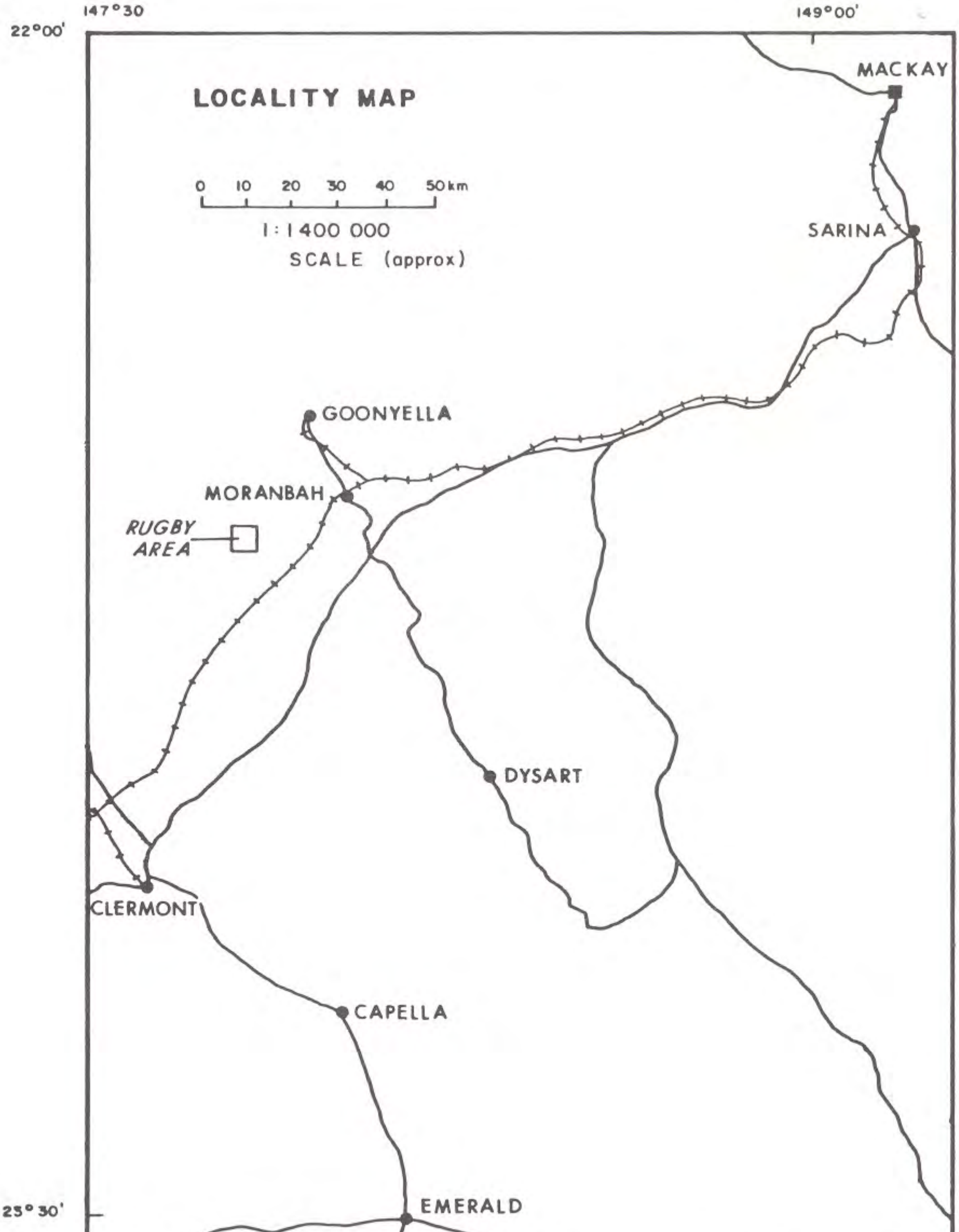
147°30
149°00'
22°00'
LOCALITY MAP
0 10 20 30 40 50km
1:1 400 000
SCALE (approx)
MACKAY
SARINA
GOONYELLA
MORANBAH
RUGBY AREA
DYSART
CLERMONT
CAPELLA
EMERALD
23°30'
ALT

FIG.1.

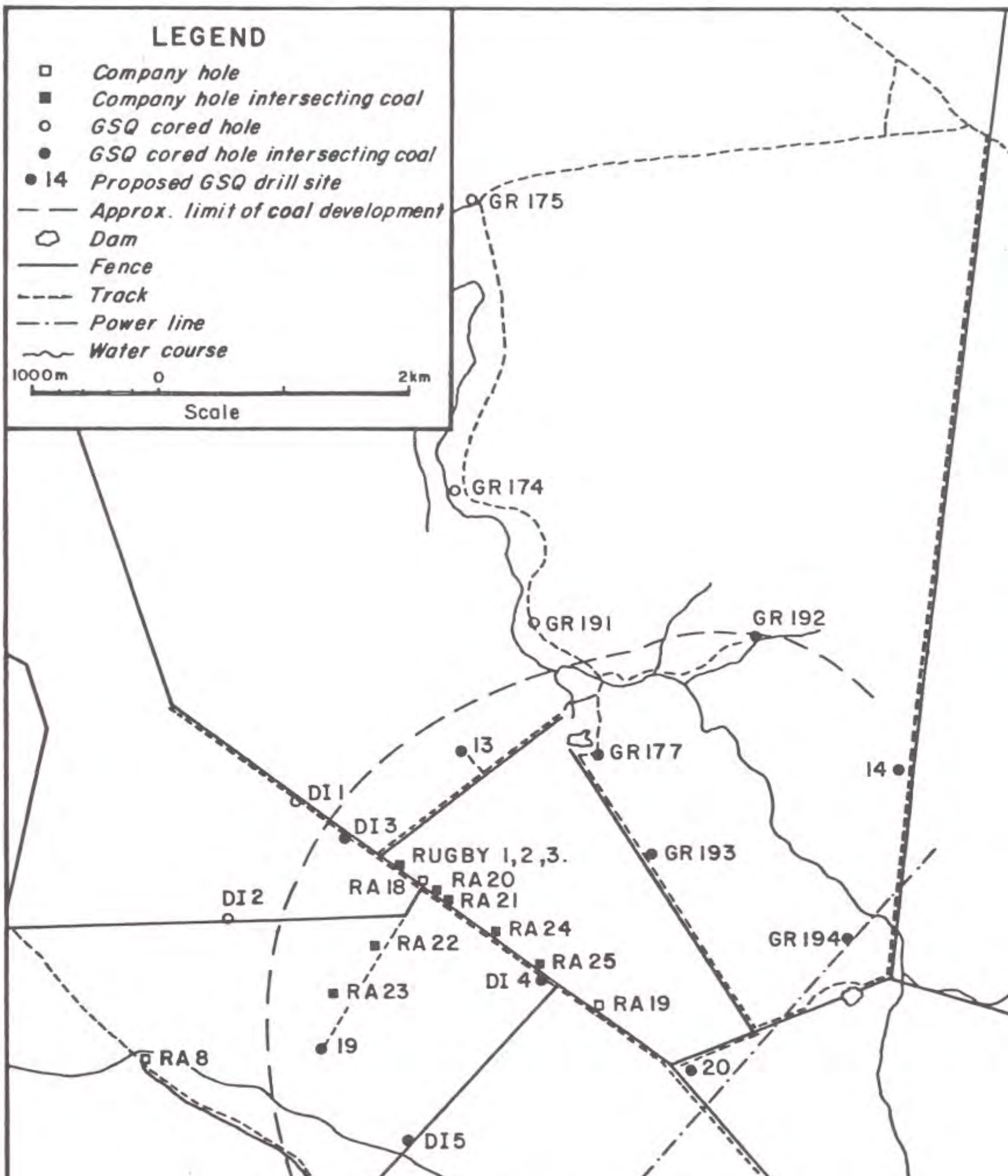

Figure.2. Borehole location map - Rugby area.

GERMAN CREEK MINE

R. Phillips, Senior Geologist, Capricorn Coal Management

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F. Mollica, Coal Quality Technician, Capricorn Coal Management

INTRODUCTION

German Creek Mine operates both open cut and underground workings at the site located between Norwich Park and Oaky Creek mines. The annual production is 3.25mt of prime coking coal won from numerous seams, some of which are relatively thin. Future production will be significantly supported by the underground workings.

STRATIGRAPHY (FIG. 1)

The column included shows a typical section through the measures. Upper most are the Rangal Coal Measures located on the eastern boundary of the lease underlain by the Burngrove Formation, the Fair Hill Formation, the Macmillan Formation, which is a marine sequence, and the German Creek Formation.

On the German Creek Mining Lease the principle seams worked are within the German Creek Formation and are the German Creek, Aquila and to a lesser extent the Tieri seams. These are supplemented by the thin seam workings of the Corvus II and German Creek Lower seams. Future interests will be shown in the Corvus I and Pleiades seams and supplementary production from the Middlemount seam of the Rangal Coal Measures from the German Creek East Lease.

Sediments in the German Creek Formation are lithic sandstone with a quartz content generally less than 50%. They are marked by a high occurrence of mica. Typically the sequence is thickly bedded sandstone with less common silty and mudstone phases. More thinly bedded sequences overlie the German Creek seam in the southern extent of the lease and laminite can be found in the sediments overlying coal seams. Massive sandstone of marine origin (Mallett, 1985) are recognised overlying the Tieri and Aquila seams.

The German Creek Formation is thus of deltaic origin with fluviatile and marine phases present. It was deposited during the Late Permian period.

STRUCTURE (FIG. 2)

The sequence strikes north-south and dips to the east at grades between 5 degrees and 10 degrees. In the area of the southern pits the major structure is a north-south trending fault with a displacement between 1m in the north to 60m in the centre and 10m on the southern boundary. It is recognised as a thrust fault where exposed in the north. Most other structures are thrust type and strike to the east.

Evidence is present throughout the German Creek pits of horizontal shearing. This can be seen in the German Creek seam by the presence of a shear zone located about mid seam and about 150mm wide. Elsewhere in the seam and overburden there are thin clay bands which demonstrate considerable horizontal movement. This is evidenced by observing the frequent dykes which are dislocated in Pits P and B. The resultant north-west movement has been measured at 10m in Pit P.

The principle joint set was formed during diagenesis (Moelle, 1985) and is presently represented by a tensional pervasive joint in the north east direction and shear in the north west direction. A later less pervasive wrenching joint occurs in the west north west direction. In the vicinity of the Central Colliery, joint blocks isolated by the pervasive north east and north west joints measure 5m x 3m.

The principle stress direction has been determined by the hydrofrac method (Enever, 1984) and two sites have been successfully tested. In the southern extent of the lease the principle maximum stress has been determined as north north east and at the Central Colliery as north east. The measurement of the magnitude of the principle maximum stress has confirmed the previously assumed ratio of horizontal stress being twice that of the vertical stress.

The above stress directions are supported by interpretation of the direction of dyke emplacement and by observation of the conjugate joint sets within the strata at the mine.

IGNEOUS ACTIVITY (FIG. 2)

The lease has considerable evidence of igneous activity in the form of dykes, sills and a volcanic plug. In the area designated the northern pits the German Creek seam has been intruded by a sill which extends from Norwich Park in the north to within 1.5km of the Middlemount access road in the south. It is also highly probable that dykes intersect all seams in the northern pits as inferred from southern projections, drill hole intersections and interpretation from magnetometer surveys.

In the southern pits both the Tieri and Aquila seams are intruded by sills in various places (possibly using the previously mentioned north south thrust fault as a conduit.) Numerous dykes, trending parallel with the north east tensional joint intersect all pits in the southern area. These dykes range from less than 0.5m to 12m wide and from highly weathered to fresh. In the Open Cut they cause considerable problems to mining activities and have been responsible for lowwall and highwall failures.

Several of these dykes trend towards the present Central Colliery and also towards future underground areas. Recent attempts to confirm their presence by the use of a caesium vapor magnetometer (Stanley, 1985) has had mixed results due to the highly weathered nature of these dykes, depth of recent alluvial and Tertiary cover and possibly due to their irregular "pod-like" occurrence.

A single basalt plug occurs in the open cut area to the east of Pit C. This has been quarried and has proved a valuable source of road base and top course material.

Petrographic analysis has been conducted on samples from each of the igneous events. The sills are classified as microsyenite or trachyandesite, the dykes as teschenites or analcite dolerites and the volcanic plug as an olivine basalt.

COAL QUALITY

The product from the German Creek Mine is a prime grade hard coking coal. A typical product analysis would be as follows:

Ash	8.5 %
Vols	21 %
Total Sulphur	0.75 %
C.S.N.	8 1/2 - 9
Auto Gieseler Fluidity	+400 ddpm
Dilatation (ISO349)	+75 %
Ro Max	1.45

The quality of the coal on the lease varies from south to north. Caking properties and yield parameters decrease northwards which significantly influences the scheduling of the operation. Fluidity, dilatation and volatiles also decrease to the north associated with an increase in the Ro Max values. Ash values are higher to the north which influence the yield of plant feed. Such constraints will have a bearing on the location of the second underground mine.

Seam Gas

The German Creek seam is characterised by an increasing seam gas content with depth. The first signs of seam gas have been detected at 100m depth of cover. This has been observed in both borecore and underground workings at the Central Colliery. Methane desorption values have shown gas contents of 15 m3/tonne at 400m depth of cover. Gas composition is 95% or greater methane.

APPROACH TO MINING

Open Cut

The open cut is worked as a strip mine along strike. Overburden is drilled by three Marion M4's with 280mm diameter holes on a 9m grid. Blasting is generally done with ICI explosives, although some Dupont explosive is also used. Four Marion 8050 draglines remove 8 million m3/year of prime overburden each uncovering the German Creek, Aquila and Tieri seams. Following removal of overburden, coal is cleaned by the dragline dozer and then by auger scrapers. Coal mining in pit is by front end loaders where the seam dip is moderate. When the pit floor gradient increases the coal is benched using Caterpillar bulldozers and mined by Liebherr 11 m3 capacity backhoes. Coal strength at German Creek is low enough not to require blasting prior to mining.

Daily production is arranged such that a specified feed is delivered to the ROM hopper for stockpiling on 20 000 tonne raw coal piles. This is achieved by scheduling the fleet of seven Terex 150 tonne trucks to the appropriate pits to supply the requisite plant feed. The two raw piles are reclaimed and fed through the plant which uses dense medium cyclones, spiral concentrators and froth flotation. The feed is split to 50mm x 1.4mm, 1.4mm x 0.4mm and 0.4mm x 0mm fractions for these circuits respectively.

Thin Seams

The primary thin seam worked is the German Creek Lower. This is recovered from where it splits from the German Creek seam in Pit P to Pit B. The parting rapidly increases in thickness northwards to a consistant 3.5 to 4.0m. Average thickness of this seam is 0.6m.

Parting is drilled using a GD25R with 150mm diameter holes on a 5m grid. After blasting the parting is removed by Liebherr backhoe into 85 tonne Terex rear dump trucks. Direct dozing of parting into voids is currently being trialed.

Recent trials of pre-stripping by dragline to the Corvus II seam where its thickness is approximately 0.6m has proved successful. In appropriate areas the Corvus I and II seams will be recovered using a two pass dragline method.

Factors Influencing Open Cut Mining

Both highwall and lowwall stability at the mine is in general sound. Highwalls are cut to about 72 deg. and at this angle are stable and lowwalls cut to 45-50 deg. with a berm width of 10 meters. In the southern most German Creek pit and Tieri pit where seam dips increase significantly to angles of 10 deg., this steepening has acted together with weak floor material, minor faults and dykes to cause lowwall problems. Lowwalls are battered back to 45 degrees in the worst areas with berm widths of 15m. Cleaning of the pit floor by the dragline prior to spoiling has proved advantageous to lowwall stability in Pit P.

Underground Mining

One underground mine, the Central Colliery, is presently developing and a second mine, the Southern Mine, is in the planning stages.

The Central Colliery is mining the German Creek seam in an area east of Pit C. The mine enters the seam at the sub-crop by two drifts and has developed on 50m pillars to the 2 East panel where gateroads are being driven for the installation of the first longwall.

The mine is being developed exclusively for longwall extraction with the first panel commencing at 150m depth of cover and 2.4m seam thickness. Panels will be extracted parallel to seam strike with subsequent panels being developed parallel with these down dip. A principle consideration in the layout has been the evidence of gas with increasing depth.

In the area of the longwall panels the roof material is sandstone and is expected to form a competent and sound roof. The presence of the shear zone in the coal seam and low UCS values of approximately 8MPa for the coal, may lead to rib stability problems in deeper workings.

The longwall unit is to be installed in March, 1986. It is a Dowty 200m long face with 800 tonne chock shields using an Eickhoff shearer.

OTHER LEASES & AUTHORITIES TO PROSPECT (FIG. 3)

Capricorn Coal Management Pty Ltd holds Authorities to Prospect 315C Middlemount, and 414C German Creek East. These two authorities adjoin ML1306 German Creek Mining Lease on the eastern boundary and contain coal of the Rangal and Burngrove Coal Measures. Economic seams in these two authorities are the Middlemount, Pisces and Girrah seams. These seams are medium to low ash steaming coal with minor coking coal plies.

A small mining lease ML1908 is located on the boundary between German Creek and Norwich Park Mines. This small triangle contains minor Tieri seams which form part of the planned northern pit area.

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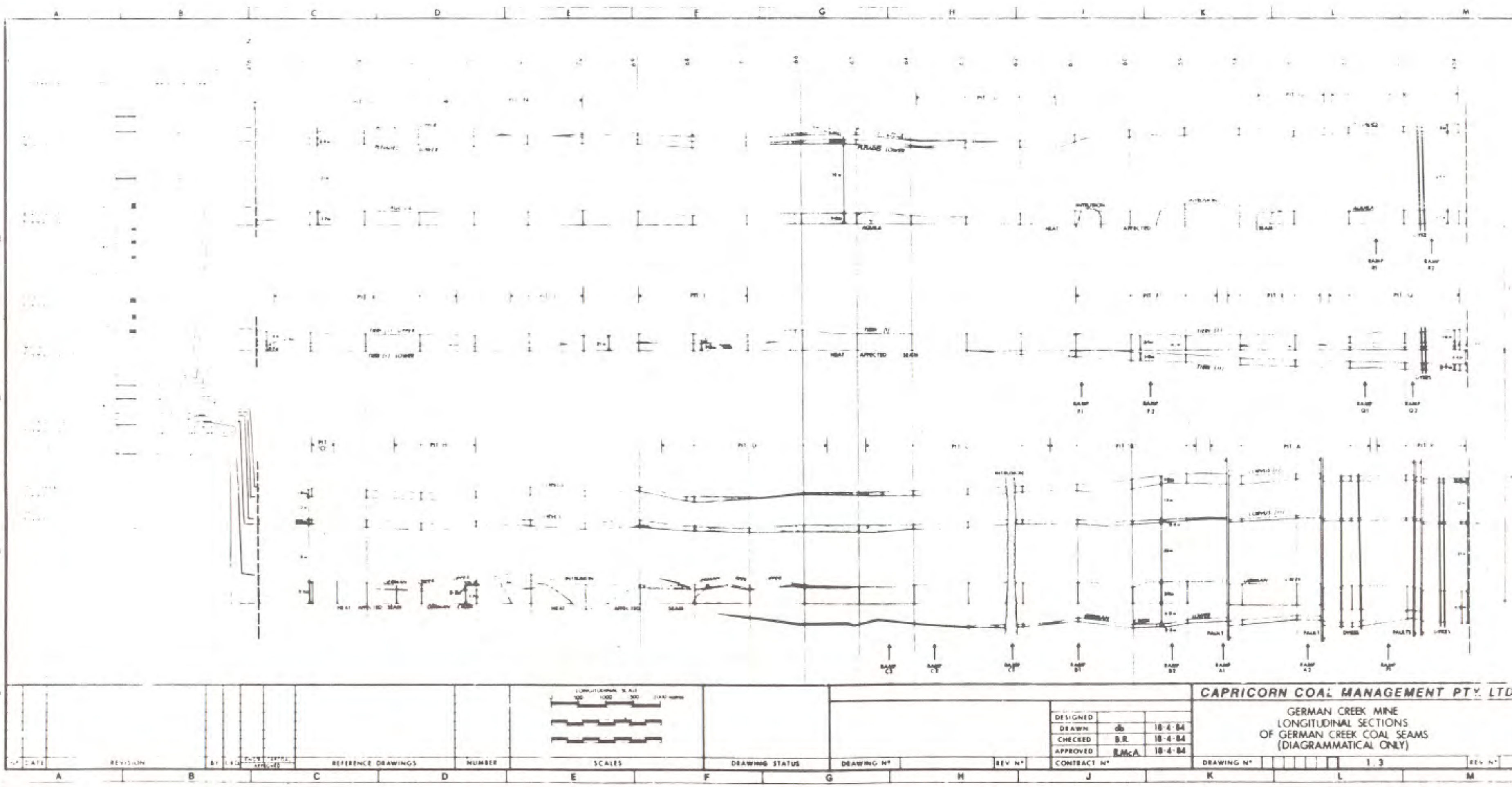


Figure 1: Geological sections

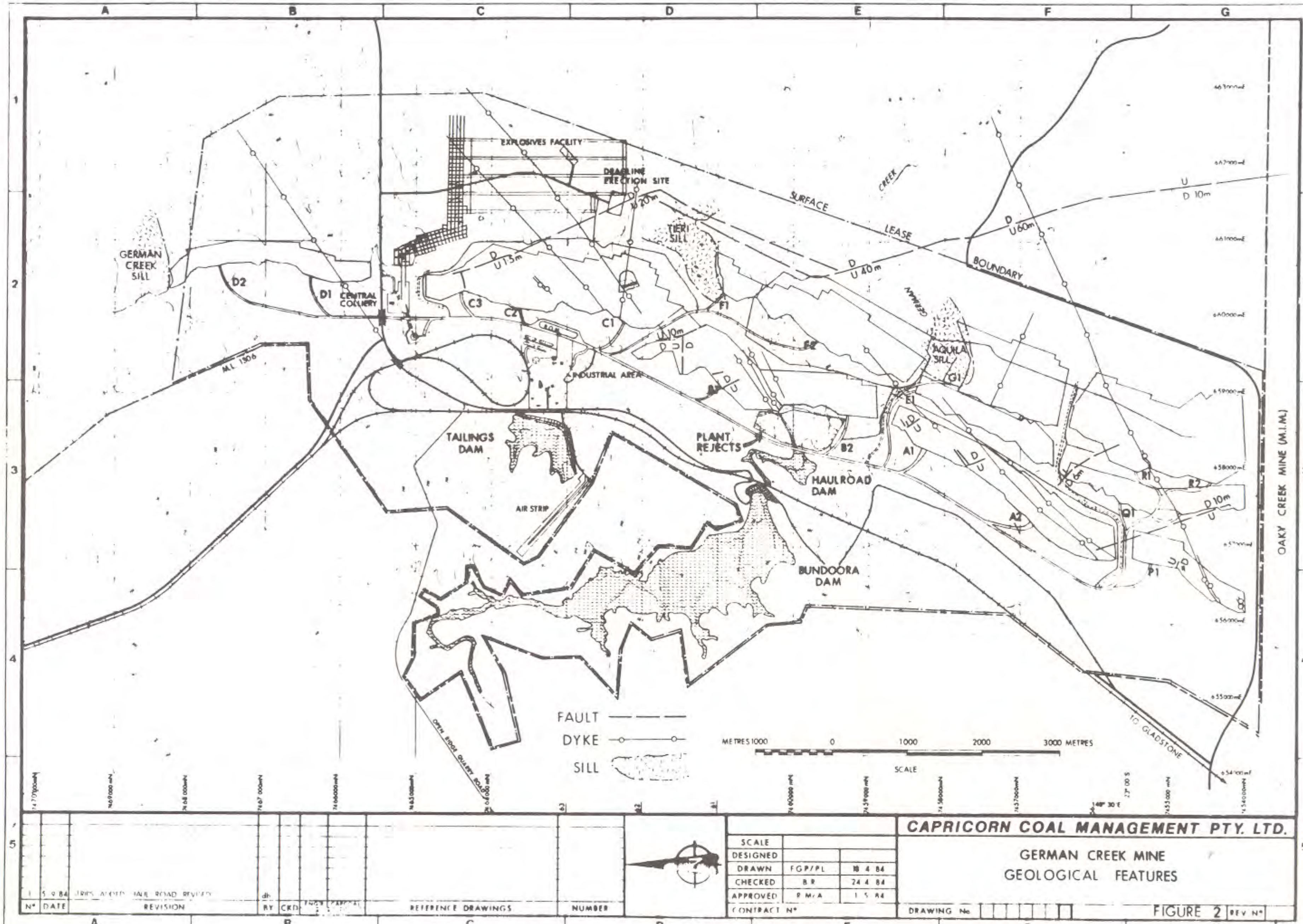


Figure 2. Geological features

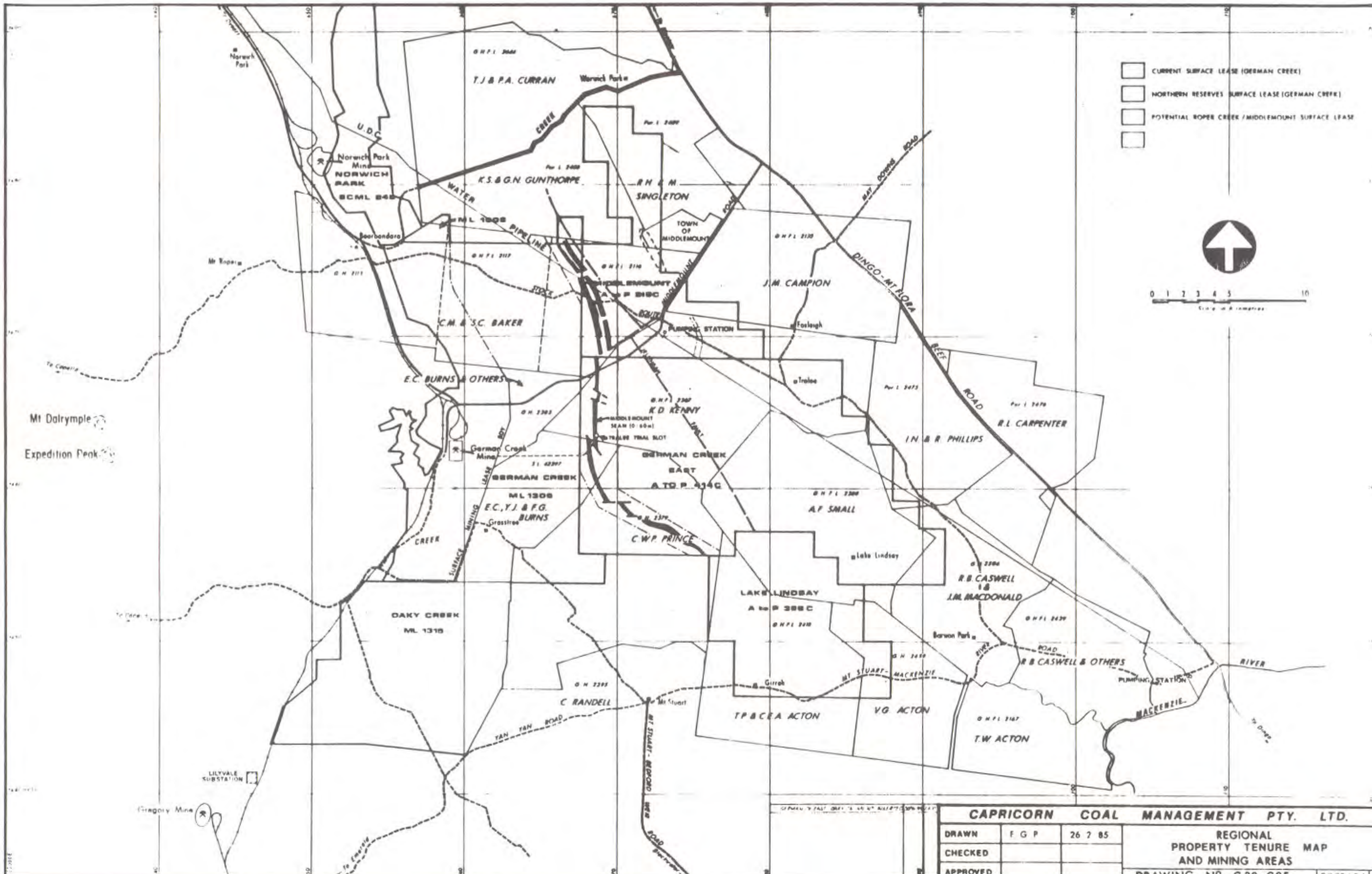


Figure 3: Lease areas

MOURA-KIANGA-NIPAN

G.W. Quinn, Thiess Dampier Mitsui Coal Pty Ltd

General

The Moura mine is located in the south-eastern extremity of the exposed Bowen Basin, 184 km west of Gladstone by rail. Coal is extracted from five seams by both open-cut and underground conventional methods.

TDM holds 20 Special Coal Mining Leases in the Moura district which aggregate some 30,800 hectares.

Geology

The coal seams of the Moura field occur in the upper 'productive member' of the Baralaba Coal Measures which is equivalent to the Rangal Coal Measures (Quinn, this volume). Conformably underlying the coal measures is the barren Gyranda Formation and overlying them is the equally barren Permo-Triassic Rewan Group (Figure 1).

Six coal seams occur in the sequence and are designated 'X,A,B,C,D and E' in descending order.

The 'X' seam is less than a metre thick and uncommercial. The underlying seams 'A to E' have been exploited by existing operations and range in thickness from 2 m to 7 m. Coalescing and splitting of seams is common and lateral variation of the inter-seam sediments occurs throughout the field.

Dip of the seams is to the west and ranges from 5^{o} at Kianga, 8^{o} at Moura and up to 15^{o} at Nipan.

Several major thrust faults associated with the nearby Dawson Tectonic Zone traverse the mining area in a north-westerly direction.

Both Tertiary basalt and Cretaceous trachyte occur locally in the northern part of the mine workings.

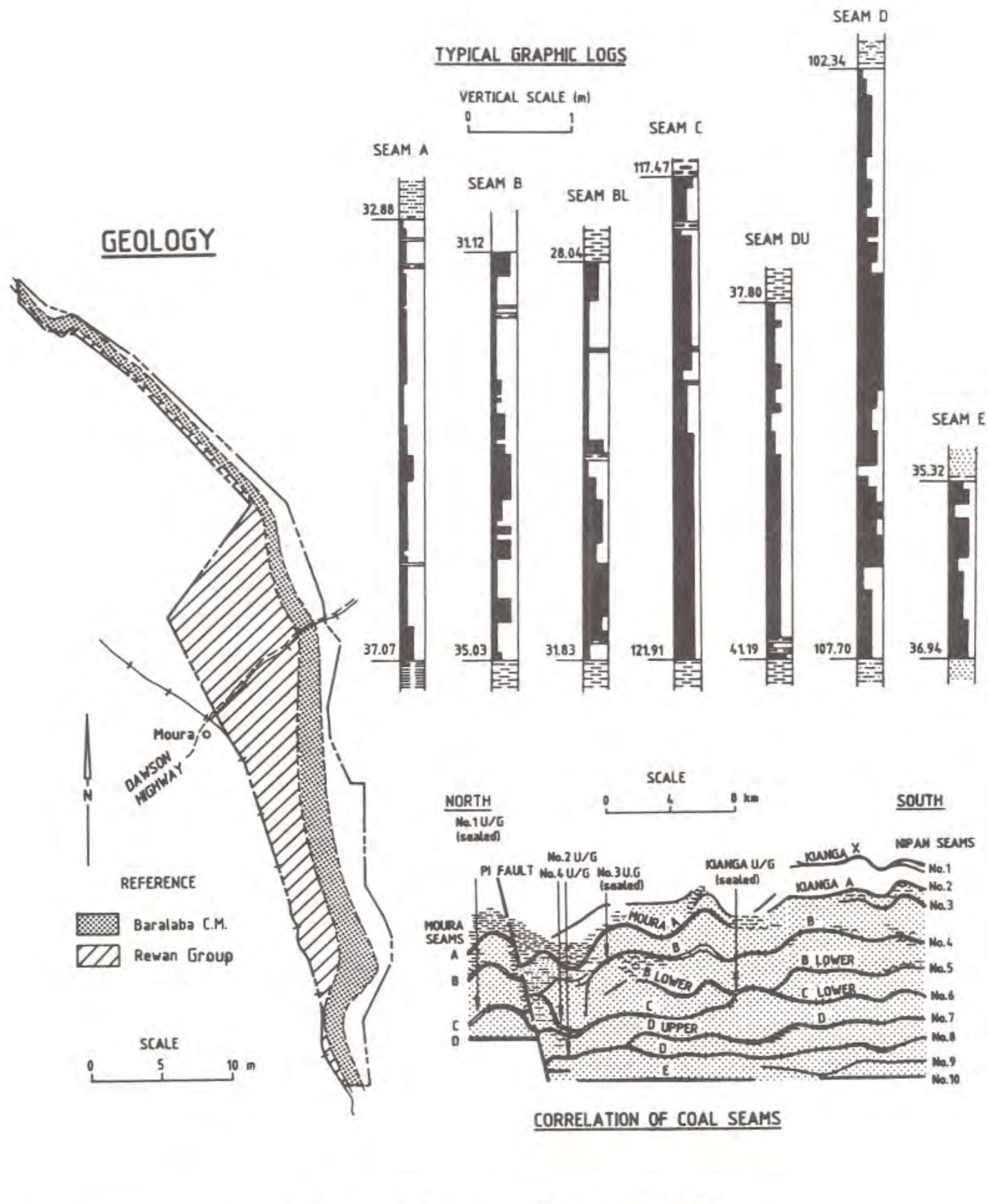
Coal Quality and Reserves

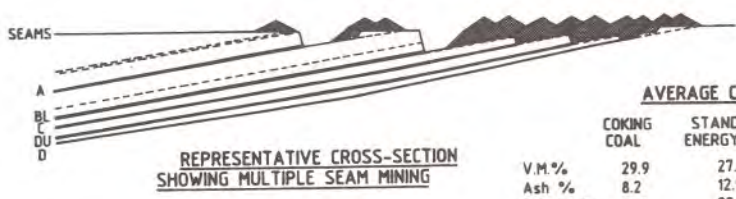
Measured reserves of open-cut coal to 55 metres amount to 140.6 million tonnes. Measured underground reserves are very large.

The immense size of the mine area and the natural northerly increase in rank of the coal allows the mine to produce four products ranging from metallurgical coal through high-volatile PCI coal to various grades of energy coal.

Average quality of the main products is reproduced hereunder (adb).

	Coking Coal	Standard Energy Coal	High Vol. Energy Coal	P.C.I. Coal
Volatile Matter %	29.9	27.9	30.6	31.3
Ash %	8.2	12.9	9.6	8.2
Specific Energy (MJ/kg)	31.8	29.57	30.76	31.3
Initial Def. Temp (^{o}C)	1230	1230	1300	1330
Total Sulphur (%)	0.46	0.50	0.49	0.45
C.S.N.	7.5	-	-	3
Ro max	0.95	-	-	0.8
Hardgrove Grind. Index	-	60	58	59





RESERVES

Opencut	140.6m.t.
Underground	Large

AVERAGE COAL QUALITY (adb)

	COKING COAL	STANDARD ENERGY COAL	HIGH VOL. ENERGY COAL	P.C.I. COAL
V.M.%	29.9	27.9	30.6	31.3
Ash %	8.2	12.9	9.6	8.2
S.E. MJ/kg	31.8	29.57	30.76	31.3
I.D.T. (C°)	1230	1230	1300	1330
T.S.%	0.46	0.50	0.49	0.45
C.S.N.	7.5	-	-	3
Ro max	0.95	-	-	0.8
H.G.I.	-	60	58	59

FIGURE 1: Geology of the Moura-Kianga-Nipan Coal-field.

RIVERSIDE (ML 152, ML 310, ML 1963 CLERMONT)

G.W. Quinn, Thiess Dampier Mitsui Coal Pty Ltd

General

Riverside is one of Central Queensland's newest open-cut coking coal mines taking its name from a pastoral property which occupied a major part of the lease area.

The mine is located 35 km by road north of the township of Moranbah and approximately 200 km by road west of the coastal town of Mackay.

The Riverside mine is owned by Thiess Dampier Mitsui Coal Pty Ltd (T.D.M.) and is situated on mining leases ML 152 'Riverside', ML 310 'Riverside Extended' and ML 1963 'Riverside West'. Total lease area encompasses 3383 hectares.

Annual production is 3.3 million tonnes of prime coking coal which is shipped through Dalrymple Bay Coal Terminal at Hay Point, south of Mackay.

Geology

The Riverside mine works the Goonyella Lower seam within the Moranbah Coal Measures (Figure 1). Eventually the Goonyella Middle seam will also be worked.

These seams dip between 2° and 5° to the east and have an average thickness of 8 and 6 metres respectively. They are covered by overburden varying in depth from 20 to 70 metres.

In the southern part of the mine area, the Goonyella Lower seam splits into an upper and a lower split of 1.8 and 4.9 metres respectively.

Another seam called the 'Basal' seam lies 30 metres below the Lower seam but has no economic potential.

Overlying the coal measures are varying thicknesses of Tertiary sediments and in some cases basalt.

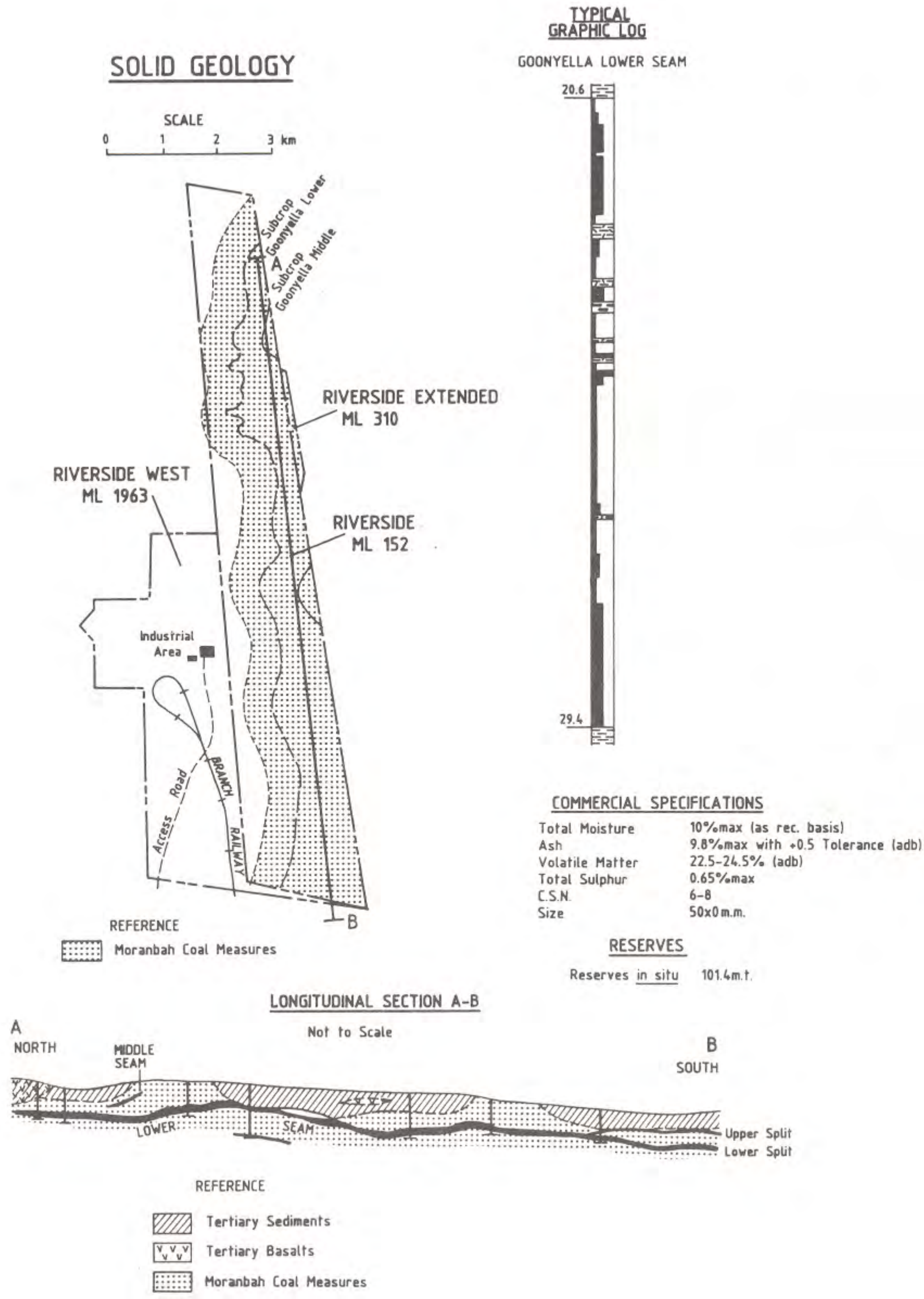


Figure 1: Geology of Riverside Mine

Quality and Reserves

Riverside coal is a high quality medium volatile hard coking coal. The coal produces an excellent coke on its own or can be blended to enhance coals of lower quality. Commercial specifications are:-

Total Moisture	10.0% max. (as received basis).
Ash	9.8% max. with + 0.5% tolerance (adb)
Volatile Matter	22.5 - 24.5% (adb)
Total Sulphur	0.65% max.
C.S.N.	6-8
Size	50 x 0 mm

Steaming coal is also produced from partly oxidised coal from near the subcrop.

Reserves total 101.4 million tonnes in situ to 70 metres depth of overburden.

THE NEBO RESOURCE AREA

G.W. Quinn, Thiess Dampier Mitsui Coal Pty Ltd

General

TDM holds large coal reserves in readiness to service future market requirements. These deposits known as Wards Well, Poitrel, Kemmis Walker, South Walker, Bee Creek, Suttor Creek and Broadmeadow are collectively called the Nebo Resource Area and are amenable to both open cut and underground mining (Figure 1).

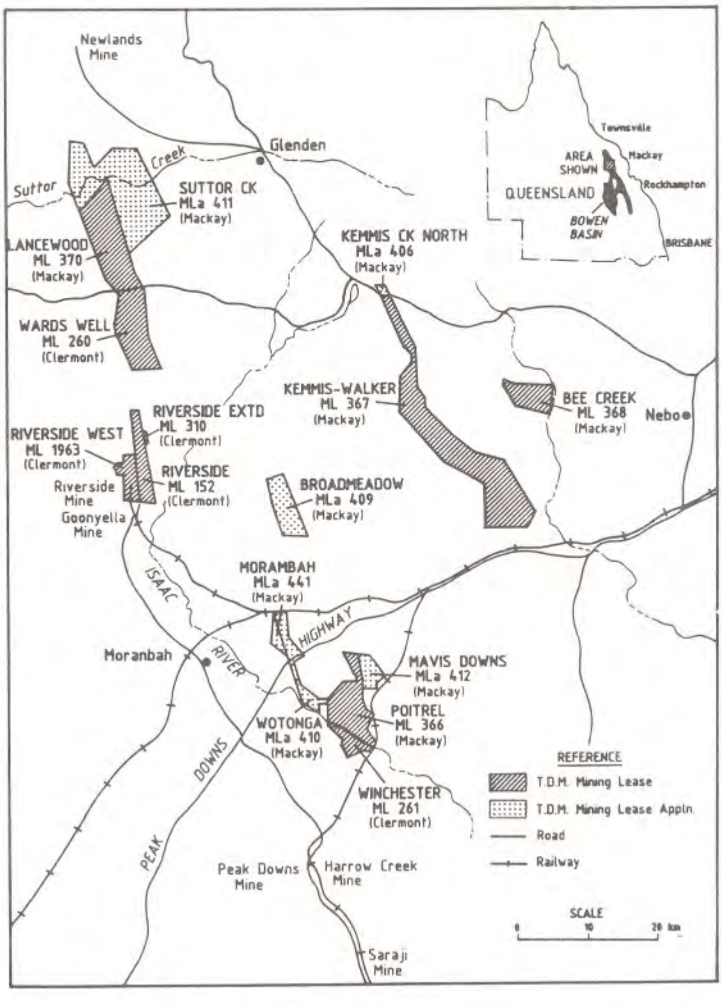


Figure 1: Locality Map, Nebo Resource Area.

The reserves of the Nebo Resource Area contain a range of coals varying from highest quality coking coal to energy coals of varying rank. At Wards Well there are large underground reserves of medium volatile hard coking coal. In the Kemmis Walker and Bee Creek fields it is possible to obtain a low recovery coking coal and a "middlings" steam coal fraction, or alternatively, an energy coal. The Poitrel field has large reserves of steaming coal as well as prime coking coal. Suttor Creek is primarily a medium volatile export steaming coal.

An Environmental Impact Study has been completed. Preliminary feasibility studies have been carried out on all deposits.

WARDS WELL (ML 260, CLERMONT AND ML 370 MACKAY)

General

The Wards Well coal-field lies 135 km west of Mackay and 15 km north of the Goonyella open-cut mine.

This deposit is a northern extension of the prime coking coal seams mined at the Riverside and Goonyella mines. The seams do not crop out at the surface and all coal in the field must be extracted by underground mining techniques.

Geology

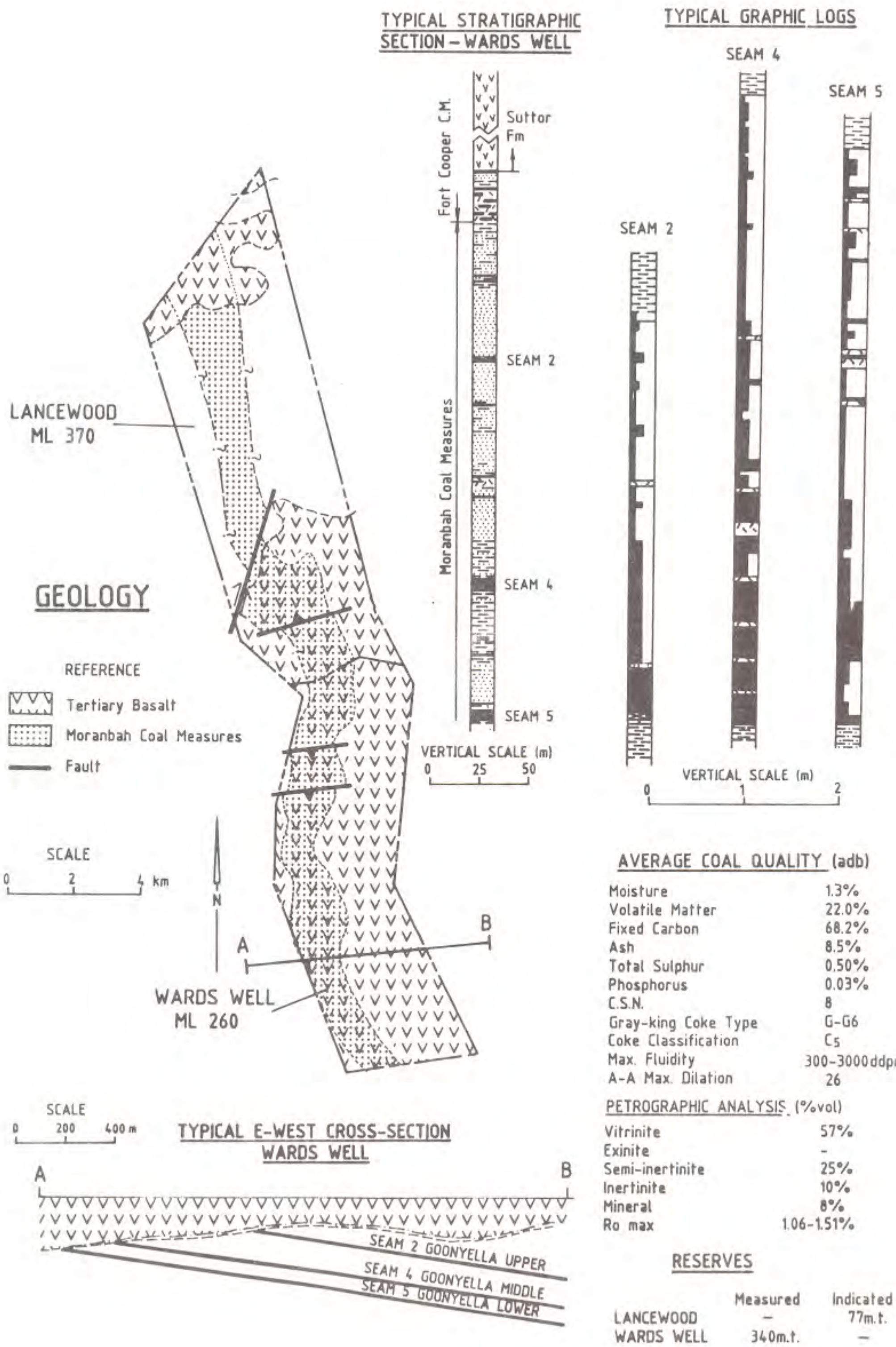
At Wards Well the subcrop of the Permian Moranbah Coal Measures is covered by up to 175 m of Tertiary volcanics and sediments of the Suttor Formation (Figure 2).

The Moranbah Coal Measures range from 485 m to 515 m in thickness and contain up to five recognised seams plus splits. These seams are numbered 1 to 5 in descending order. Only Seams 2, 4 and 5 are economic. Seam 4 is equivalent to the Goonyella Middle seam at Goonyella and Seam 5 is equivalent to the Goonyella Lower seam at Riverside.

Regional structure is a simple, easterly dipping monocline with dips between 6^{o} and 9^{o}. Several east-west faults are inferred.

Coal Quality and Reserves

All three economic seams are comparatively thick with high quality lower sections of workable height. Indicative quality and reserves of coking coal is summarised below.



AVERAGE COAL QUALITY (adb)

Moisture	1.3%
Volatile Matter	22.0%
Fixed Carbon	68.2%
Ash	8.5%
Total Sulphur	0.50%
Phosphorus	0.03%
C.S.N.	8
Gray-king Coke Type	G-G6
Coke Classification	C5
Max. Fluidity	300-3000 ddpm
A-A Max. Dilation	26

PETROGRAPHIC ANALYSIS (%vol)

Vitrinite	57%
Exinite	-
Semi-inertinite	25%
Inertinite	10%
Mineral	8%
Ro max	1.06-1.51%

RESERVES

	Measured	Indicated
LANCEWOOD	-	77m.t.
WARDS WELL	340m.t.	-

Figure 2: Geology of the Wards Well Coal-field.

	Tonnes (in situ) x 10^6 Measured	Indicated
Lancewood	-	77
Wards Well	340	-
Total	417	

Average Quality as to be sold (adb)	
Volatile Matter	22.0%
Ash	8.5%
Total Sulphur	0.50%
Phosphorous	0.03%
C.S.N.	8
Gray-King Type	G-G6
Max.Gieseler Fluidity	300-3000 ddpm
Total Dilation	56 %
Ro max.	1.06-1.51%
Vitrinite (Vol)	57 %

KEMMIS-WALKER CREEK (ML 367, MACKAY)

General

The Kemmis-Walker Creek deposit lies 100 km south-west of Mackay and extends from the Nebo-Collinsville road in the north almost to the Peak Downs highway in the south. The coal is amenable to open-cut mining and potential for both coking and energy coals exists.

Geology

Coal reserves occur within the Rangal Coal Measures which crop out within the area (Figure 3).

In the northern part of the lease referred to as Kemmis Creek, the Elphinstone and Hynds seams are the principal coal seams present. In the vicinity of the diorite intrusion the Hynds seam splits and the upper ply coalesces with the Elphinstone seam to form the Walker Creek Main seam. South of Archies Fault the Main seam splits to form the Main tops and Main bottoms.

All economic coal reserves occur within the Elphinstone and Main seams.

The Hynds seam contains the Yarrabee Tuff Bed.

Structure is relatively simple but increases in complexity towards the north.

Coal Quality and Reserves

The coal ranges from low-volatile bituminous to semi-anthracite rank (ASTM Classification). Ash is low to moderate and a raw product energy coal is feasible in the South Walker Creek area.

Large reserves are available and mining conditions over most of the area are relatively favourable with thick seams, low ratios and relatively soft overburden.

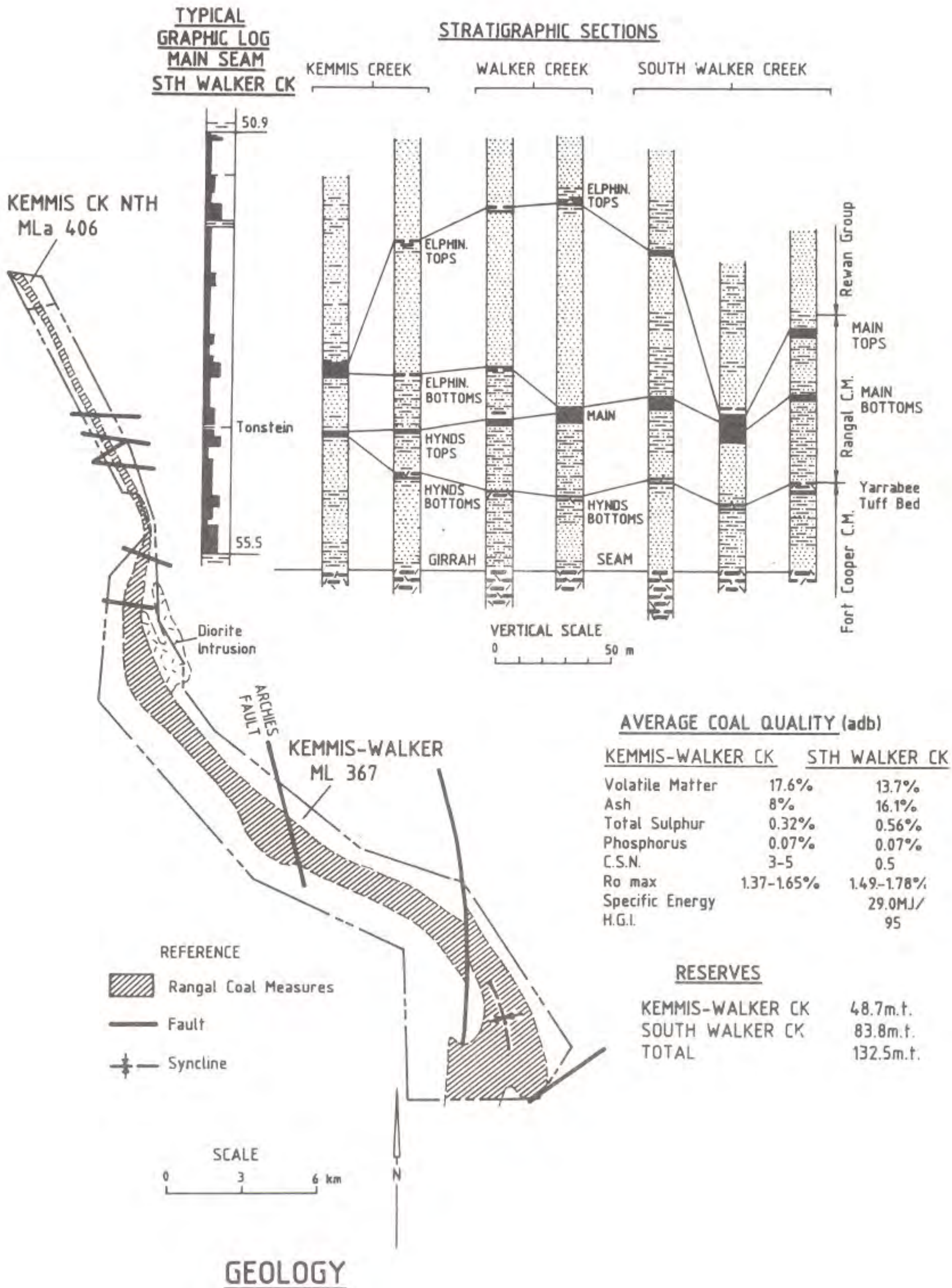


Figure 3: Geology of the Kemmis-Walker Creek Coal-field

The GSA Coal Geology Group, Bowen Basin Coal Symposium, November 1985

Tonnes (in situ) x 10^6	
Kemmis-Walker Creek	48.7
South Walker Creek	83.8
Total	132.5

Average Quality as to be sold (adb)

	KEMMIS-WALKER CK	STH WALKER CREEK
Volatile Matter	17.6%	13.7%
Ash	8 %	16.1%
Total Sulphur	0.32%	0.56%
Phosphorus	0.07%	0.07%
CSN	3-5	0.5
Ro max	1.37-1.65%	1.49-1.78%
Specific Energy		29.0 MJ/kg
HGI		95

BEE CREEK (ML 368, MACKAY)

General

The Bee Creek coal-field is approximately 100 km south-west of Mackay and 20 km north-west of Nebo. This is a potential open-cut coking and non-coking mine to be developed as an extension of the nearby Kemmis-Walker and South Walker Creek deposits.

Geology

The deposit extends along 8 Km of the southern nose of the Hail Creek Syncline within the Rangal Coal Measures (Figure 4). The Rangal Coal Measures in this area vary from 60 m to 175 m in thickness and contain two seams, the Elphinstone seam and the Hynds seam. Both are thick (3 to 9m) seams and are present throughout the area. The Hynds seam lies 15 to 85m below the Elphinstone seam and contains the Yarrabee Tuff Bed.

Structure is relatively simple in this area with dips varying from 8^{o} to 14^{o}. Two faults have been inferred from drilling data.

Coal Quality and Reserves

Reserves in both seams have been calculated at 20.7 million tonnes of raw coal in situ. Coal quality is similar to that of the Walker Creek area in ML 367. Rank is low volatile bituminous (ASTM Classification).

Average Quality as to be sold (adb)

Volatile Matter	14.7%
Ash	8.8%
Total Sulphur	0.41%
Phosphorus	0.04%
C.S.N.	2
Ro max	1.70-1.83%
Specific Energy	31.9 MJ/kg

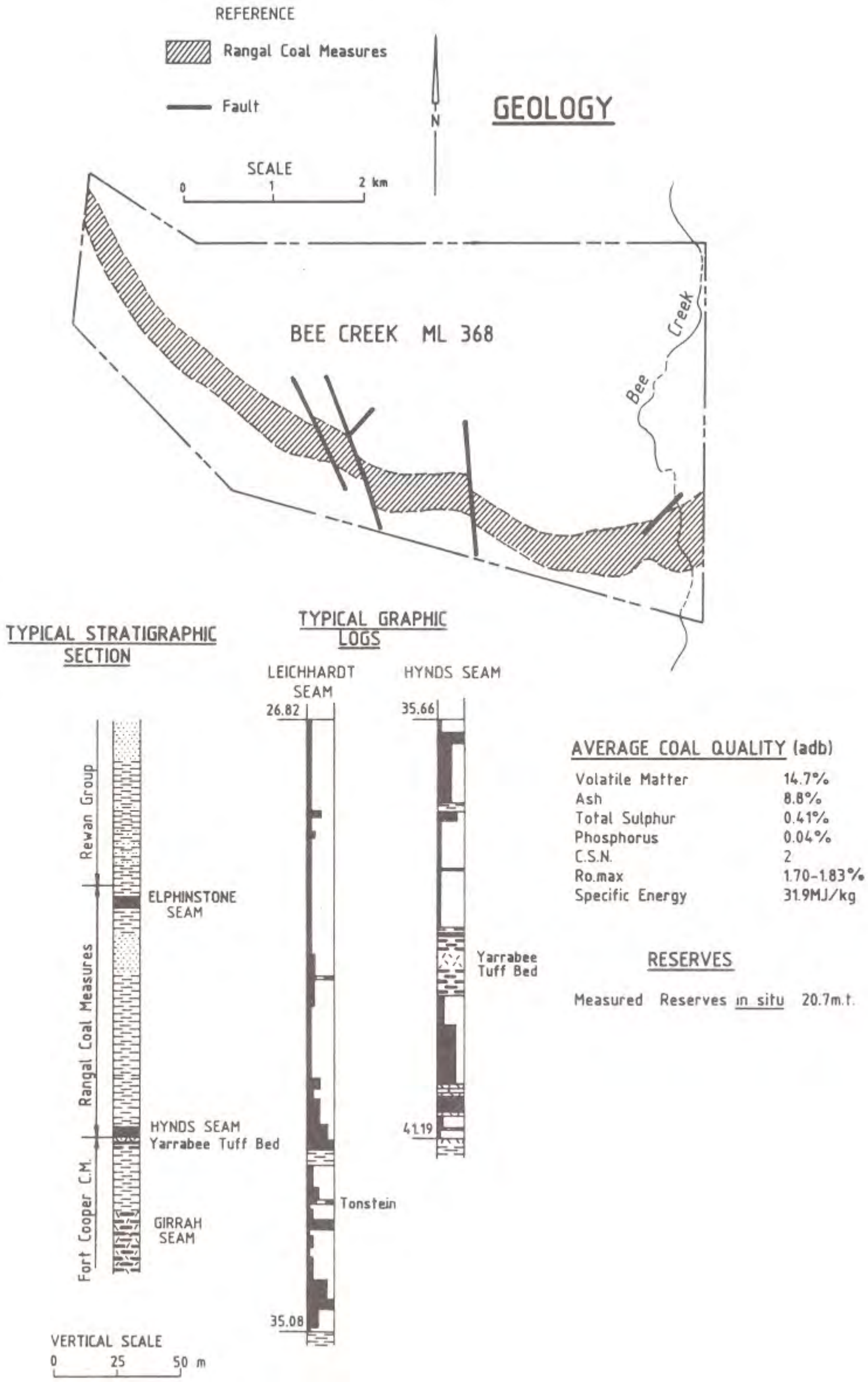


Figure 4: Geology of the Bee Creek Coal-field.

POITREL (ML366, ML(a)410, ML(a)412, ML(a)441 MACKAY & ML 261 CLERMONT)

General

The Poitrel coal-field is located approximately 200 kms west of Mackay and 25 kms south-east of Moranbah. This field contains large open-cut reserves of energy coal and significant reserves of high quality coking coal.

Geology

The Poitrel deposit is in the Rangal Coal Measures. It occupies a drag syncline on the upthrown western side of an extension of the Burton Range Fault locally known as the New Chum Fault (Figure 5).

Two major seams occur in the area, the lower Vermont (or Poitrel Middle) seam and the upper Leichhardt (or Poitrel Upper) seam. The Leichhardt seam contains 3 to 6 metres of durainous coal and is predominantly an energy coal. The Vermont seam has a 1 to 2 metre thick bright ply overlying a further metre of dull coal with the Yarrabee Tuff Bed below. Beneath the tuff, coal is dull and tuffaceous and uneconomic. The bright ply at the top of the Vermont has excellent coking properties.

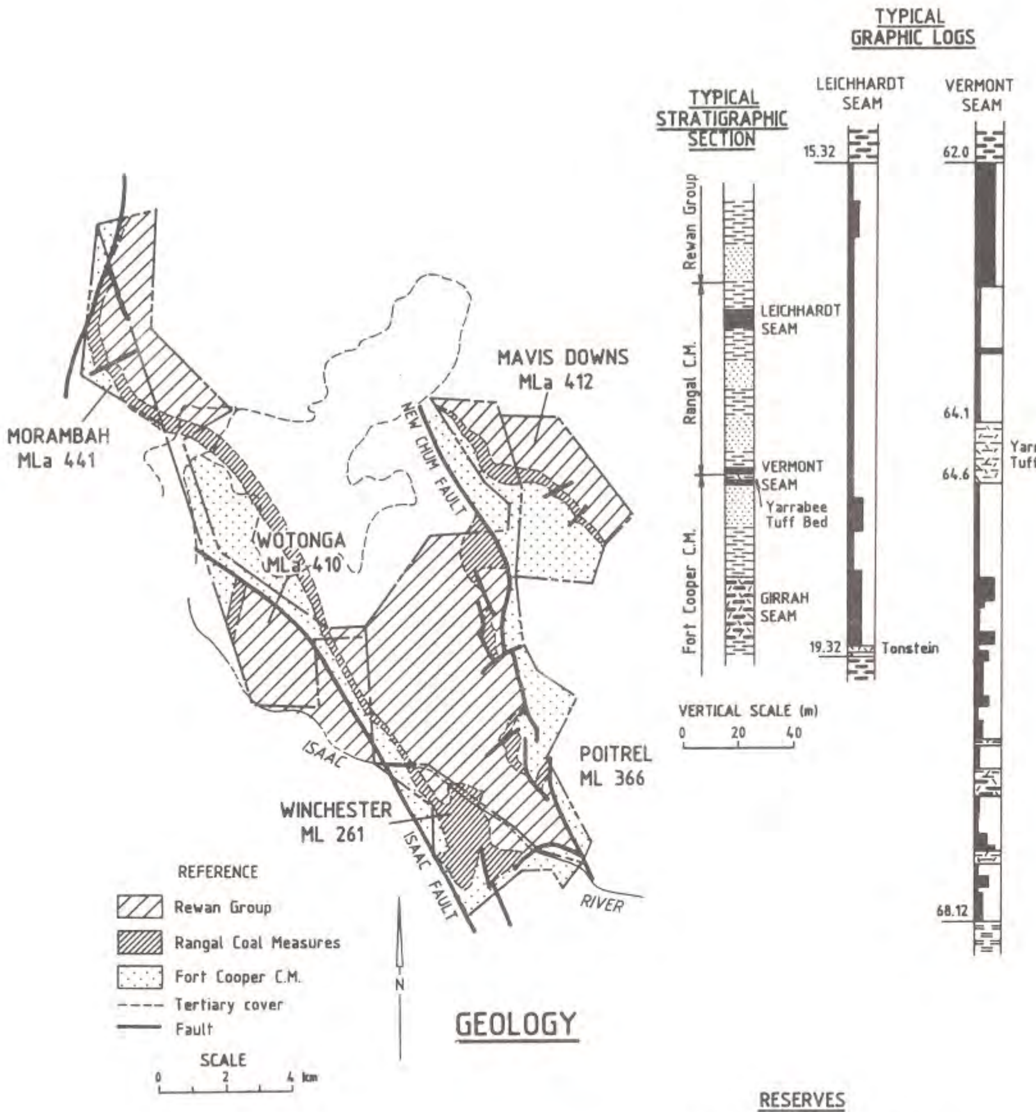
Structural complexity is moderate.

Coal Quality and Reserves

Measured reserves total 33 million tonnes of coking coal and 115 million tonnes of energy coal.

Average Quality as to be sold (adb)

	non-coking	coking
Volatile Matter	22%	25.5%
Ash	12%	8.7%
Specific Energy	30.0 MJ/kg	30.7 MJ/kg
HGI	71	-
Init. Def. Temp.	1400°C	-
Total Sulphur	0.35%	0.45%
Phosphorus	0.06%	0.006%
C.S.N.	1	7
Gray-King Coke Type	-	G_1-Gx
Vitrinite (Vol.)	39%	61%
Ro max	1.12%	1.16%



RESERVES

Opencut	Coking	33m.t.
"	non-coking	115m.t.

AVERAGE COAL QUALITY (adb)

	NON-COKING	COKING
Volatile Matter %	22	25.5
Ash %	12	8.7
Specific Energy MJ/kg	30.0	30.7
H.G.I.	71	-
I.D.T. (°C)	1400	-
Total Sulphur %	0.35	0.45
Phosphorus %	0.06	0.006
C.S.N.	1	7
Gray-king Coke Type	–	G_1–Gx
Vitrinite (Vol %)	39	61
Ro max (%)	1.12	1.16

Figure 5: Geology of the Poitrel Coal-field.

SUTTOR CREEK (ML(a)411, MACKAY)

General

The Suttor Creek coal-field lies in the north-western limb of the Bowen Basin about 200 km by road west of Mackay and 17 km south of the Newlands mine.

The deposit contains open-cut and underground reserves of high quality medium volatile energy coal.

Geology

The majority of open-cut reserves are within the Leichhardt seam of the Rangal Coal Measures (Figure 6). Opencut reserves also occur in partly intruded seams of the Moranbah Coal Measures.

The Rangal Coal Measures occupy the eastern part of the lease. Both the Leichhardt seam and Vermont seam have been identified but only the Leichhardt seam contains economic reserves. The Vermont seam contains the Yarrabee Tuff Bed and coalesces with the Girrah seam over most of the area. In places all three seams coalesce.

A major reverse fault associated with the Burton Range Fault traverses the area repeating the outcrop of the Leichhardt seam and effectively doubling open-cut reserves in the area.

Regional dip is to the east and varies from less than 5^{o} to a maximum of 15^{o}.

The Moranbah Coal Measures in the western port of the area are either partly intruded or covered by thick Tertiary basalts of the Suttor Formation. However, some open-cut reserves are present.

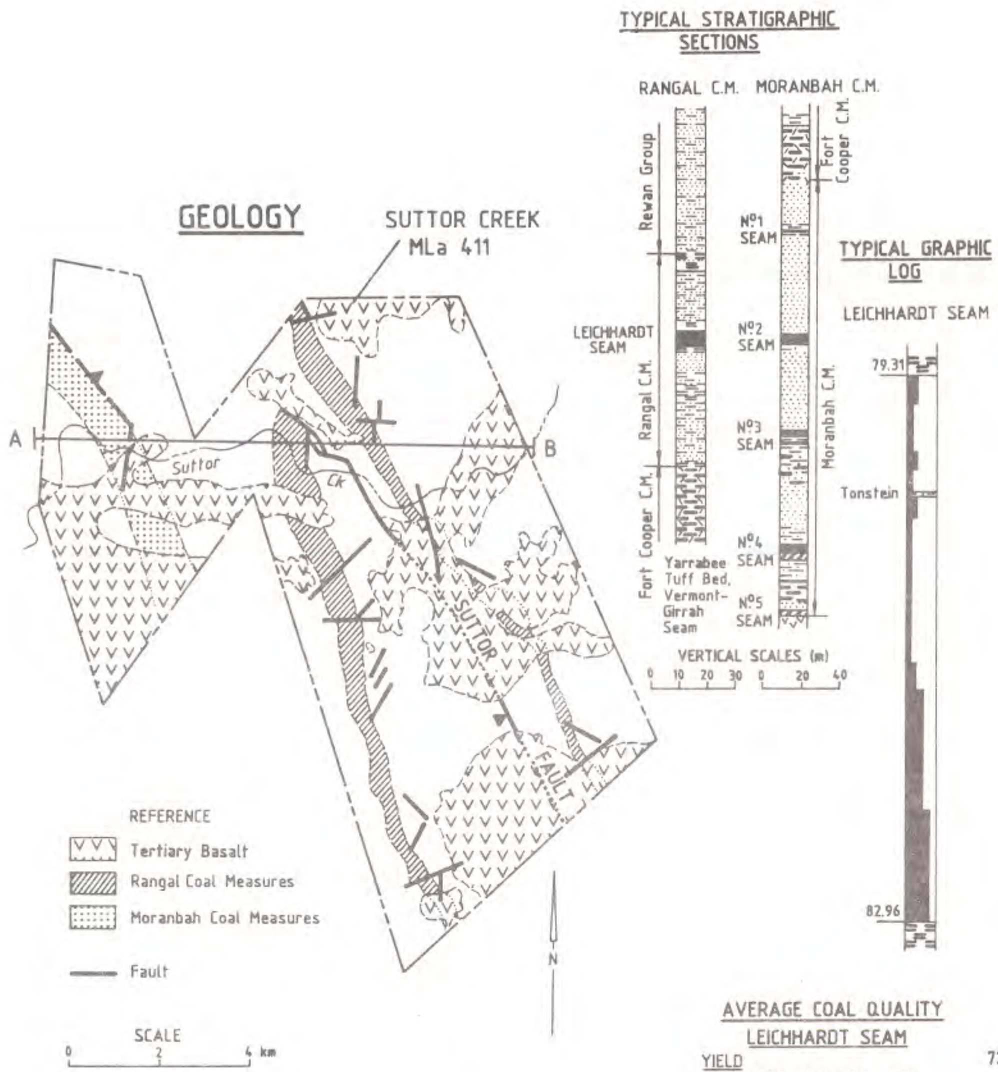
The Suttor Creek coalfield occurs in a virtual window in the thick Tertiary basalt cover and was located by an aeromagnetic survey.

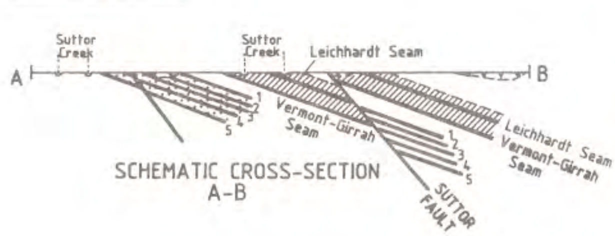
Coal Quality and Reserves

All proven open-cut reserves are contained in the Leichhardt seam of the Rangal Coal Measures. These total 38 million tonnes of open-cut and 90 million tonnes of underground measured reserves.

Coal quality as to be sold (adb)

Theoretical Recovery	72%
Volatile Matter	26.1%
Ash	14 %
Specific Energy	28.66 MJ/kg
Total Sulphur	0.37%
HGI	56
Init. Def. Temp.	1200-1600^{o}C





AVERAGE COAL QUALITY

LEICHHARDT SEAM

YIELD	72%
PROXIMATE ANALYSIS (adb)	
Inherent Moisture	2.6%
Volatile Matter	26.1%
Ash	14.0%
Fixed Carbon	57.3%
SPECIFIC ENERGY (adb)	28.66MJ/kg
TOTAL SULPHUR (adb)	0.37%
HARDGROVE GRINDABILITY INDEX	56

SEAMS 3 & 4

Recovery	67%
Ash	10.3%
Volatile Matter	20.9%
Sulphur	0.5%
C.S.N.	8

RESERVES

LEICHHARDT SEAM	38m.t. O/C 90m.t. U/G
SEAM 3	30m.t.
SEAM 4	40m.t

Figure 6: Geology of the Suttor Creek Coal-field.

Seams 3 and 4 of the Moranbah Coal Measures contain measured reserves totalling 70 million tonnes. Weighted average quality of both seams is as follows (adb):-

Theoretical Recovery	67%
Ash	10.3%
Volatile Matter	20.9%
Total Sulphur	0.50%
C.S.N.	8

BROADMEADOW (ML(a) 409 MACKAY)

General

The Broadmeadow coal-field lies 200km south-west of Mackay and 25km north-east of Moranbah. This is a small to medium size deposit which will form a northern extension of the Poitrel mine.

Geology

The deposit lies immediately east of the Burton Range Fault and is an upthrown inlier of Rangal Coal Measures which would normally be expected at depth in this area (Figure 7). The Burton Range Fault has a vertical throw of approximately 400 metres at Broadmeadow. Regional dip is to the east and varies from 8^{o} to 16^{o}.

The Leichhardt seam contains all of the reserves in this area. The Vermont seam has not been positively identified and may not be well developed. The Yarrabee Tuff Bed has not been identified at Broadmeadow. The deposit is bounded in the north by the Burton Range Fault and in the south by thick Tertiary sediments.

Coal Quality and Reserves

Broadmeadow coal is medium volatile bituminous (ASTM Classification).

Weighted average coal quality at S.G. 1.80 is as follows (adb) :-

Lab. Yield	91%
Ash	11.9%
Volatile Matter	22.3%
Total Sulphur	0.45%
C.S.N.	3
Specific Energy	30.45 MJ/kg
HGI	77

Open-cut measured reserves total 8.35mt *in situ*. Underground measured and indicated reserves total 58.3mt.

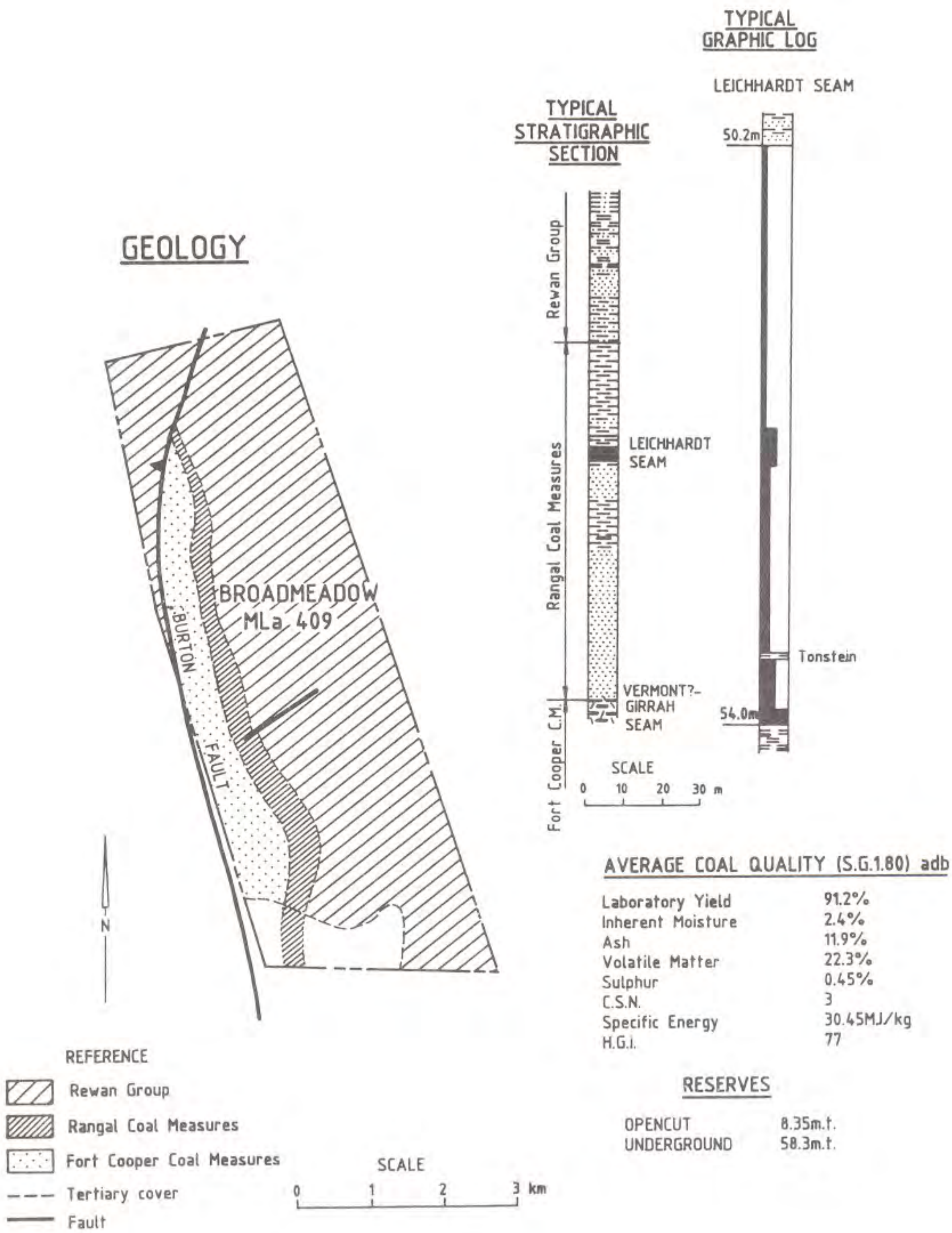


Figure 7: Geology of the Broadmeadow Coal-field.

The GSA Coal Geology Group, Bowen Basin Coal Symposium, November 1985

REGIONAL CHARACTERISATION OF THE UPPER BURNGROVE FORMATION

M.P. Thornton, Geological Survey of Queensland

Previous workers have selected the top of the Burngrove Formation in various ways. Their boundaries were taken from:

(a) the top of the Virgo seam
(b) the first significant tuffaceous unit
(c) the top of a marked gamma log response related to (b) above.

A brief survey of cored Departmental bore holes between Emerald and Blackwater shows a regional facies variation in the top of the Burngrove Formation across the South Central Bowen Basin. Due to this variation, the Virgo seam is not always developed, thus (b) and (c) above are considered the most useful guides to selecting the stratigraphic boundary between the Burngrove Formation and the Rangal Coal Measures.

The facies change is subdivided into three zones, the sedimentological characteristics of which show a gradation between a fluvio-deltaic coal depositional environment to the northeast and a marginal pro-delta environment in the southwest. Each zone is characterised as follows:

Zone 1. This zone contains three or more coal seams, the uppermost being the Virgo seam. Numerous well developed tuff bands are present, interlaminated and interbedded with grey-green sandstones and siltstones. Some minor bioturbation is present, usually in siltstones about the lower coal seams.

Zone 2. No major coal seams are developed but numerous carbonaceous bands are present. Tuffaceous mudstone and claystone bands are interbedded with grey-green sandstone and siltstone beds. Minor slumping occurs and the siltstones are slightly to moderately bioturbated from the top of the formation.

Zone 3. Coal and carbonaceous mudstones are present only as reworked fragments. Sediments are poorly sorted silty sandstones, mottled green and white in colour, and may be tuffaceous throughout. Churning and slumping is commonplace and bioturbation is heavy in the finer grained material. Dewatering and injection structures are also common.

It is therefore suggested that these three zones are characteristic of the Burngrove Formation in this area (see map) and that, in conjunction with the first significant tuffaceous unit and corresponding marked gamma log response, they indicate the top of the formation.

The data used is reported in numerous existing GSQ Records but also includes data from Togara, Arcturus, Mt Stuart-Girrah and North East Blackwater drilling, most of which are in preparation.

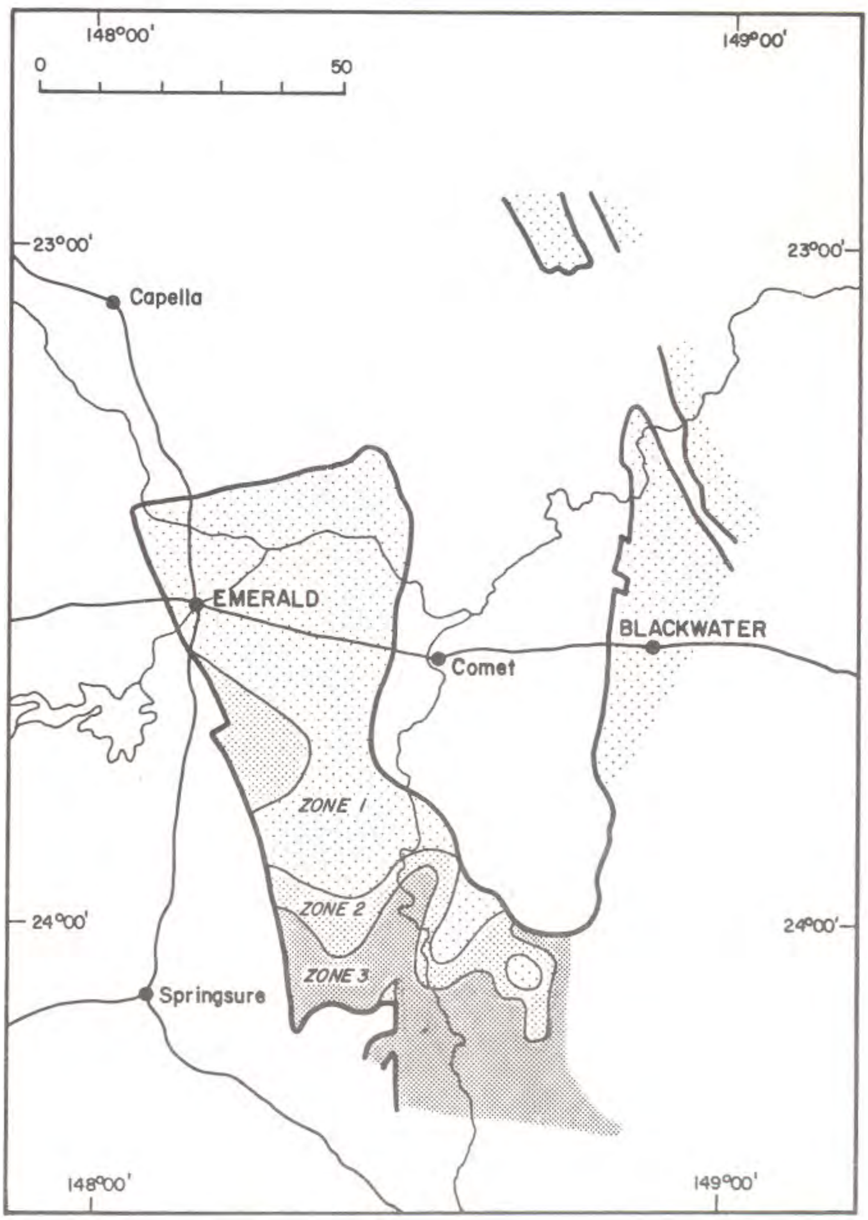


Figure 1. Top of the Burngrove Formation

This paper is published with the permission of the Chief Government Geologist, Queensland Department of Mines.

BLACKWATER MINE

Utah Development Company Limited Staff

LOCATION

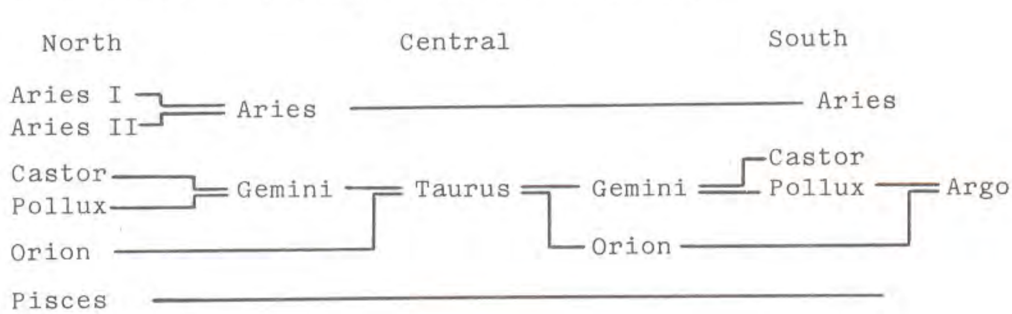
The mine is 20 km southwest of Blackwater and 315 km by rail from the port at Gladstone.

GEOLOGY

The economic seams occur in the Upper Permian unit, the Rangal Coal Measures, which is conformably underlain by the Burngrove Formation and overlain by the Triassic Rewan Group. These strata dip gently (3°-5°) to the east into the Taroom Trough away from the Comet Ridge to the west. In the south of the mine area, the subcrop of the Rangal Coal Measures is unconformably overlain by thick Tertiary sediments.

Along the 30 km subcrop of the coal measures, there are considerable seam splitting, coalescence and deterioration, and rapid lateral variation in interseam lithology. Lithology consists of mudstone, siltstone, lithic and calcareous sandstone with coal seams, carbonaceous shale in the Rangal Coal Measures, and greenish siltstone/sandstone and mottled red/green silty mudstones (red beds) in the overlying Rewan Group at depth away from the current workings. Faults are common, but minor for open-cut operations and intrusions are very rare.

Seam correlation along strike is as follows:



Seams being worked at present are the Gemini, Taurus and Argo which are varying coalescences of the Castor, Pollux and Orion seams, and the Castor and Aries seams.

COAL QUALITY

Selective mining is undertaken to produce an export quality coking coal and a domestic steaming coal. Usually, the coking coal fraction occurs in the bright coal sections at the base of the seams, with the upper dull sections contributing to the steaming coal, although in places the full seam section is entirely coking coal. Typical clean coal quality is as follows:

		Coking Coal	Steaming Coal
Total moisture (as received)	%	9.5	-
Inherent moisture (air dried)	%	2.0	2.2
Ash (air dried)	%	8.3	11.5
Volatile matter (air dried)	%	27.0	24.1
Sulphur (as received)	%	0.5	0.3
CSN		5.5-6.5	-
Size mm		32 x 0	-
Specific Energy	MJ/kg	31	29

MINING

Mining commenced in 1968 with a cumulative total production to 1983 of 45 million tonnes of coking coal and 13 million tonnes of steaming coal. Current production capacity is 4.0 million tonnes of coking coal and 2.6 million tonnes of domestic steaming coal.

The poster display shows the mine's location, geological setting and the stratigraphic succession. Geological maps show a solid geology plan, three dip direction cross-sections and one strike longitudinal section. A coal quality table and various aspects of geological problems are included.

DAUNIA PROJECT

Utah Development Company Limited Staff

LOCATION

The coal deposits of the Daunia project are located 10 km south-east of Moranbah in SCML 244, adjacent to the railway to the port of Hay Point, distant some 170 km from Daunia.

GEOLOGY

The exploitable seams lie within the Rangal Coal Measures unit at the top of the Permian sequence. This unit is conformably underlain and overlain by the Fort Cooper Coal Measures and the basal unit of the Triassic Rewan Group, respectively. The deposit occurs within a graben-like deformed structual basin with limited thicknesses of Rewan sediments remaining as outliers in the deeper parts of this basin and in the northeast of the deposit where the strata dip deeply into the western flank of the Carborough Syncline. The deposit is structurally complex, and whilst intrusions are rare and small within the actual deposit, large intrusive bodies occur adjacent to and underneath it.

The stratigraphy is as follows:

Triassic	Rewan Group (basal unit)	
Permian	Rangal Coal Measures	Leichhardt Seam Vermont Seam
	Fort Cooper Coal Measures	Girrah Seam

The Fort Cooper Coal Measures consist of labile sandstones and siltstones with abundant tuffaceous and carbonaceous beds, often with thin coal plies. The thick Girrah Seam forms the top of the unit and is of inferior quality owing to abundant "stone" plies.

The Rangal Coal Measures consist generally of labile sandstones, siltstones and shale with minor strong calcareous siltstones and sandstones and two to three coal seams (the lower Vermont splits in some parts of the deposit).

The Rewan Group consists of labile greenish sandstones and mottled red and green "red beds" mudstone. In the deposit area, only the basal beds of this unit are present and the lithology is similar to the underlying Rangal Coal Measures, except for the absence of carbonaceous material.

STRUCTURE

The deposit is structurally located along the Burton Fault zone within the Nebo Synclinorium and not on the Collinsville Shelf side, and is strongly folded and faulted. The main feature is a longitudinal graben aligned north-north-west up to 10 km long, with bounding faults of up to 70 m throw. Dips of the seams are very variable, ranging from 5° to 30°, excluding minor heavily faulted areas, but large areas having gentle dips are present.

INTRUSIONS

Numerous intersections of igneous rock have been made underneath and adjacent to the main coal deposit, but in general the areas of coked coal are few and minor within the resource.

GEOLOGICAL HAZARDS

Large quantities of groundwater have been encountered during drilling of the deposit, with flows of up to 10 litres/second.

The abundant faulting and steep dips in certain small areas will cause overburden and seam handling problems. Thin beds of puggy claystone above the Leichhardt Seam will cause problems in areas of steeper dips.

COAL QUALITY

Various methods of treating the seams for production of both coking coal and steaming coal have been considered. The quality of the product coal from both seams is as follows.

COAL QUALITY DAUNIA

RESULTS OF TESTS ON 200 MILLIMETRE CORES

Forty-five large diameter holes were drilled along the strike line of the deposit. Cores were tested by the Australian Coal Industry Research Laboratories Limited and Utah Development Company's Research and Development Laboratory; typical results are given below.

		Coking Coal	Steaming Coal
PROXIMATE ANALYSIS (Air Dried Basis)			
Inherent Moisture	%	2.0	2.0
Ash	%	8.0	14.0
Volatile Matter	%	20.5	20.0
Fixed Carbon	%	69.5	64.0
TOTAL SULPHUR (air dried)	%	0.5	0.4
PHOSPHORUS (air dried)	%	0.05	-
CRUCIBLE SWELLING NUMBER		6	-
SPECIFIC ENERGY (air dried)	MJ/kg	32.31	29.7
HARDGROVE GRINDABILITY INDEX		85	80
ULTIMATE ANALYSIS (Dry Ash-Free Basis)			
Carbon (corrected for CO_2 for coking coal)	%	88.20	87.10
Hydrogen	%	4.84	4.70
Nitrogen	%	1.67	1.56
Sulphur	%	0.47	0.51
Oxygen (by difference)	%	4.74	6.13
Carbonates (as CO_2)	%	0.62	-
Carbon Dioxide		-	0.26
GIESELER PLASTOMETER TESTS			
(Constant Torque Apparatus)			
Initial Softening Temperature	°C	420	N/A
Fusion Temperature at 5 dd/m	°C	440	
Maximum Fluidity Temperature	°C	460	
Resolidification Temperature	°C	484	
Range Soften to Resolidify	°C	64	
Maximum Fluidity	dd/m	40	
AUDIBERT-ARNU DILATOMETER TESTS			
Softening Temperature	°C	390	N/A
Maximum Contraction Temperature	°C	440	
Maximum Dilatation Temperature	°C	470	
Maximum Contraction	%	30	
Maximum Dilatation	%	-20	

		Coking Coal	Steaming Coal
ASH FUSION PROPERTIES			
(Reducing Atmosphere)			
Deformation Temperature	°C	1300	1560
Hemisphere Temperature	°C	1400	over 1600
Flow Temperature	°C	1500	over 1600
MEAN MAXIMUM REFLECTANCE	%	1.28	-

POSTER DISPLAY

The location of the coal deposit, the geological setting and the position in the stratigraphic succession of the Bowen Basin are shown on the poster display. Geological maps for the deposit include a geological plan, several cross-sections and one longitudinal section. Tables of the results of testing of the steaming coal and coking coal potential products of the deposit are shown in more detail than in these notes.

GOONYELLA MINE

Utah Development Company Limited Staff

LOCATION

The mine is 25 km north of Moranbah and 198 km by rail from the port of Hay Point.

GEOLOGY

The economic seams occur in the Moranbah Coal Measures, an Upper Permian unit conformably overlain and underlain by the Fort Cooper Coal Measures and the German Creek Formation, respectively. Located on the Collinsville Shelf, the strata are relatively undisturbed, and dip gently (3°-5°) to the east towards the Burton Range Fault (Zone).

The subcrop of the Moranbah Coal Measures is unconformably overlain by up to 60 m of variably consolidated Cainozoic sediments with some Tertiary basalt, generally weathered in the mine area.

The lithology consists of labile sandstone, shale, mudstone and siltstone with several thick coal seams, and rare tuffaceous beds in the Moranbah Coal Measures, and with labile sandstones and siltstones and thick interbedded coal, carbonaceous shale and tuff beds in the overlying Fort Cooper Coal Measures. The underlying German Creek Formation unit contains labile and quartzose sandstones, siltstones and rare thin coal seams. Faulting is rare and minor, and a few thin kaolinised dykes, sometimes laterally displaced, have been exposed in the pits. Seam splitting is not pronounced in the area, with one seam, the Goonyella Middle Seam, retaining continuity along the full 21 km subcrop. The stratigraphic succession and seam correlation are as follows:

North	Central	South
	Fort Cooper Coal Measures	
Goonyella Upper Seam		[Goonyella Upper Seam 1 [Goonyella Upper Seam 2
P Seam		
P Tuff		
	Goonyella Middle Seam	
Goonyella Lower Seam	[Goonyella Lower Seam 1] [Goonyella Lower Seam 2]	Goonyella Lower Seam
(Exmoor Fm) German Creek Formation		

The seams being mined at present are the Goonyella Middle Seam and the Goonyella Lower Seam.

COAL QUALITY

The seams produce a uniform quality, high yield coking coal product, as follows:

Chemical Analysis:

Total Moisture (as received)	%	9.5
Volatile Matter (air dried)	%	25.5
Ash (air dried)	%	8.0
Sulphur (air dried)	%	0.5
Crucible Swelling Number (F.S.I.)		8.0
Phosphorus (in coal)	%	0.02
Alkali (in ash)	%	1.0

Dilation:

Softening Temperature	°C	375
Max. Contraction Temperature	°C	425
Max. Dilatation Temperature	°C	470
Max. Contraction	%	26
Max. Dilatation	%	+140

Gieseler Plastometer:

Initial Softening Temperature	°C	405
Temperature of Maximum Fluidity	°C	455
Resolidification Temperature	°C	495
Plastic Range	°C	90
Maximum Fluidity	ddpm	1750

Petrographic Analysis:

Mean Maximum Reflectance of Vitrinite	%	1.12
Maceral Composition		
Vitrinite	%	60
Exinite	%	1
Semi-Fusinite	%	26
Other Inertinite	%	9
Mineral Matter	%	4

MINING

Mining commenced in 1971 in the Goonyella Middle Seam, and in 1983 in the Goonyella Lower Seam. Dragline removal of overburden is assisted by a bucket-wheel excavator which prestrips the poorly consolidated Cainozoic and weathered Permian material. To date, cumulative production is 50 million tonnes of product coal.

POSTER DISPLAY

On the poster display are shown the location, geological setting and stratigraphic succession for the mine in the Bowen Basin. Further maps are the mine geology plan, four cross-sections and one strike-direction longitudinal section, and examples of various aspects of geological work carried out, including detailed highwall mapping.

A coal quality table and a schematic diagram of the bucket-wheel operation is included.

PEAK DOWNS MINE, HARROW CREEK TRIAL COLLIERY, SARAJI MINE, AND NORWICH PARK MINE

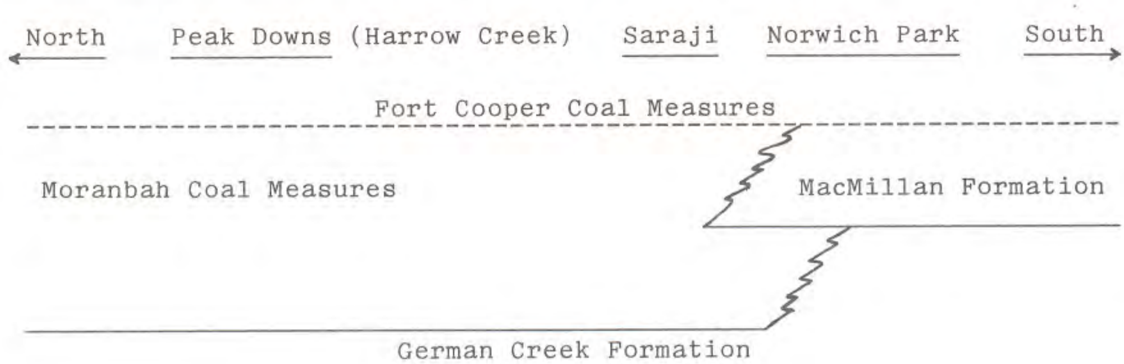
Utah Development Company Limited Staff

LOCATION

These mines are located along a continuous mining lease strip extending for almost 100 km from Moranbah to 30 km south of Dysart. Peak Downs Mine (which also handles Harrow Creek Colliery coal) is 192 km, Saraji is 212 km and Norwich Park is 256 km by rail from the port of Hay Point.

GEOLOGY

The economic seams in this strip pass laterally south to north from the upper section of the German Creek Formation into the lower section of the Moranbah Coal Measures via a gradual facies change in the Norwich Park area. A marine unit transgressing from the south, the MacMillan Formation, terminated the deposition of the upper section of the Moranbah Coal Measures south of the Saraji area. The Moranbah Coal Measures and the MacMillan Formation are conformably overlain by the Fort Cooper Coal Measures and underlain by the German Creek Formation. The stratigraphic succession is as follows:



The lithology of the German Creek Formation consists of quartzose and labile sandstones, siltstones and mudstones with coal seams, thicker at the top of the sequence. The Moranbah Coal Measures have a similar lithology except for a more labile sandstone, less abundant quartzose and generally thicker coal seams. The MacMillan Formation consists of generally fine-grained sediments, mudstone and siltstone with minor sandstone, and contains marine fossils and bioturbation of the finer beds. The Fort Cooper Coal Measures consist of labile sandstone, siltstone and thick sequences of interbedded coal, carbonaceous shale and abundant tuffs.

The 98 km mining lease strip covers the subcrop of the Moranbah Coal Measures and the upper section of the German Creek Formation, these Permian strata being overlain at their crop by varying thicknesses of Cainozoic sediments and some Tertiary basalt.

This lease strip is located along the Colinsville Shelf and the northern part of the Comet Ridge, so the strata are relatively structurally undisturbed, with a gentle regional dip of 3°-5° to the east towards the Taroom Trough. Faulting is common though minor, producing local steepening of coal seam dips to 10°-12°, and intrusions become more common and of greater size towards the south, especially in the Norwich Park Mine where large areas of coal seams have been heat-affected, being strongly coked in places.

Seam splitting and coalescing are common over the 98 km strike length and in the downdip direction from the subcrop. The seams being worked are as follows:

Mine:	Seams Worked:
Peak Downs	Dysart Upper Dysart K Dysart Dysart Lower
Harrow Creek Colliery	Harrow Creek Upper Seam
Saraji	Dysart K Dysart Dysart Lower
Norwich Park	Dysart Rider Dysart Dysart Lower

All the mines produce export coking coal. In addition, Norwich Park produces export steaming coal. The quality of the washed product coking coal is as follows:

		NORWICH PARK	SARAJI	PEAK DOWNS HARROW CR.
Chemical Analysis				
Total Moisture (as received)	%	9.0	9.5	9.5
Volatile Matter (air dried)	%	17.2	19.5	21.0
Ash (air dried)	%	9.5	9.3	9.5
Sulphur (air dried)	%	0.65	0.55	0.55
Crucible Swelling Number (F.S.I.)		8-9	8-9	8-9
Phosphorus (in coal)	%	0.03	0.02	0.03
Alkali (in ash)	%	1.3	1.4	1.5
Dilatation				
Softening Temperature	°C	425	410	395
Max. Contraction Temperature	°C	460	445	440
Max. Dilatation Temperature	°C	490	485	480
Max. Contraction	%	24	24	25
Max. Dilatation	%	+30	+65	+80
Gieseler Plastometer				
Initial Softening Temperature	°C	450	435	425
Temperature of Maximum Fluidity	°C	480	475	470
Resolidification Temperature	°C	505	505	500
Plastic Range	°C	55	70	75
Maximum Fluidity	ddpm	25	125	275
Petrographic Analysis				
Vitrinite Type	%	V14- 3	V13- 1	V13-25
	%	V15-46	V14-40	V14-68
	%	V16-49	V15-47	V15- 7
	%	V17- 2	V16-12	
Mean Maximum Reflectance of Vitrinite	%	1.60	1.50	1.40
Maceral Composition				
Vitrinite	%	73	70	69
Exinite	%	0	0	0
Semi-Fusinite	%	14	17	18
Other Inertinite	%	8	8	8
Mineral Matter	%	5	5	5

MINING

Peak Downs, Saraji and Norwich Park are typical, large open-cut mines with overburden removal by dragline. Harrow Creek Colliery is a trial underground mine using a bord and pillar system utilising continuous miners and shuttle cars.

Particulars of each mine are as follows:

Mine	Commenced Year	Production in Million Tonnes Capacity per annum	Cumulative
Peak Downs	1972	5.4	48
Harrow Creek	1978	0.4	2
Saraji	1974	4.7	36
Norwich	1979	4.3	13

POSTER DISPLAY

The display shows the location of the mines, their geological setting and position in the stratigraphic succession. A solid geology plan of the mining lease strip, several cross-sections and one longitudinal section showing the stratigraphic succession in the mine area and seam correlation, are included. Also present are photographs of various aspects of the mining and a coal quality table.

GREGORY MINE

Utah Development Company Limited Staff

LOCATION

The mine is located 60 km northeast of Emerald and some 375 km by rail from the port at Gladstone.

GEOLOGY

The seam being mined is the informally named Lilyvale Seam of the German Creek Formation, and occurs at the same stratigraphic horizon as the German Creek Seam in the Oakey Creek Mine and the Dysart Seam in the Norwich Park Mine. Other seams are present in the German Creek Formation and in the Freitag Formation. Faulting is common and often major, but dips are generally shallow and intrusions are rare and minor. In much of the lease, the Permian strata are unconformably overlain by Tertiary basalt flows, the open-cut mine areas comprising denuded "windows" in the basalt cover.

STRATIGRAPHY

Tertiary	Basalt with minor sediments		60 m
Permian	MacMillan Formation		50- 70 m
	German Creek Formation		
	Upper Section -		120 m
	Pleiades Seam	1-2 m	
	Aquila Seam	0-1 m	
	Tieri I Seam	0-1 m	
	Tieri II Seam	0-1 m	
	Corvus Seam	0-1 m	
	Lilyvale Seam	1-5 m	
	Lower Section - (Upper Shell Fossil Horizon at base)		80 m
	Ingelara Formation		80 m
	Freitag Formation (Liskeard Seam near top)		50 m

The Freitag Formation is a transitional unit overlying a major marine unit, and consists of labile fine-grained sediments with a thin, often split paralic coal seam at the top, which seam subcrops north and west of the mine workings. The overlying Ingelara Formation and the lower "barren section" of the German Creek Formation are marine transgressive units consisting of finely interbedded sandstone, siltstone and mudstone with some laminite and pyritic coal laminae, and a persistent coquinite bed at the base of the German Creek Formation. The upper section of the German Creek Formation consists of labile and quartzose sandstone, siltstone and mudstone with up to six coal seams, the lowest of which is the economic Lilyvale Seam.

The German Creek Formation is overlain by a further marine transgressive unit, the MacMillan Formation, consisting predominantly of mudstone and siltstone with minor sandstone and abundant marine macrofossils.

STRUCTURE

The Gregory Mine is located on the western limb of the gently dipping and mildly crenulated Talagai Syncline which plunges gently southwest between the stable Capella Block to the northwest and the Comet Ridge to the east. Major faulting of up to 60 m throw in the lease area combined with the mild crenulation of the syncline has produced a large number of fault blocks of generally gentle dips of variable direction. A few small steeply dipping blocks are present.

INTRUSIONS

Igneous intrusions are rare and small in size in relation to the mine area. The coal seams have been coked over a lateral extent of tens of metres and the igneous rock has been heavily altered to clay.

GEOLOGICAL HAZARDS

Steep-sided canyons of up to 100 m depth cut through the coal measures during Tertiary times and have been infilled with basalt flows and sandy alluvium. These now represent highly charged aquifers which often abut the seam subcrops.

Possible additional open-cut reserves may be mineable under the thinner basalt flows.

A major seasonal watercourse traverses the mine area.

COAL QUALITY

The coal produced is a high volatile, high fluidity coking coal. The coal quality is as follows:

Typical Properties Utah Coking Coal:		Gregory
Chemical Analysis		
Total Moisture (as received)	%	8.0
Volatile Matter (air dried)	%	32.0
Ash (air dried)	%	8.5
Sulphur (air dried)	%	0.65
Crucible Swelling Number (F.S.I.)		8-9
Phosphorus (in coal)	%	0.03
Alkali (in ash)	%	1.1
Dilatation		
Softening Temperature	°C	350
Max. Contraction Temperature	°C	420
Max. Dilatation Temperature	°C	465
Max. Contraction	%	27
Max. Dilatation	%	+100
Gieseler Plastometer		
Initial Softening Temperature	°C	400
Temperature of Maximum Fluidity	°C	440
Resolidification Temperature	°C	470
Plastic Range	°C	70
Maximum Fluidity	ddpm	3500
Petrographic Analysis		
Vitrinite Type	%	V 9-20
	%	V10-45
	%	V11-30
	%	V12- 5
Mean Maximum Reflectance of Vitrinite	%	0.98
Maceral Composition		
Vitrinite	%	69
Exinite	%	4
Semi-Fusinite	%	14
Other Inertinite	%	11
Mineral Matter	%	2

POSTER DISPLAY

The location of the Gregory Mine, the geological setting and position in the stratigraphic succession of the Bowen Basin are shown on the display. Further maps at larger scale show the detailed mine geology including plans and cross-sections. Photographs of the mining operations and a coal quality table are also included.

MINING

The mine is a single seam open cast operation with overburden removal by dragline. Mining commenced in 1979, with production to date of 7 million tonnes. Current capacity is 3 million tonnes per annum.

GEOLOGY OF A TO P 426C (ENSHAM)

C.I. Wallin, Exploration Manager, A.Q.C.-Pacific Pty Ltd
A.R. Dawson, Senior Geologist, A.Q.C.-Pacific Pty Ltd

REGIONAL GEOLOGY

A to P 426C (Ensham) is located in the western part of the Central Bowen Basin, along the western flank of a broad eroded anticlinorium which plunges gently to the south and is referred to as the Comet Ridge or Comet Platform. A location map is included as Figure 1.

The two principal coal-bearing sequences in the region are the German Creek Formation and the stratigraphically higher Rangal Coal Measures, both of Late Permian age.

Reserves of coal within the German Creek Formation are inferred to exist at considerable depth within A to P 426C. This formation contains high quality coking coal which is mined to the north at the Gregory Colliery.

The proven coal reserves of A to P 426C occur within the Rangal Coal Measures which also form major coal deposits on the eastern flank of the Comet Ridge which are currently worked at the Curragh, Blackwater, South Blackwater and Cook Collieries.

Within the A to P area there is a paucity of outcrop with the Permo-Triassic Strata being obscured by Tertiary and/or Quaternary deposits.

The Rangal Coal Measures subcrop near the northern and eastern boundaries of the A to P and dip to south and west respectively (Figure 2), generally at less than 5 degrees, to form a broad synclinal structure. This structure strikes NE-SW and has a shallow plunge to the SW. Secondary folding, particularly towards the west, and some faulting also appears to affect the seams within the A to P area.

GEOLOGY OF THE ENSHAM OPENCUT AREA

The thickest coal development within A to P 426C occurs where the Aries 2 and underlying Castor seam coalesce to form the Aries Castor seam (A2C or A22C) some 4.5 to 6.5m thick. Around the subcrop of this thick seam Tertiary and Quaternary cover are thin and this area (termed the Ensham Opencut Area) has been investigated in the greatest detail. The seam splits to the north and south into thinner subsections. A total strike length of approximately 16km is presently being investigated.

The Rewan Group, which overlies the Rangal Coal Measures, outcrops in creeks and erosional gullies around Ensham homestead and is covered by only a thin veneer of soil over much of the Ensham property. Outcrop of the Rangal Coal Measures is limited and the general stratigraphy has therefore been compiled from borehole data utilizing the rock chip and core descriptions and wireline log interpretation.

The Coal Measure sequence consists of interbedded light grey lithofeldspathic labile sandstones, grey siltstones, dark grey mudstones and coal seams. The nature and distribution of the various sedimentary facies, both laterally and vertically, indicates a possible transitional lower delta plain environment of deposition for the coal measures. The pattern of development and controls for peat accumulation within this type of environment depends to a large extent on the nature and volume of sediments in channels contemporaneous with the peat swamps with the peat accumulating on a series of broad, flat "islands" flanked by slowly moving channels in which sand material is steadily being deposited.

The drilling carried out to date has demonstrated the existence of such channel sandstone facies recognised at various stages in the stratigraphic column with the most significant being developed between the Castor/Aries Castor seams and the Aries 1 seam. A generalised strike section and seam correlation diagram is included as figure 3 together with a typical cross section (figure 4) and stratigraphic section (figure 5).

Within the open cut area the majority of faults have been interpreted as principally normal faults with throws of between 5 and 20 metres generally downthrown to the west. Some strike slip component is suspected with this faulting and a major stirke slip has been interpreted from structure contours particularly in the southern portion while minor flexures possibly resulting from differential compaction around the channel sand bodies, are suspected throughout.

The more significant seams developed within the open cut area include the Pollux, the Aries Castor (A2C, A22C) and the Aries 1 seams. The Pollux seam is present throughout the area and is the lowermost significant seam of the Rangal Coal Measures identified within the A to P. The seam consists of interbedded carbonaceous mudstone and three or four thin, discrete coal plies, and is considered to have only minor economic potential although the proportion of coal within the seam increases in the north of the area.

The various coalescences of the Aries 2 seam and the underlying Castor seam gives rise to the A22C and A2C seams.

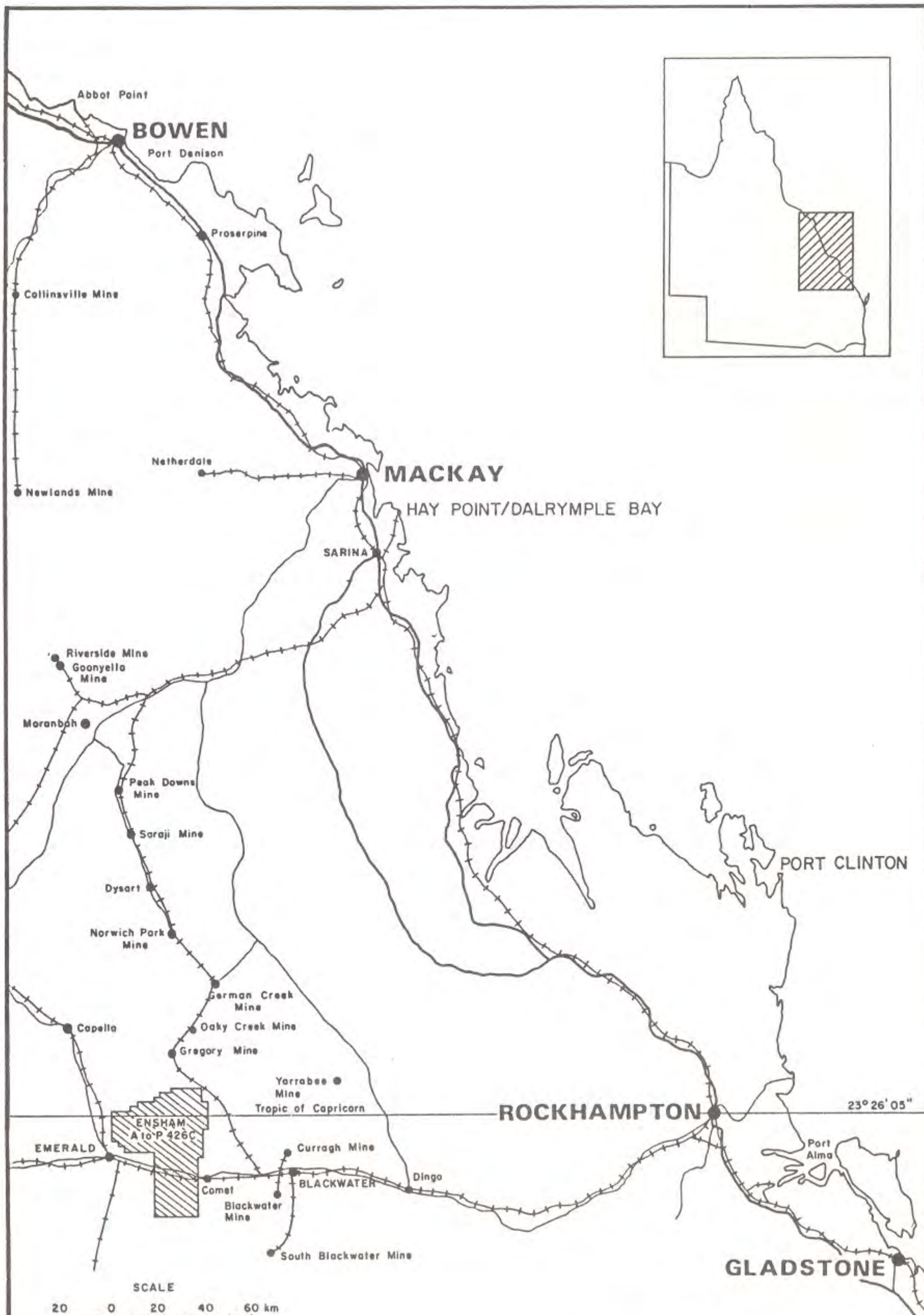
The A22C and A2C seams consist predominantly of dull coals in the upper half of the seam and brighter coals in the basal half with a persistent thin stone band (approximately 0.2m thick) generally 0.4m from the base of the seam. A thin stone band is often identifiable 0.4-0.5 metres down from the top of the seam. The thin basal coal ply is considered to be the equivalent of the C22 split, which is recognised to the north, and the upper coal ply may be correlatable with the A22 seam which splits off from the A22C seam to the south. A typical seam profile of the A2C seam is presented as figure 6.

The uppermost seam in the sequence is the Aries 1 seam which is of a consistent thickness (around 0.75m) and character throughout the opencut area. It contains several thin stone bands.

Average raw coal quality of the Aries Castor seam from 1984 bore core analysis was:-

	% air dried
Moisture	4.2
Ash	12.7
Volatile Matter	26.7
Fixed Carbon	56.4
Total Sulphur	0.6
Specific Energy	27.8 MJ/kg (6600 kcal/kg)

Laboratory tests reveal that a low ash steaming coal and a soft coking coal fraction can be produced by washing.



LOCATION MAP
FIGURE 1

LOCATION MAP OF OPEN CUT AREA WITHIN A TO P 426 C

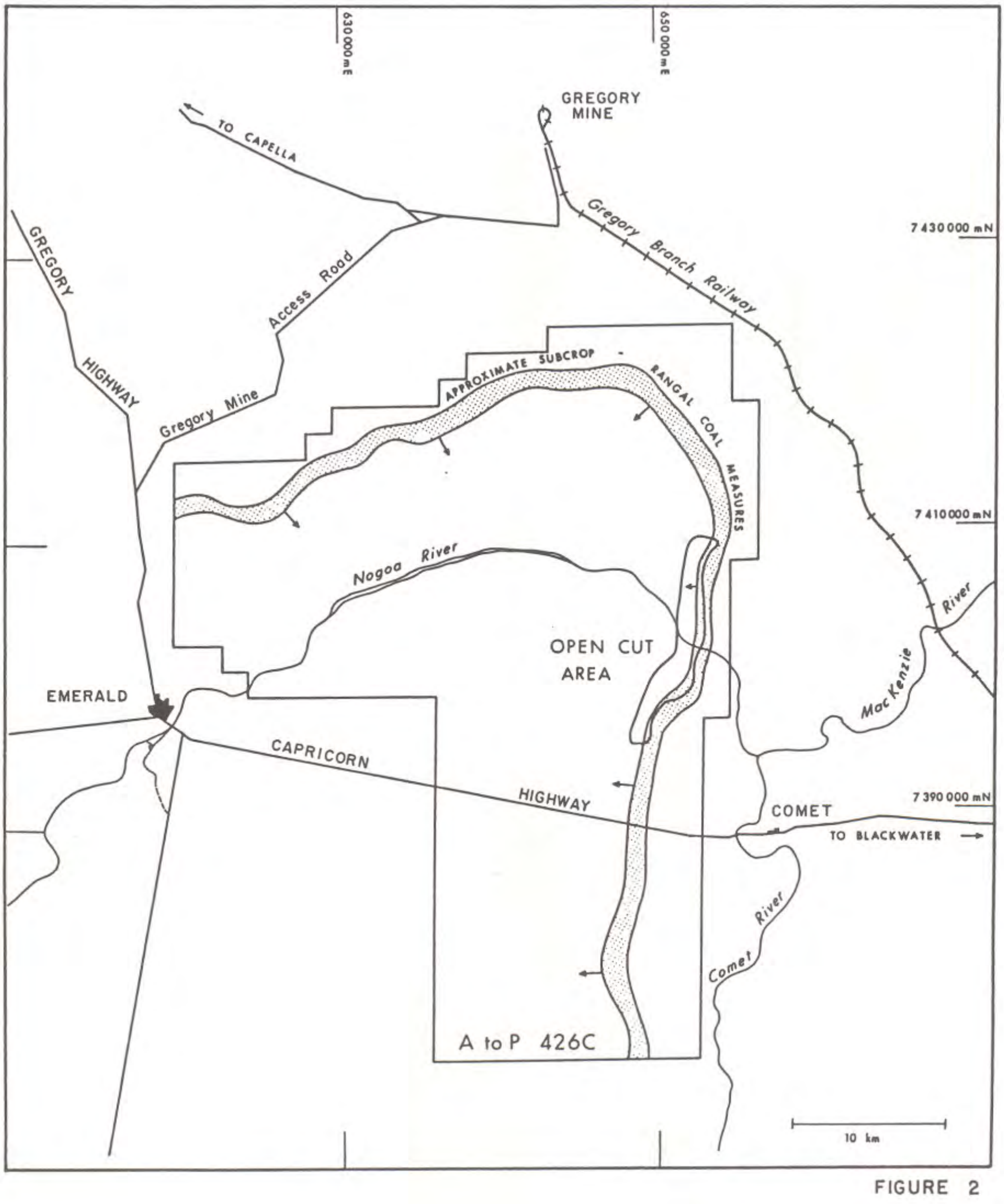


FIGURE 2

GENERALISED STRIKE SECTION AND SEAM CORRELATION DIAGRAM

ENSHAM OPENCUT AREA

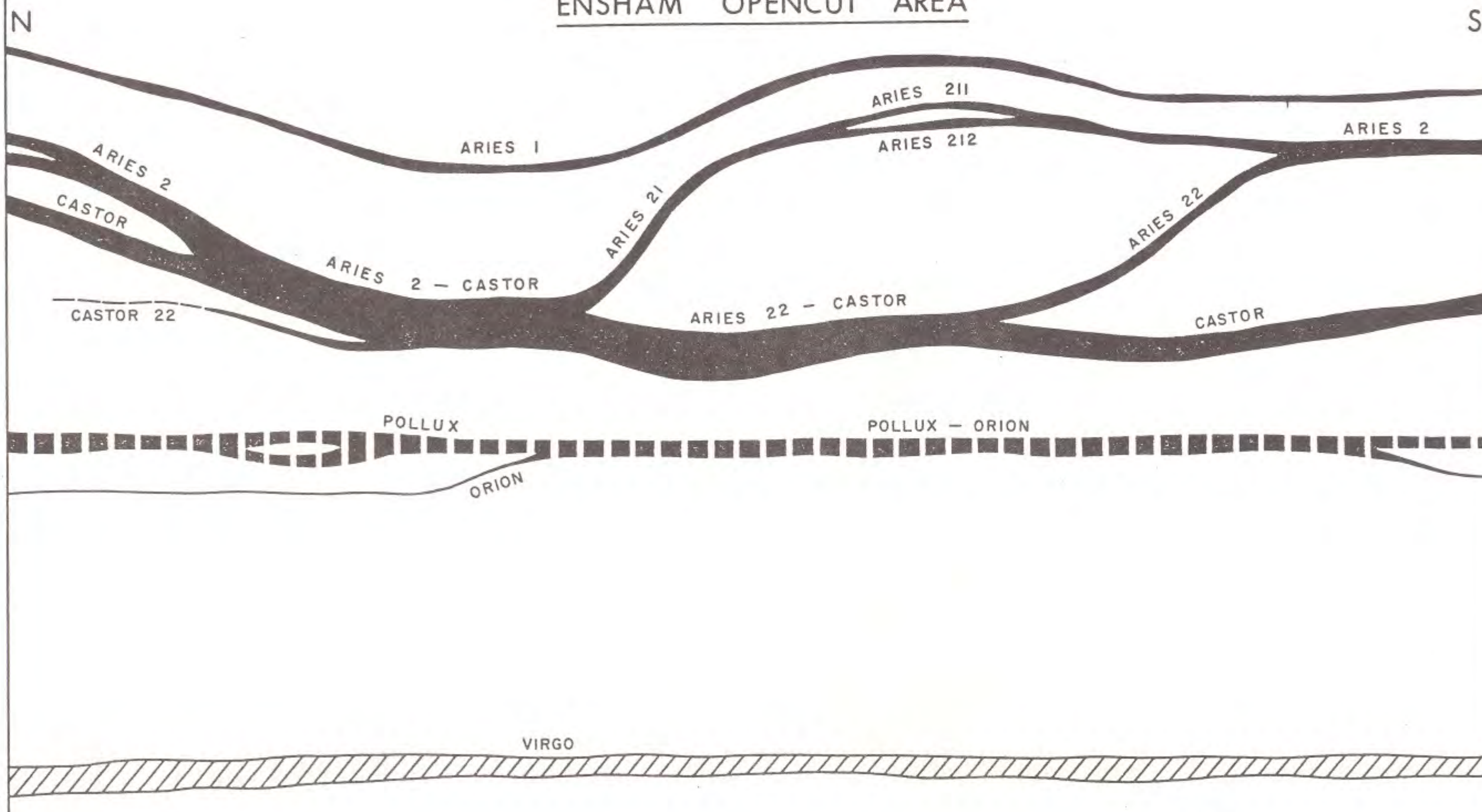


FIGURE 3

TYPICAL CROSS SECTION
ENSHAM OPEN CUT DEPOSIT
NORTH CENTRAL AREA

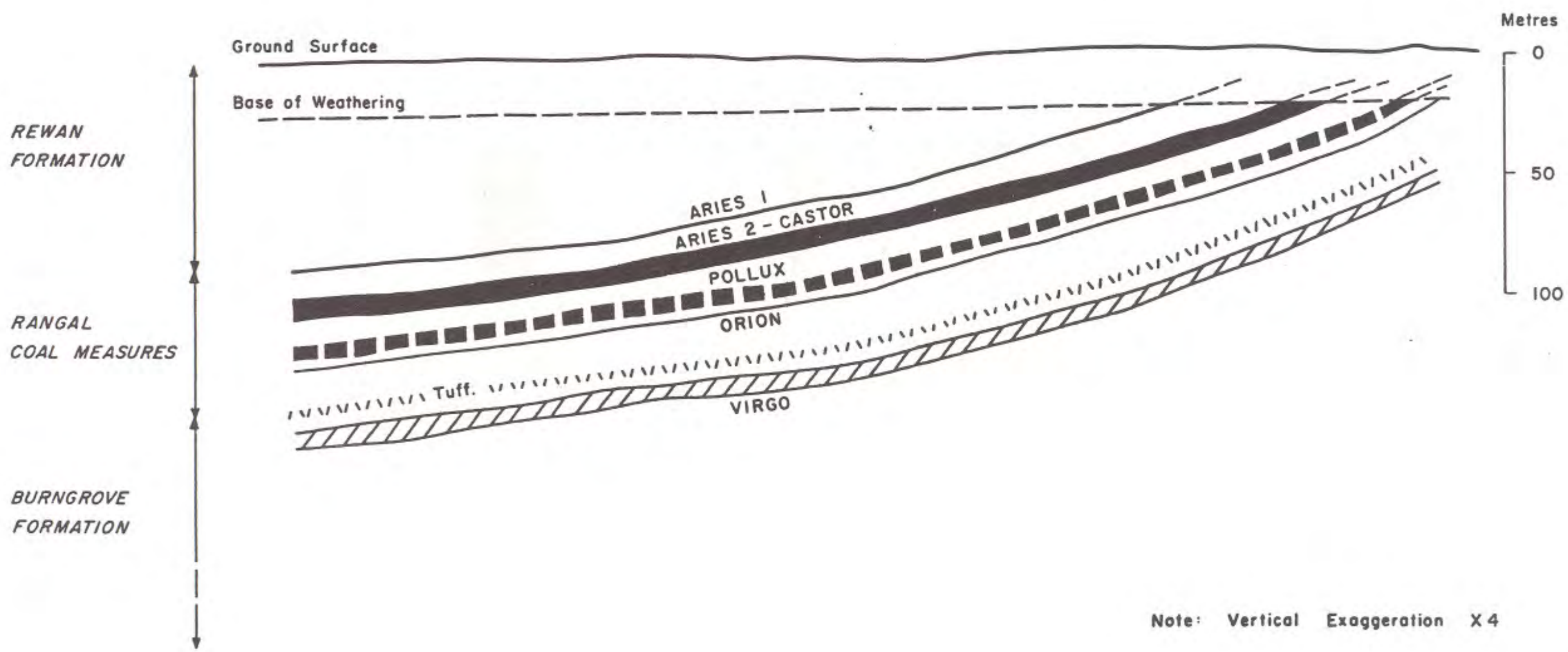


FIGURE 4

TYPICAL STRATIGRAPHIC SECTION
CENTRAL ENSHAM OPEN CUT DEPOSIT

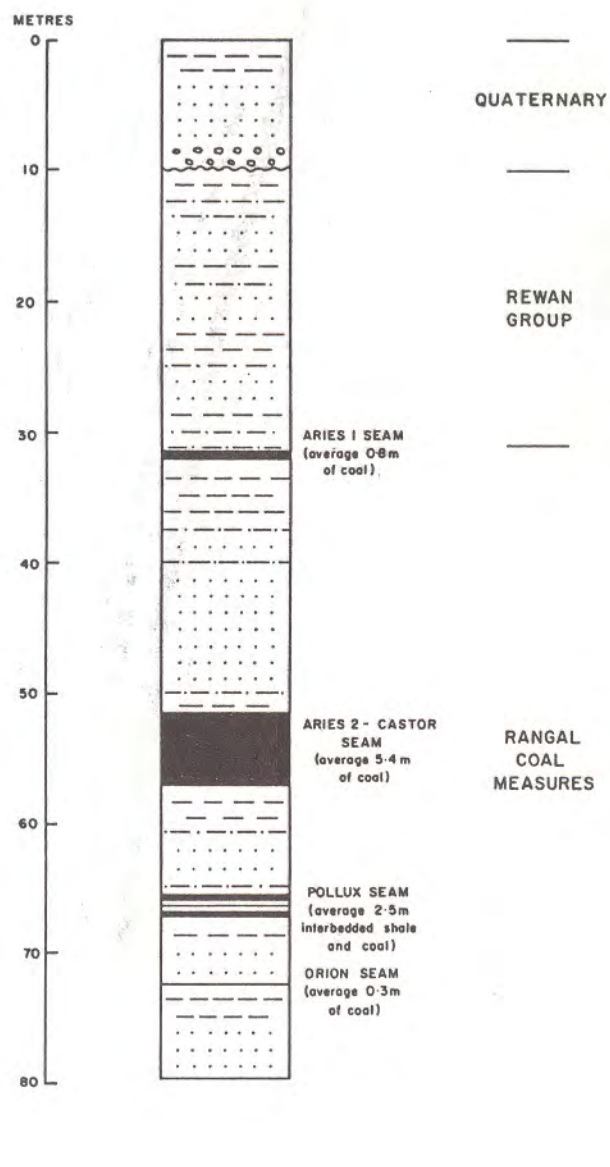


FIGURE 5

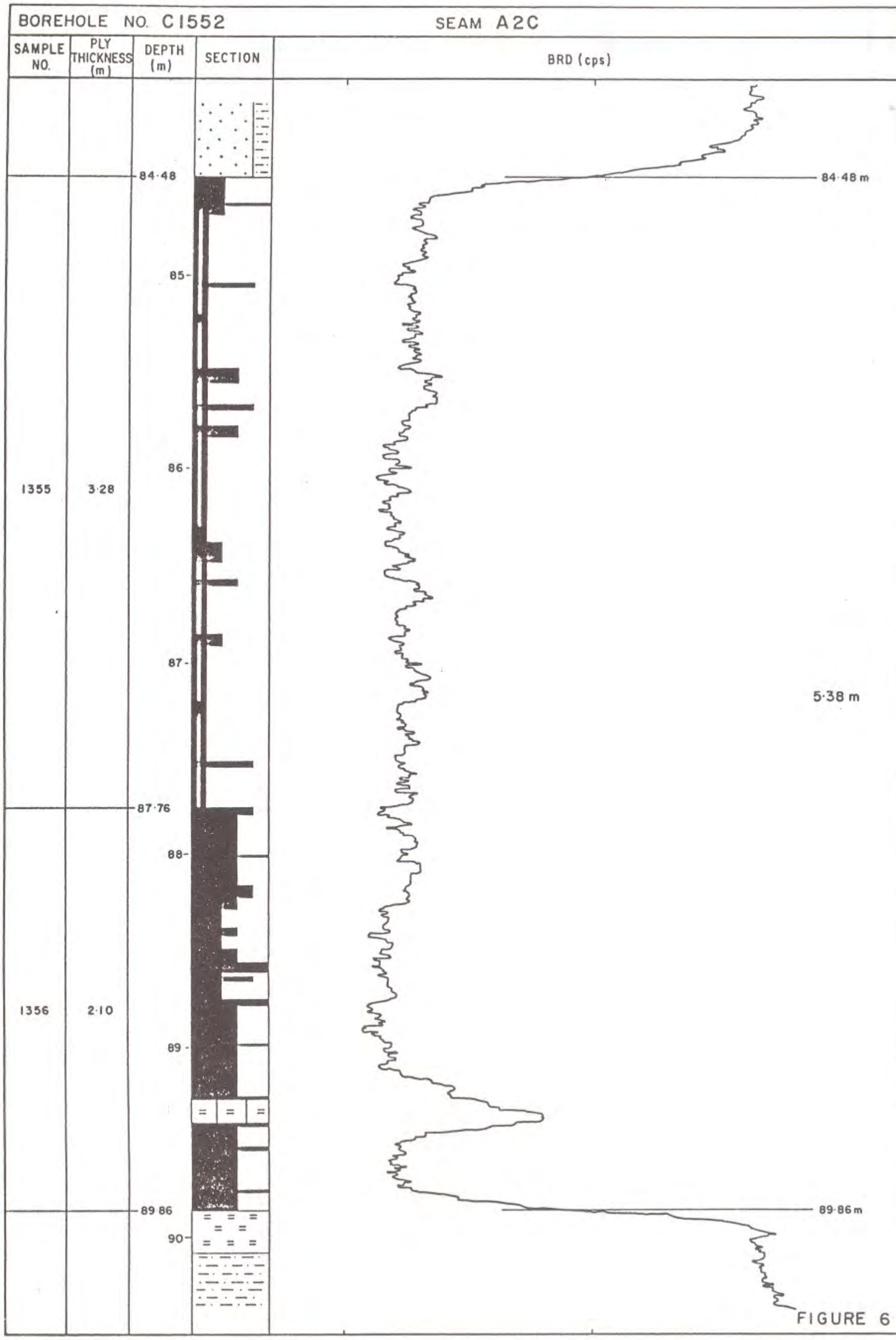

BOREHOLE NO. C1552
SEAM A2C
SAMPLE NO.
PLY THICKNESS (m)
DEPTH (m)
SECTION
BRD (cps)
84·48
85
86
87
87·76
88
89
89·86
90
1355
3·28
1356
2·10
84·48 m
5·38 m
89·86 m

FIGURE 6

Supplement to:

GEOLOGICAL SOCIETY OF AUSTALIA

ABSTRACTS
NUMBER 17

BOWEN BASIN COAL SYMPOSIUM

An Historical Review of the Bowen Basin Stratigraphy

P.L. PRICE
CSR OIL & GAS DIVISION

Since the delineation by Daintree in 1872 of the Permian and Triassic sediments which are now included in the Bowen Basin, it has been the subject of study by Geoscientists from a range of organisations, including Geological Survey of Queensland, University of Queensland, Bureau of Mineral Resources, Oil Exploration Companies and Coal Exploration Companies. As part of their studies, they have subdivided the sections and correlated these stratigraphical units across the Basin. A comprehensive compilation of the Bowen Basin's stratigraphy was presented in 1972 by Dickens and Malone (B.M.R. Bulletin No. 130) but with the change of geological concepts and the acquisition of new subsurface data, it has been modified. A view of the modifications is summarised on the accompanying stratigraphical tables, together with the palynostratigraphical units currently being used by CSR.

TABLE 1

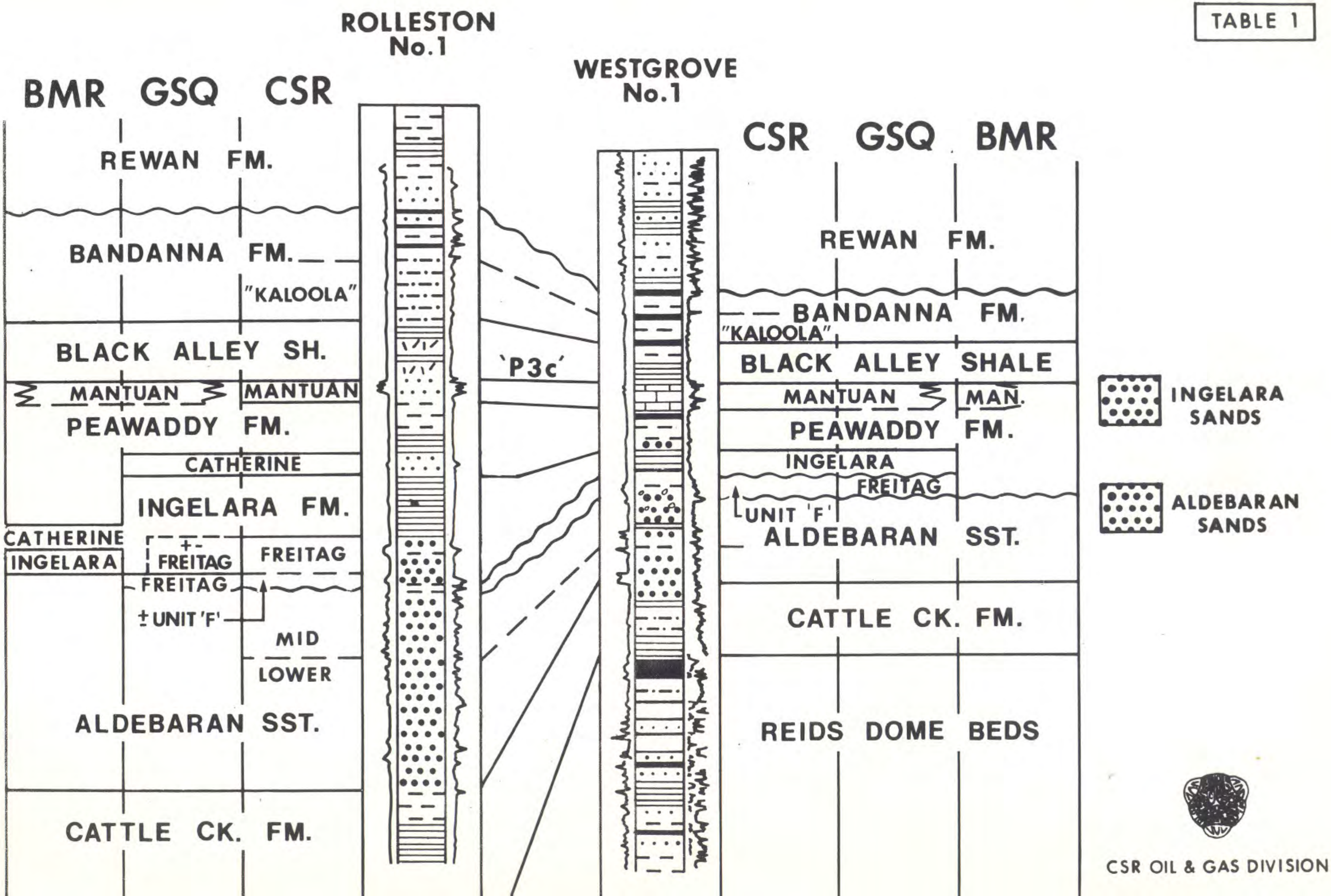

ROLLESTON No.1
WESTGROVE No.1
BMR GSQ CSR
REWAN FM.
BANDANNA FM.
"KALOOLA"
BLACK ALLEY SH.
MANTUAN
MANTUAN
PEAWADDY FM.
CATHERINE
INGELARA FM.
CATHERINE
INGELARA
+- FREITAG
FREITAG
FREITAG
± UNIT 'F'
MID
LOWER
ALDEBARAN SST.
CATTLE CK. FM.
'P3c'
CSR GSQ BMR
REWAN FM.
BANDANNA FM.
"KALOOLA"
BLACK ALLEY SHALE
MANTUAN
MAN.
PEAWADDY FM.
INGELARA
FREITAG
UNIT 'F'
ALDEBARAN SST.
CATTLE CK. FM.
REIDS DOME BEDS
INGELARA SANDS
ALDEBARAN SANDS
CSR OIL & GAS DIVISION

TABLE 2

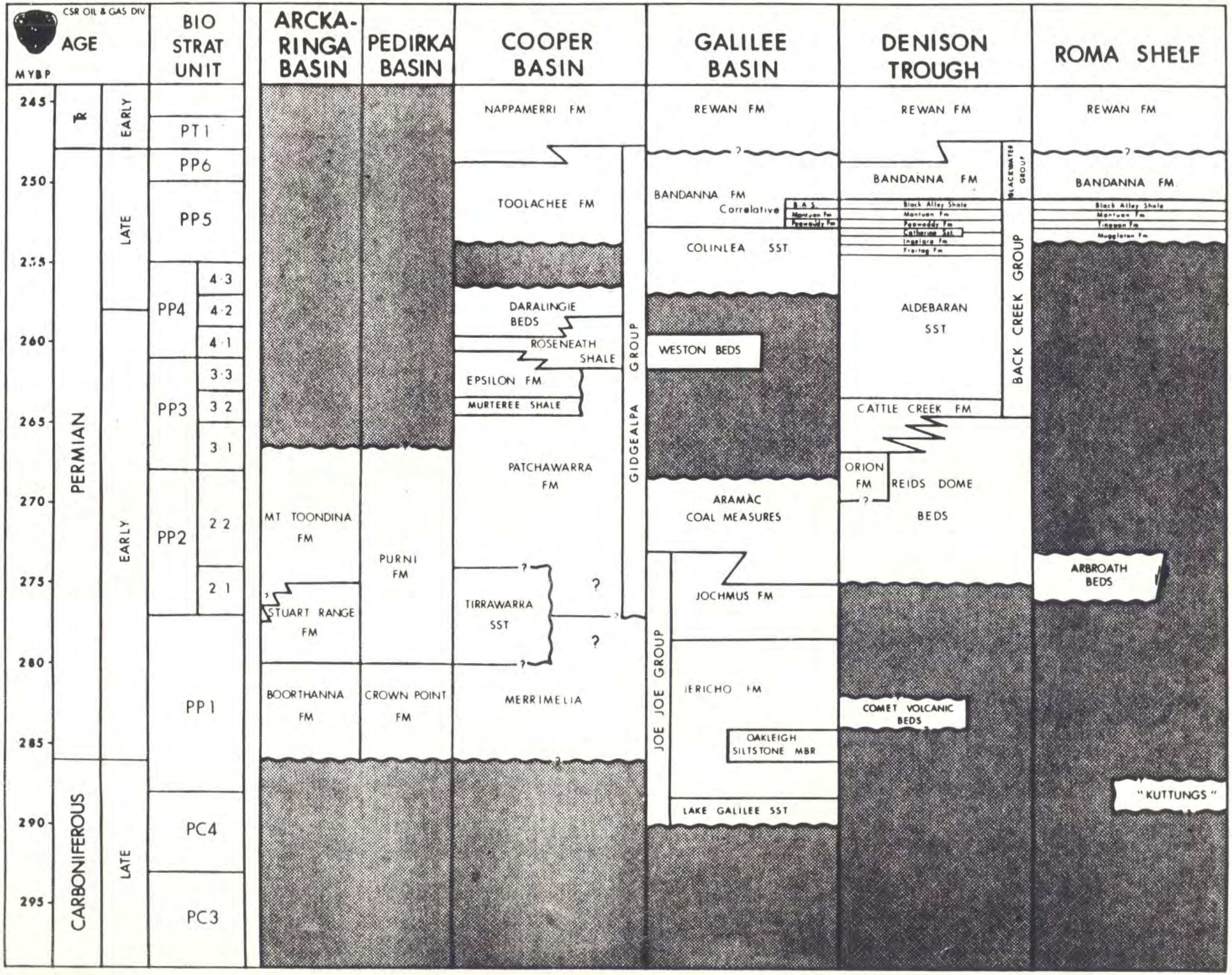

CSR OIL & GAS DIV
AGE
MYBP
BIO STRAT UNIT
ARCKARINGA BASIN
PEDIRKA BASIN
COOPER BASIN
GALILEE BASIN
DENISON TROUGH
ROMA SHELF
245
250
255
260
265
270
275
280
285
290
295
Ʀ
EARLY
PERMIAN
LATE
EARLY
CARBONIFEROUS
LATE
PT1
PP6
PP5
PP4
4·3
4·2
4·1
PP3
3·3
3·2
3·1
PP2
2·2
2·1
PP1
PC4
PC3
MT TOONDINA FM
STUART RANGE FM
BOORTHANNA FM
PURNI FM
CROWN POINT FM
NAPPAMERRI FM
TOOLACHEE FM
DARALINGIE BEDS
ROSENEATH SHALE
EPSILON FM
MURTEREE SHALE
PATCHAWARRA FM
TIRRAWARRA SST
MERRIMELIA
GIDGEALPA GROUP
REWAN FM
BANDANNA FM Correlative
B.A.S.
Mantuan Fm
Peawaddy Fm
COLINLEA SST
WESTON BEDS
ARAMAC COAL MEASURES
JOCHMUS FM
JERICHO FM
OAKLEIGH SILTSTONE MBR
LAKE GALILEE SST
JOE JOE GROUP
REWAN FM
BANDANNA FM
BLACKWATER GROUP
Black Alley Shale
Mantuan Fm
Peawaddy Fm
Catherine Sst
Ingelara Fm
Freitag Fm
ALDEBARAN SST
BACK CREEK GROUP
CATTLE CREEK FM
ORION FM
REIDS DOME BEDS
COMET VOLCANIC BEDS
REWAN FM
BANDANNA FM
Black Alley Shale
Mantuan Fm
Tinowon Fm
Muggleton Fm
ARBROATH BEDS
"KUTTUNGS"

TABLE 4

LATE PERMIAN STRATIGRAPHIC UNITS

ROMA SHELF	DENISON TROUGH	CONNET BLACKWATER	COLLINVILLE	CORRELATABLE EVENTS
BANDANNA FM	BANDANNA FM	RANGAL C M	RANGAL C.M.	◄ TOP COAL MEASURE DEPOSITION
"KALOOLA"	"KALOOLA"	BURNGROVE FM	FORT COOPER C.M.	◄ TOP ABUNDANT TUFF
BLACK ALLEY SHALE (WINNATHOOLA COAL MBR)	BLACK ALLEY SHALE	BLACK ALLEY SHALE		
MANTUAN FM	MANTUAN FM	FAIR HILL FM		◄ 'P3c' ARCITARCH
TINOWON FM (WALLABELLA COAL MBR)	PEAWADDY FM			
		MACMILLAN FM	MORANBAH C.M.	◄ BASE ABUNDANT TUFF
	CATHERINE SST	CROCKER SAND		◄ 'P' TUFF
			GOONYELIA SM	
MUGGLETON FM	INGELARA FM	GERMAN CK FM	EXMOOR FM	
LORELLE SST			BLENHEIM FM (SCOTTVILLE)	
	FREITAG FM	MARIA FM		

CSR OIL & GAS DIV.

TABLE 3

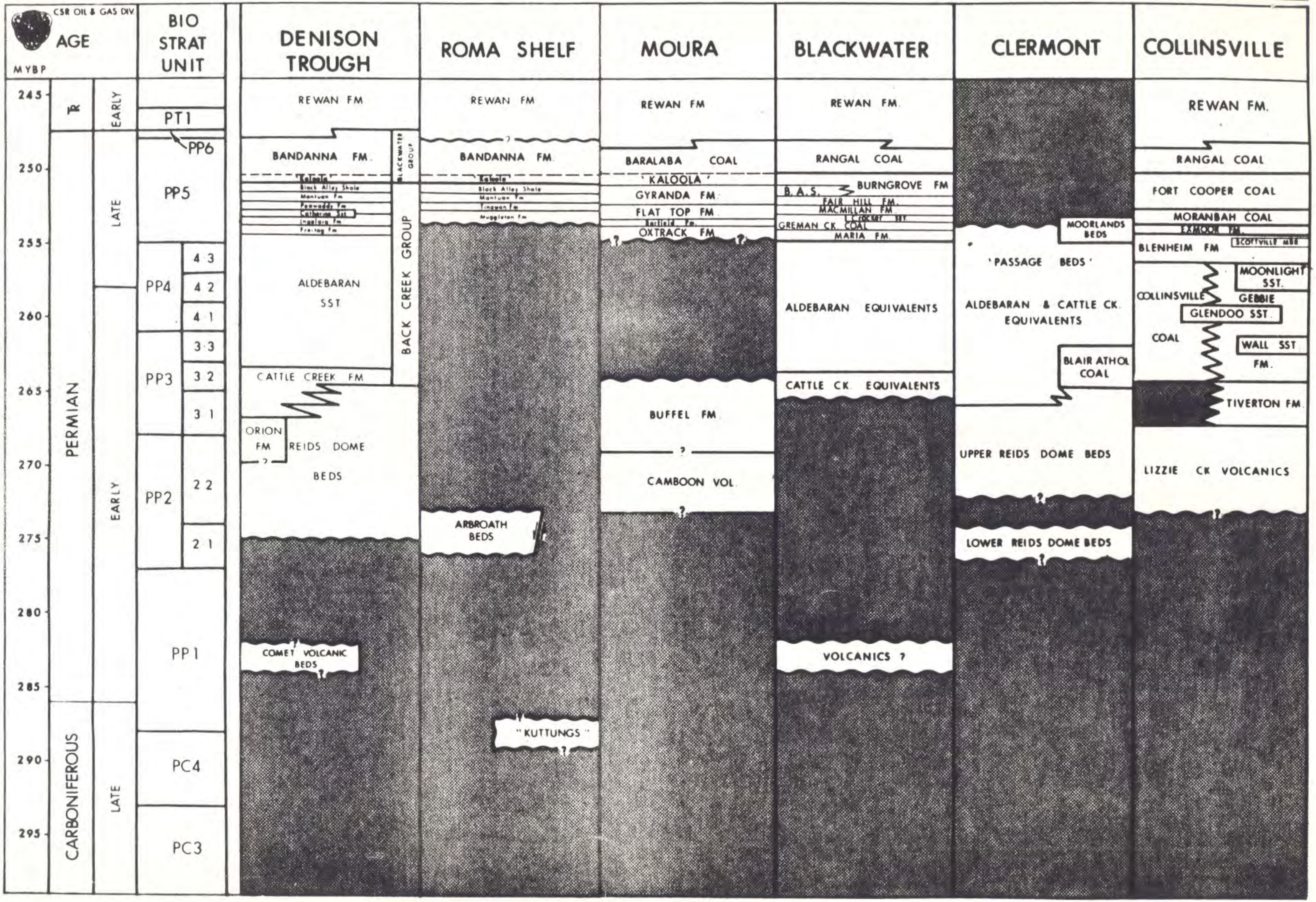

CSR OIL & GAS DIV.
AGE
MYBP
BIO STRAT UNIT
DENISON TROUGH
ROMA SHELF
MOURA
BLACKWATER
CLERMONT
COLLINSVILLE
245
250
255
260
265
270
275
280
285
290
295
PERMIAN
CARBONIFEROUS
EARLY
LATE
EARLY
LATE
PT1
PP6
PP5
PP4
4 3
4 2
4 1
PP3
3 3
3 2
3 1
PP2
2 2
2 1
PP1
PC4
PC3
REWAN FM
BANDANNA FM.
BLACKWATER GROUP
Kaloola
Black Alley Shale
Mantuan Fm
Peawaddy Fm
Catherine Sst
Ingelara Fm
Freitag Fm
ALDEBARAN SST
BACK CREEK GROUP
CATTLE CREEK FM
ORION FM
REIDS DOME BEDS
COMET VOLCANIC BEDS
REWAN FM
BANDANNA FM.
Kaloola
Black Alley Shale
Mantuan Fm
Tinowon Fm
Muggleton Fm
ARBROATH BEDS
"KUTTUNGS"
REWAN FM
BARALABA COAL
'KALOOLA'
GYRANDA FM.
FLAT TOP FM.
Barfield Fm.
OXTRACK FM
BUFFEL FM.
CAMBOON VOL.
REWAN FM.
RANGAL COAL
B.A.S.
BURNGROVE FM
FAIR HILL FM.
MACMILLAN FM.
GREMAN CK. COAL
MARIA FM.
ALDEBARAN EQUIVALENTS
CATTLE CK. EQUIVALENTS
VOLCANICS ?
MOORLANDS BEDS
'PASSAGE BEDS'
ALDEBARAN & CATTLE CK. EQUIVALENTS
BLAIR ATHOL COAL
UPPER REIDS DOME BEDS
LOWER REIDS DOME BEDS
REWAN FM.
RANGAL COAL
FORT COOPER COAL
MORANBAH COAL
EXMOOR FM.
BLENHEIM FM
SCOTTVILLE MBR
MOONLIGHT SST.
COLLINSVILLE
GEBBIE
GLENDOO SST.
COAL
WALL SST.
FM.
TIVERTON FM.
LIZZIE CK VOLCANICS

TABLE 5

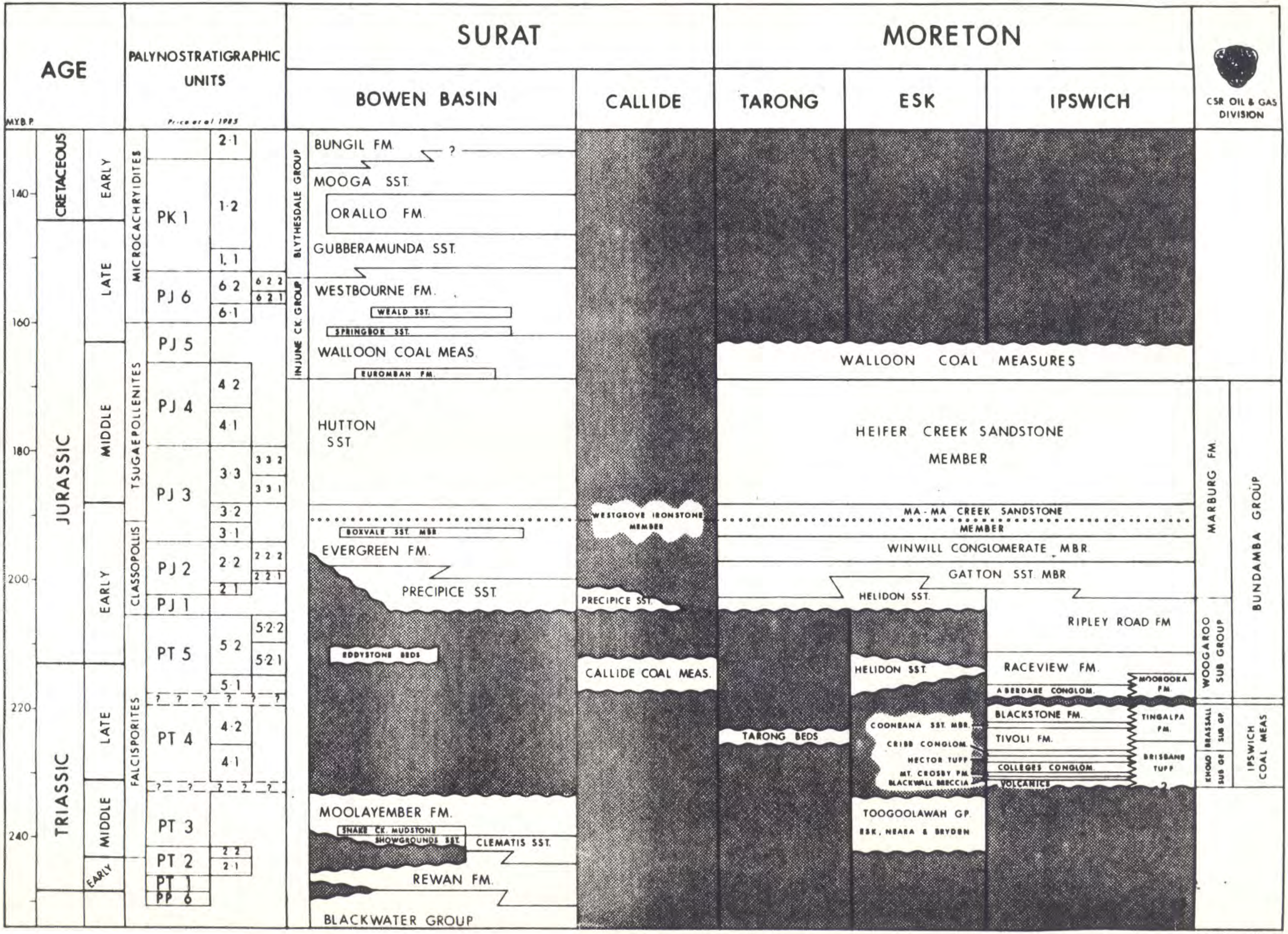

AGE
M.Y.B.P.
PALYNOSTRATIGRAPHIC UNITS
Price et al 1985
SURAT
MORETON
BOWEN BASIN
CALLIDE
TARONG
ESK
IPSWICH
CSR OIL & GAS DIVISION
140
160
180
200
220
240
CRETACEOUS
JURASSIC
TRIASSIC
EARLY
LATE
MIDDLE
MICROCACHRYIDITES
TSUGAEPOLLENITES
CLASSOPOLLIS
FALCISPORITES
PK 1
PJ 6
PJ 5
PJ 4
PJ 3
PJ 2
PJ 1
PT 5
PT 4
PT 3
PT 2
PT 1
PP 6
2·1
1·2
1.1
6·2
6·1
4·2
4·1
3·3
3·2
3·1
2·2
2·1
5·2
5·1
4·2
4·1
2·2
2·1
6 2 2
6 2 1
3 3 2
3 3 1
2 2 2
2 2 1
5·2·2
5·2·1
BLYTHESDALE GROUP
INJUNE CK. GROUP
BUNGIL FM.
MOOGA SST.
ORALLO FM.
GUBBERAMUNDA SST.
WESTBOURNE FM.
WEALD SST.
SPRINGBOK SST.
WALLOON COAL MEAS.
EUROMBAH FM.
HUTTON SST.
BOXVALE SST. MBR
EVERGREEN FM.
PRECIPICE SST.
EDDYSTONE BEDS
MOOLAYEMBER FM.
SNAKE CK. MUDSTONE
SHOWGROUNDS SST.
CLEMATIS SST.
REWAN FM.
BLACKWATER GROUP
WESTGROVE IRONSTONE MEMBER
PRECIPICE SST.
CALLIDE COAL MEAS.
WALLOON COAL MEASURES
HEIFER CREEK SANDSTONE MEMBER
MA-MA CREEK SANDSTONE MEMBER
WINWILL CONGLOMERATE MBR
GATTON SST. MBR
HELIDON SST.
RIPLEY ROAD FM.
HELIDON SST.
RACEVIEW FM.
MOOROOKA FM.
ABERDARE CONGLOM.
BLACKSTONE FM.
TINGALPA FM.
TIVOLI FM.
BRISBANE TUFF
COLLEGES CONGLOM.
VOLCANICS
TARONG BEDS
COONEANA SST. MBR.
CRIBB CONGLOM.
HECTOR TUFF
MT. CROSBY FM.
BLACKWALL BRECCIA
TOOGOOLAWAH GP.
ESK, NEARA & BRYDEN
MARBURG FM.
BUNDAMBA GROUP
WOOGAROO SUB GROUP
BRASSALL SUB GP
KHOLO SUB GP
IPSWICH COAL MEAS.

TABLE 6

CSR OIL AND GAS DIVISION - TRIASSIC NOMENCLATURE

ADOPTED AGES		PRE-1985 USAGE	CURRENT NOMENCLATURE (INTERVAL ZONES)			INDEX FORMS
JUR.	EARLY	J1	PJ1			*Classopollis classoides*
TRIASSIC	LATE	BASAL BUNDAMBA ASSEMBLAGE	PT5	PT5.2	PT5.2.2	*Retitriletes austroclavatidites*
					PT5.2.1	*Retitriletes rosewoodensis*
				PT5.1		*Polycingulatisporites crenulatus/P. mooniensis*
		H I A T U S				
		IPSWICH ASSEMBLAGE	PT4	PT4.2		*Annulispora densata*
				PT4.1		*Annulispora folliculosa*
		H I A T U S				
	MIDDLE	Tr3c-d	PT3			*Lycopodiacidites kuepperi* (sp. 84)
		Tr3a-b	PT2	PT2.2		*Rugulatisporites trisinus* (sp. 708)
	EARLY	Tr2b				
		Tr2a		PT2.1		*Aratrisporites* spp.
		Tr1b	PT1			*Lunatisporites pellucidus*
PERM.	LATE	Tr1a	PP6			*Triplexisporites playfordii*

MAY, 1985

CSR OIL AND GAS DIVISION - PERMIAN NOMENCLATURE

ADOPTED AGES		PRE-1985 USAGE		CURRENT NOMENCLATURE (INTERVAL ZONES)			INDEX FORMS
TRI.	EARLY	Trlb		PT1			*Lunatisporites pellucidus*
PERMIAN	LATE	Unit Trla		PP6			*Triplexisporites playfordii*
		upper stage 5	U5b-c	PP5	PP5.2		*Dulhuntyispora stellata*
			U5a		PP5.1		*Dulhuntyispora parvitholus*
		lower stage 5	L5c	PP4	PP4.3		*Dulhuntyispora dulhuntyi*
	EARLY		L5b		PP4.2		*Didecitriletes ericianus* (sp.7)
			L5a		PP4.1		*Dulhuntyispora granulata*
		stage 4	U4b	PP3	PP3.3	PP3.3.2	*Lopadiospora vermithola*
						PP3.3.1	*Acanthotriletes villosus*
			U4a		PP3.2		*Praecolpatites sinuosus* (sp.21)
			L4		PP3.1		*Phaselisporites cicatricosus*
		stage 3	3b	PP2	PP2.2		*Granulatisporites trisinus*
			3a		PP2.1		*Pseudoreticulatispora pseudoreticulata*
		stage 2		PP1			*Protohaploxypinus* spp.
CARB.		stage 1		PC4			*Potonieisporites* spp.

SOME STRUCTURAL FEATURES ALONG THE WESTERN MARGIN OF THE BOWEN BASIN

D. Devey and I. Price (UDC)

INTRODUCTION

Regional drilling of the coalfields on the central-western margin of the north Bowen Basin was commenced by Utah on widely spaced drill lines in 1963. This early exploration covered a 25 km wide belt which extended 240 km north from Blackwater to Goonyella. The initial evaluation quickly indicated that the sub-cropping Rangal Coal Measures tended to be more structurally complex than the sub-cropping Moranbah-German Creek (M.G.CK.) sequence. This observation reflected the structural positions of the sub-crop lines of the coal bearing horizons relative to the Dawson Tectonic Zone and the projected Burton Range-Jellinbah fault zones. Numerous reports on the Utah exploration of the area have been compiled by King, Goscombe, Hansen, Bekker and Milligan during the period 1963 to 1972.

Within the Rangal Coal Measures major faults with vertical displacements greater than 100 m were detected and the dominant N-S to NNW fault-trend was recognised. In contrast, few large faults (throw greater than 20 m) or structurally complex areas were indicated along the sub-crop of the M.G.CK. sequence. Most of the structural interpretation was derived from drilling concentrated near the sub-crops of main coal horizons. Most of the drill lines trended E-W to NE-SW, making detection of E-W structures difficult.

Subsequent drilling during the period 1972 to 1985 has shown that the dominant N-S to NNW-SSE fault trend of the Rangal Coal Measures is also common to the M.G.CK. sequence in the Norwich Park-Goonyella area of the Collinsville Shelf. In addition, the frequency of structures significant to mining, proved greater than was previously indicated by the pre-1973 drilling. The detailed drilling extended over a strike distance of 140 km between Goonyella and Norwich Park in SCMLs 127, 210, 245 and 244 (Figure 1).

GOONYELLA MINE (SCML 127)

Major tectonic structures are rare in the Goonyella area. The region is characterised by shallow easterly dips which range from 2° to 5° and locally reach a maximum of 8°. Smaller fault and fold structures, which appear to be predominantly sedimentary in origin, have been exposed in the existing opencut and inferred from drillholes. These structures are not vertically continuous and appear to have developed independently at different coal horizons.

An arcuate NNE to NNW trending thrust fault extends 3.8 km south from Ramp 4 to beyond Ramp 2. This major fault, the Eureka Fault, dips at 15° to 35° east and has resulted in a zone of seam repetition up to 120 m wide. The eastern fault block appears to have been thrust in a SW direction.

Two other thrusts trending NW to NNW have been detected by drilling in the deeper areas of the lease and these are shown in Figure 3.

Drill holes are sparse in the deep areas of the Goonyella lease. Hence the apparent absence of major structures will not be resolved until the drill hole spacing is significantly reduced.

DAUNIA (SCML 244)

The Daunia deposit is contained within a faulted synclinal structure approximately 20 km long and 2 to 4 km wide. It is located 25 km north-east of the Peak Downs Mine and 7 km east of a southern extension of the Burton Range Fault, locally known as the Isaac Fault. The coal reserves are contained within three seams of the Rangal Coal Measures - Leichhardt, Vermont and Vermont Lower. The deposit contains large open cut reserves of both energy and coking coal.

The Daunia Syncline is a shallow NNW trending fold which appears to have been offset midway by a NNE-SSW trending reverse fault across the area. This fault, the Daunia Dividing Fault (D.D.F.), effectively separates the deposit into two distinct zones. The area north of the D.D.F. is characterised by steeper dips ranging from 10° to 45° and a maximum depth to the Leichhardt seam of 160 m. The syncline in the southern zone is asymmetrical with the eastern flank dipping more steeply at 30° to 45°. The southern area appears to have a lower fault frequency but this may simply reflect the wider drill hole spacing. The structure in the southern half of the northern zone could be described as a graben. In this area the folding is less severe and flat dips are common along the axis of the structure which is bounded by two high-angle normal faults.

The Daunia deposit is dominated by four NNW trending fault zones as well as the NNE trending D.D.F. The main fault zones are sinuous and have a tendency to branch near their terminations. The main structures in the Daunia area are shown in Figure 4.

The Daunia West Fault (D.W.F.) is the major fault in the lease and extends over a strike length of 7.5 km. Vertical displacement ranges from 22 to 90 m with an average of 60 m. The D.W.F. appears to be a high-angle, dip-slip fault which has experienced significant horizontal displacement. In the region of grid line 57,000m N, the average Vermont seam thickness on the western side of the D.W.F. is 4 m, while on the eastern side, the thickness is 1.8 m. A 4 m thick Vermont seam occurs east of the D.W.F. in the region of grid line 55,000m N. Similarly, there is a significant change in Leichhardt-Vermont interseam thickness across the D.W.F. These observations imply that the D.W.F. has experienced horizontal movement of at least 2 km, in a dextral sense.

This movement direction is the opposite of the horizontal direction previously inferred (Milligan, 1970) on the Burton Range-Isaac fault zone located 7.5 km west of the D.W.F. Hence the N-S to NNW trending zone of major faults (predominantly thrusts) which extend along the western flank of the Bowen Basin may have been subjected to several phases of horizontal movement with different faults being remobilised during successive phases.

PEAK DOWNS - NORWICH PARK REGION

The deposits of this region occur within the M.G.CK. sequence on the southern end of the Collinsville Shelf.

The Peak Downs, Saraji and Norwich Park areas are characterised by a regional easterly dip of 3° to 6°. This regular trend is disrupted by mild folding or warping on a north-east trend and locally, by zones of faulting which increase the dip to a maximum of 12°. The shallow folding or warping appears to pre-date most faulting events.

PEAK DOWNS MINE (SCML 210)

The main structures in the Peak Downs area are shown in Figure 5. The main faults in the area are predominantly high-angle normal and trend E-W, NE-SW and N-S to NW-SE.

A zone of high-angle southerly-dipping normal faults trend NE across the lease in the Peak Downs access road/railway corridor. The area north of this fault appears relatively fault free, except for a major arcuate fault, the Winchester Fault, which extends 6 km north from the railway to Ramp 7N. The throw on this NNW to NW-trending fault varies from 20 to 30 m.

South of the Peak Downs access corridor the dominant fault trend is E-W to ESE. Zones of discontinuous normal faults as well as horst and graben structures bounded by high-angle faults extend E-W across the lease. The dominant Boomerang Fault, a zone of discontinuous faults and fault blocks, extends 5 km from the northern flank of the Yura Structure across the lease with throws varying from 6 to 17 m.

In the southern area arcuate N-S to NNW-trending faults appear to terminate on the dominant E-W structures. These N-S faults, whose throws vary up to a maximum of 27 m, are considered to be subsidiary to the E-W structures. There is a significant change in the Dysart Upper 2 - Dysart Lower 2 interseam thickness across the Yura South Fault. The interseam thickness on the western downthrown block is double the thickness on the eastern block. This implies that the Yura South Fault was active contemporaneous with deposition of the Dysart coal horizon. Insufficient drill hole information is available adjacent to the other N-S faults to determine if they may have been similarly active at the time of Dysart deposition.

The Yura Structure is a NE trending warp located between Ramps 8S and 10S. This area has been interpreted as a basement high at the time of Dysart coal deposition.

SARAJI MINE (SCMLs 210 and 245)

The Saraji Mine area is relatively free of major fault structures. The main structures are shown in Figure 6.

Between Ramps 4 and 8 a monoclinal structure with associated minor faulting trends NNE to NNW for 5 km. Locally this structure increases the seam dip to 12° and produces a net change in Dysart level of 20 to 40 m down to the east. Another monoclinal structure, the Bauhinia Monocline, extends from Ramp 2 to Ramp 4 with a maximum change in the

Dysart level of 14 m. The Bauhinia structure trends NNW and also appears to be associated with minor faulting.

The major structure in the Saraji area is the Saraji South Fault, a sinuous N-S to NNW-trending zone of high-angle normal faults. This easterly dipping structure extends for approximately 6 km with throws varying from 10 to 50 m.

Further south another significant sinuous structure, the Downs Creek Fault, trends N-S to NW for 3 km before crossing the western S.C.M.L. boundary in the Norwich Park area. The Downs Creek Fault is downthrown to the east a maximum of 60 m.

NORWICH PARK MINE (SCML 245)

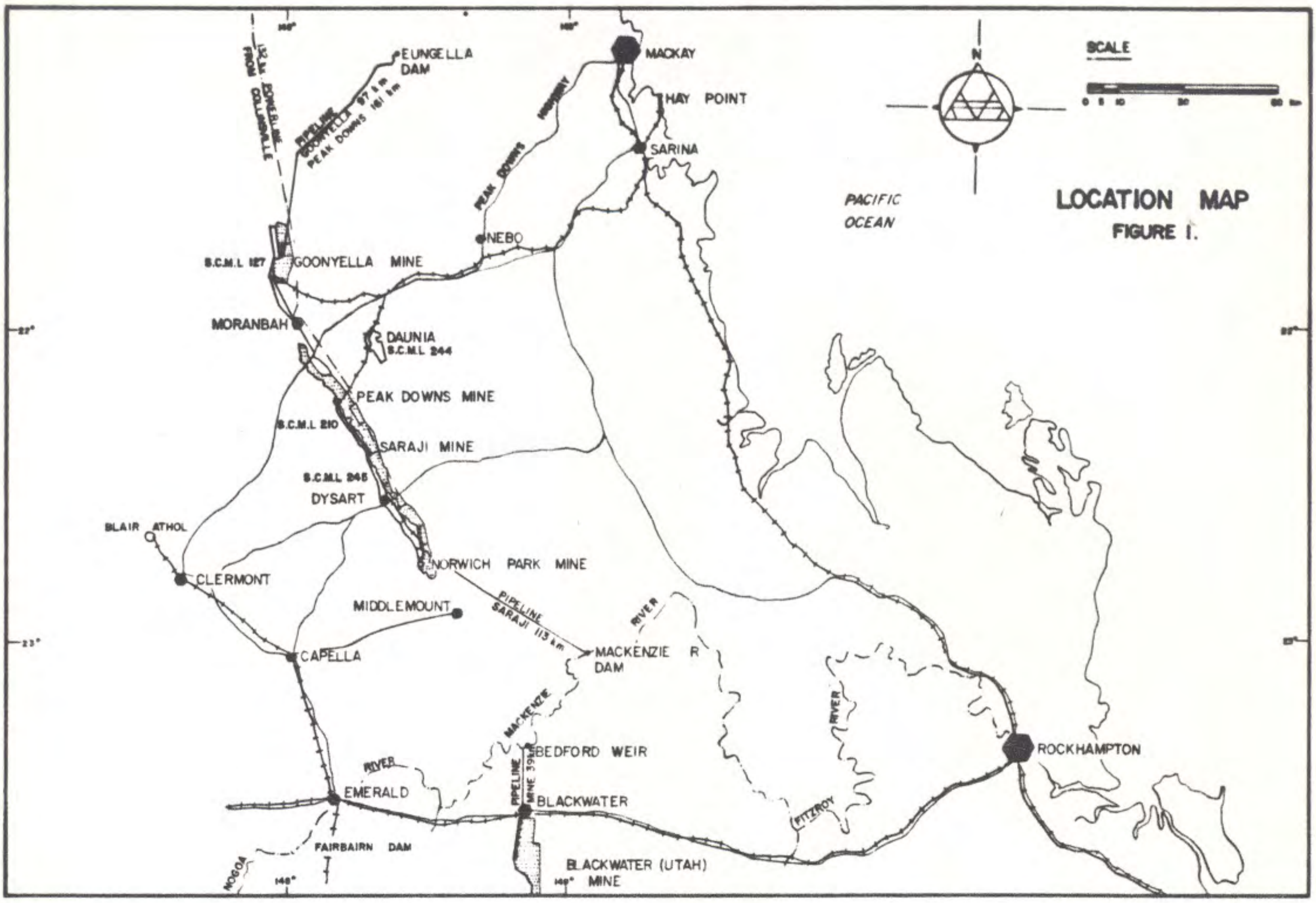
The Norwich Park area has suffered several phases of intrusion and coking of coal seams by acid to intermediate, igneous bodies which preferentially intruded the coal and adjacent roof/floor strata. This has significantly reduced the recoverable reserves of Dysart and Harrow Creek/Tieri coal.

The Norwich Park lease has a marked strike swing in the region of grid line 92000m N (Figure 7). This was caused by warping on a NE trend and an associated major fault, the Norwich Fault. The Norwich Fault appears to be a step-faulted zone trending NE-SW with a net downthrow to the SE of 60 to 70 m.

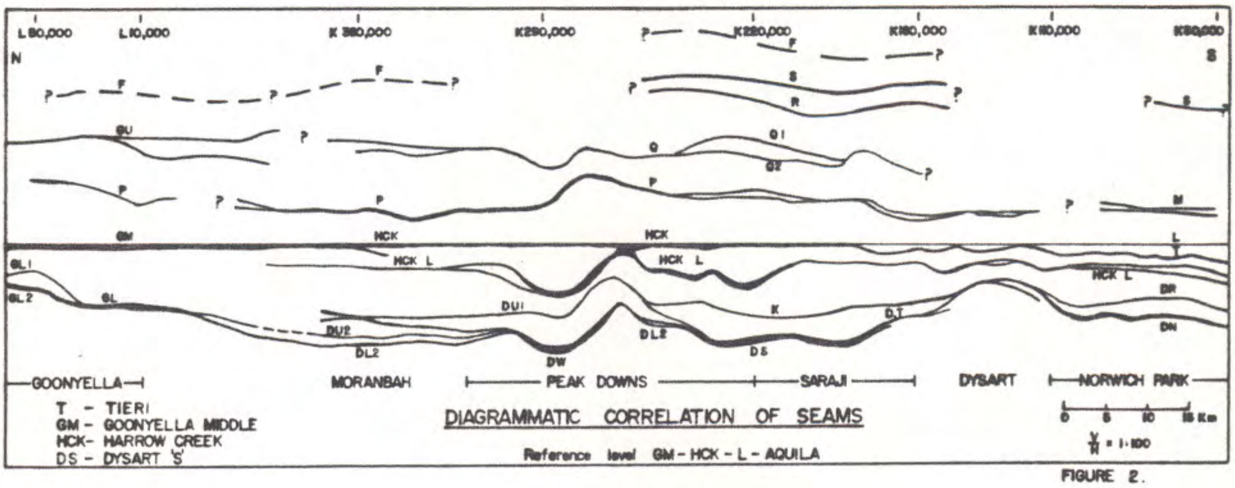
A major overthrust block extends 1 km west of the eastern SCML boundary. The fault zone at the base of the overthrust block consists of a 20 to 35 m thick slice of repeated strata bounded by two main thrust planes dipping at 5° to 15° to the east. The intersection of this thrust zone with the Norwich Structure has produced a complex faulted area which extends 3 km along the eastern SCML.

The Leichhardt South Fault (L.S.F.), a high-angle easterly-dipping normal fault, crosses the SCML at the southern boundary of the complex faulted area and extends 6 km (trending NE-SW) to the western SCML where it swings N-S. Just north of grid line 88000m N an anomalous Dysart-Tieri interseam thickness on the downthrown side of the L.S.F. may infer that the fault developed contemporaneous with deposition of the Tieri and Dysart coal horizons.

The areas of coked Dysart seam and the main structures in SCML 245 are shown in Figure 7.

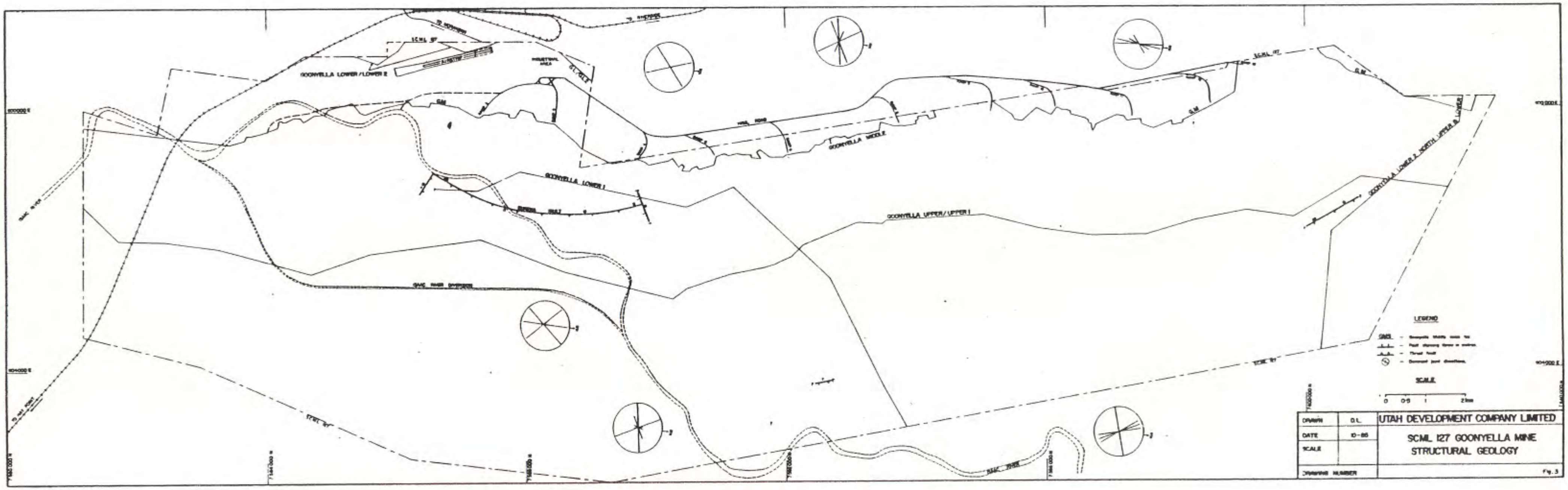


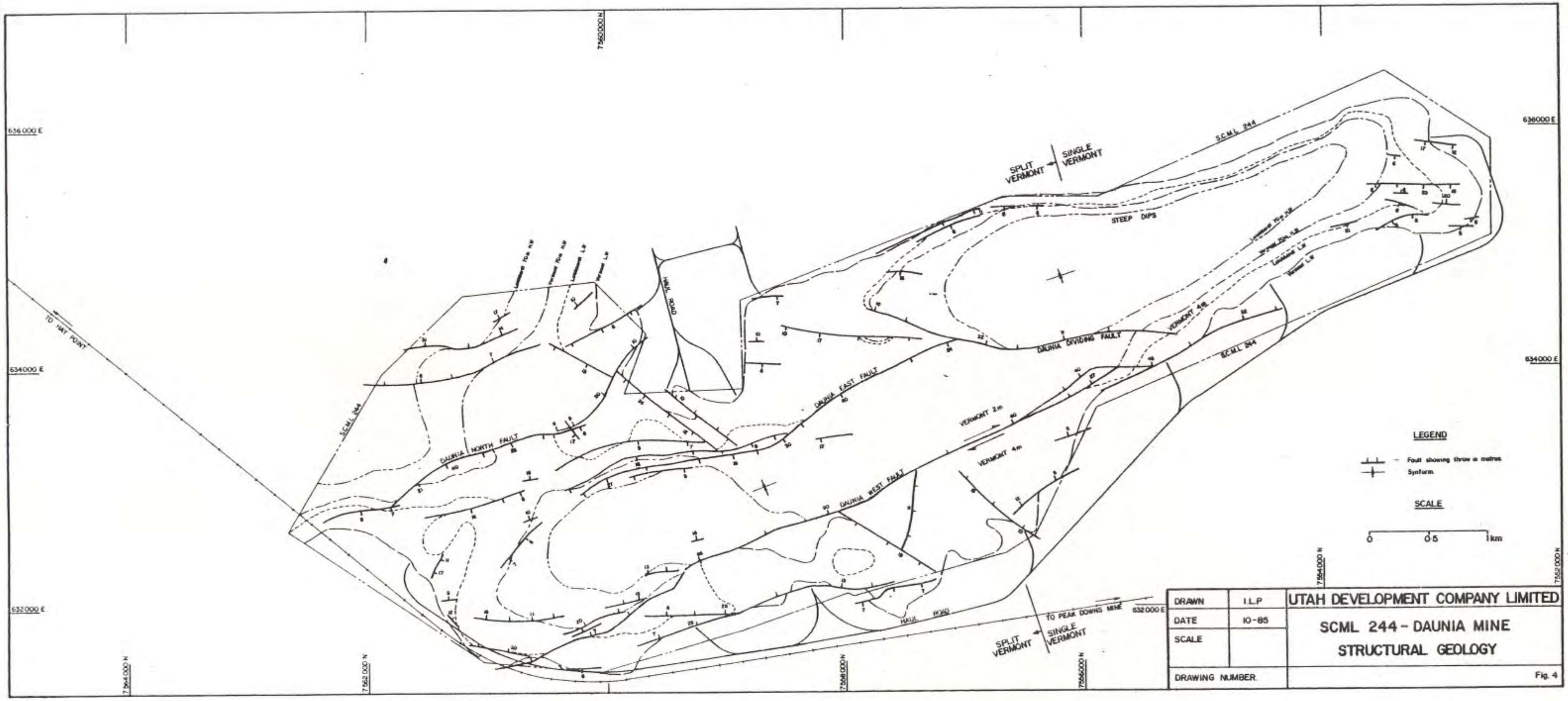
LOCATION MAP
FIGURE I.

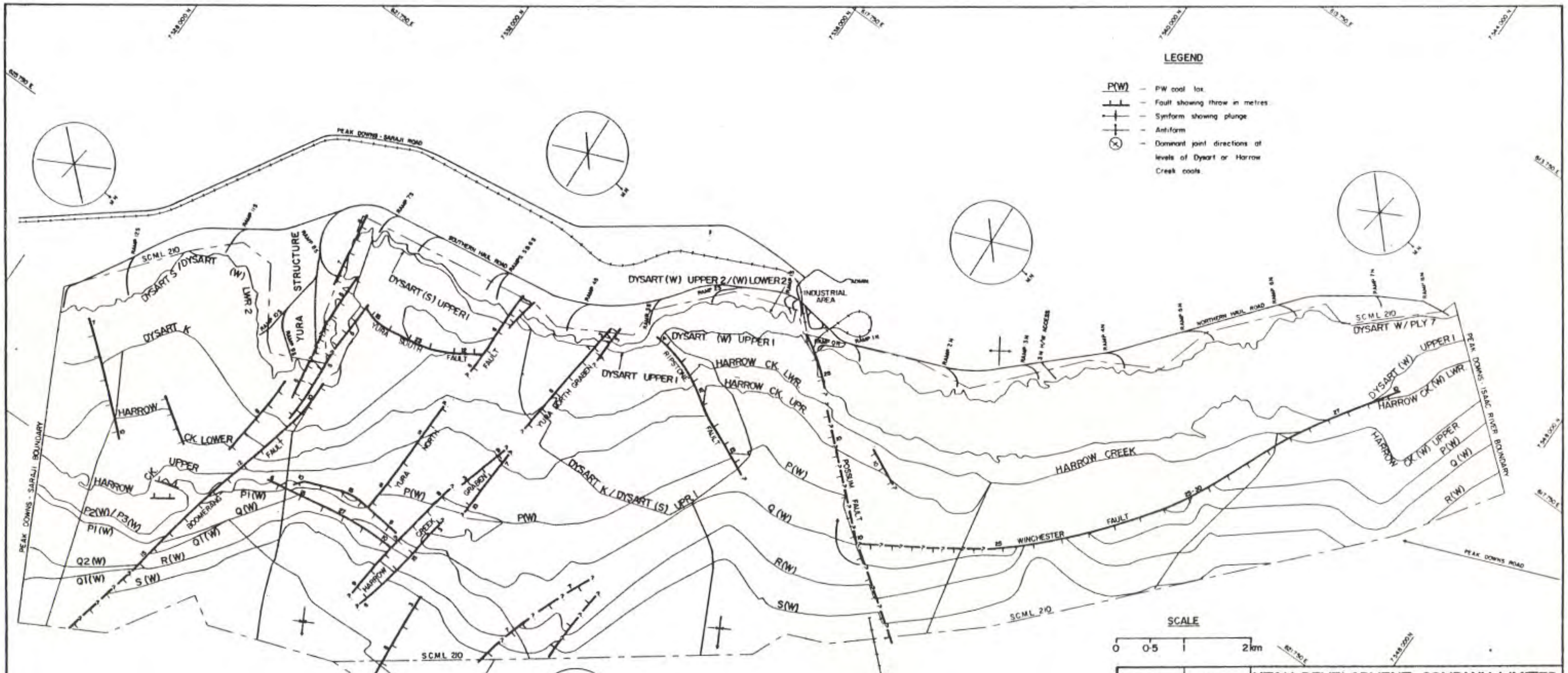


DIAGRAMMATIC CORRELATION OF SEAMS

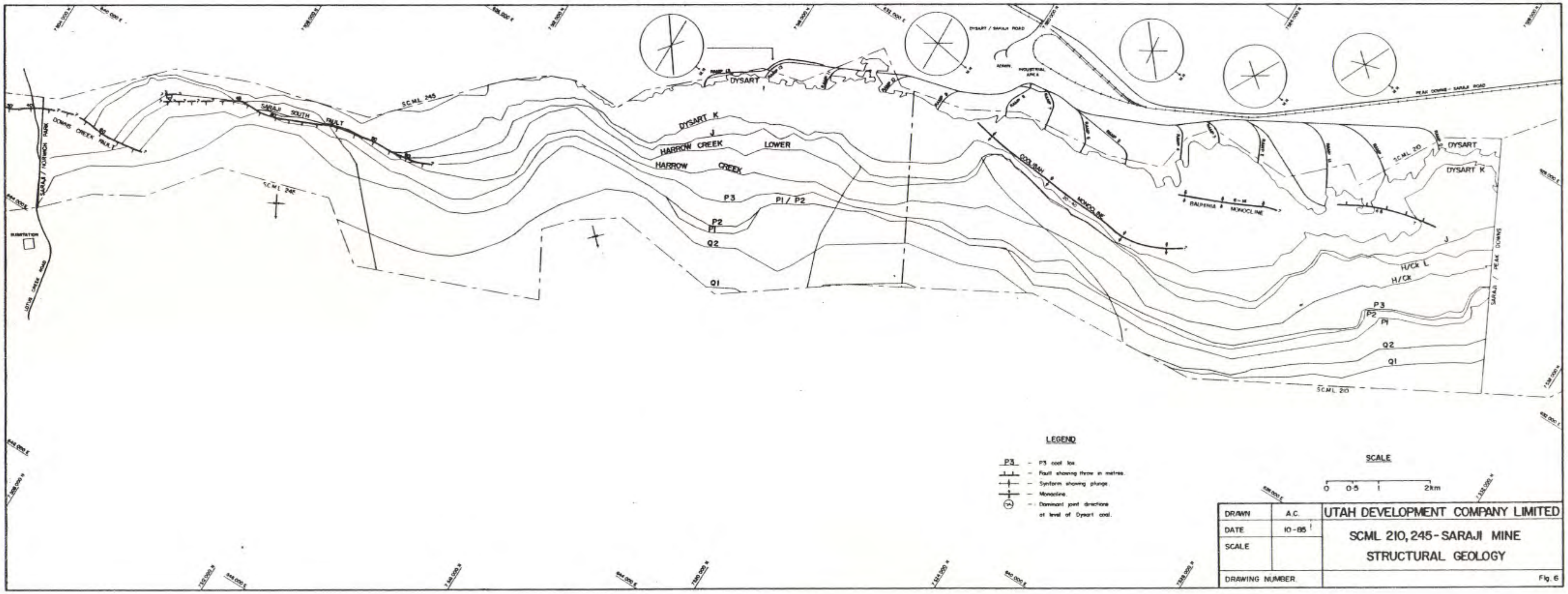
FIGURE 2.


GOONYELLA LOWER / LOWER 2
GOONYELLA MIDDLE
GOONYELLA LOWER 1
GOONYELLA UPPER / UPPER 1
GOONYELLA LOWER 2 NORTH UPPER & LOWER
LEGEND
SCALE
0 0·5 1 2 km
DRAWN
D.L.
DATE
10-86
SCALE
UTAH DEVELOPMENT COMPANY LIMITED
SCML 127 GOONYELLA MINE
STRUCTURAL GEOLOGY
DRAWING NUMBER
Fig. 3

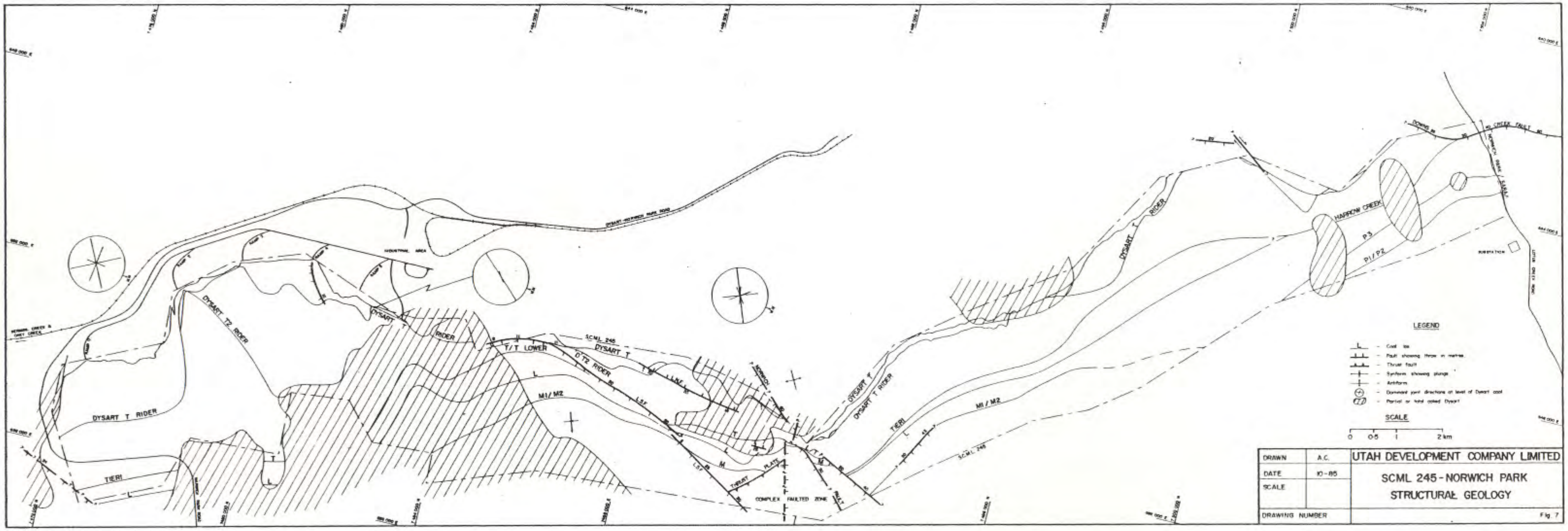

7 560 000 N
7 564 000 N
7 562 000 N
7 558 000 N
7 556 000 N
7 554 000 N
7 552 000 N
636 000 E
634 000 E
632 000 E
SPLIT VERMONT
SINGLE VERMONT
SCML 244
STEEP DIPS
HAUL ROAD
TO HAY POINT
TO PEAK DOWNS MINE
DAUNIA DIVIDING FAULT
DAUNIA EAST FAULT
DAUNIA NORTH FAULT
DAUNIA WEST FAULT
VERMONT 2m
VERMONT 4m
LEGEND
Fault showing throw in metres.
Synform.
SCALE
0 0.5 1km
DRAWN I.L.P
DATE 10-85
SCALE
DRAWING NUMBER.
UTAH DEVELOPMENT COMPANY LIMITED
SCML 244 - DAUNIA MINE
STRUCTURAL GEOLOGY
Fig. 4



DRAWN	D.L.	UTAH DEVELOPMENT COMPANY LIMITED
DATE	10-85	ML 1883, SCML 210 - PEAK DOWNS STRUCTURAL GEOLOGY
SCALE		
DRAWING NUMBER.		Fig. 5



SCML 245
SCML 210
SARAJI SOUTH FAULT
DOWNS CREEK FAULT
SARAJI / NORWICH PARK
DYSART
DYSART K
J
HARROW CREEK
LOWER
HARROW CREEK
P3
P1 / P2
P2
P1
Q2
Q1
COOLIBAH MONOCLINE
BAUHINIA MONOCLINE
H/Ck L
H/Ck
SARAJI / PEAK DOWNS
DYSART / SARAJI ROAD
PEAK DOWNS - SARAJI ROAD
INDUSTRIAL AREA
SUBSTATION
LEGEND
P3 - P3 coal lox.
- Fault showing throw in metres.
- Synform showing plunge.
- Monocline.
- Dominant joint directions at level of Dysart coal.
SCALE
0 0.5 1 2km
DRAWN A.C.
DATE 10-85
SCALE
DRAWING NUMBER
UTAH DEVELOPMENT COMPANY LIMITED
SCML 210, 245 - SARAJI MINE
STRUCTURAL GEOLOGY
Fig. 6



DYSART T2 RIDER
DYSART T RIDER
TIERI
L
T
RIDER
SCML 245
DYSART T
T/T LOWER
D'T2 RIDER
M1/M2
M
THRUST PLATE
COMPLEX FAULTED ZONE
NORWICH
DYSART T
DYSART T RIDER
TIERI
M1 / M2
SCML 245
DYSART T RIDER
HAPPENY CREEK
P3
P1 / P2
SUBSTATION
LEGEND
Coal
Fault showing throw in metres
Thrust fault
Synform showing plunge
Antiform
Dominant joint directions at level of Dysart coal
Partial or total coked Dysart
SCALE
0
0·5
1
2 km
DRAWN
A.C.
DATE
10-85
SCALE
DRAWING NUMBER
UTAH DEVELOPMENT COMPANY LIMITED
SCML 245-NORWICH PARK
STRUCTURAŁ GEOLOGY
Fig. 7