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Geology of the Late Triassic Agnes Water Volcanics, Central Queensland

DJ Purdy

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Queensland Government

ADDRESS FOR CORRESPONDENCE:

DJ Purdy
Geological Survey of Queensland
Mines and Energy
Department of Employment, Economic Development and Innovation
Block A, 80 Meiers Road, Indooroopilly, QLD 4068
Telephone: (07) 3362 9364; International +61 7 3362 9364
Facsimile: (07) 3362 9343; International +61 7 3362 9343
Internet: www.dme.qld.gov.au

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SUMMARY

The Agnes Water Volcanics are a major component of a north-north-west trending belt of Late Triassic Volcanics that extend from south-east to central Queensland. The sequence is divided into three stratigraphically separate volcano-sedimentary facies associations. Basal deposits are grouped as the Mafic to Intermediate Facies Association and comprise basaltic to andesitic lavas, thin dacitic pyroclastic deposits and laterally-restricted fluvial sediments. These rocks have similar compositions to continental arc volcanics and exhibit geochemical variation consistent with fractionation processes. They were emplaced in a relatively high-relief terrain dominated by stratovolcanoes where prevailing effusive eruptions were occasionally interspersed with minor explosive eruptions and reworking of volcanic material.

Emplacement of the overlying Dacitic Facies Association involved a period of dacitic dome growth contemporaneous with fluvial sedimentation, followed by a major explosive eruption. This led to collapse of a large (~20km diameter) caldera and emplacement of thick dacitic to rhyolitic ignimbrite. These rocks do not appear genetically related to the earlier-erupted mafic to intermediate volcanics or the later-erupted rhyolitic volcanics.

Upper parts of the sequence comprise rhyolitic ignimbrite and lavas grouped as the Rhyolitic Facies Association. Emplacement of these rocks followed a period of erosion and sedimentation and involved a second major explosive eruption that produced a larger caldera (~30km diameter) and a thicker, more extensive rhyolitic ignimbrite. Caldera structural margins are apparent on regional geophysical images; these define the Agnes Water Caldera Complex. At ~229Ma, shortly following the second caldera forming event, lava domes and cryptodomes were emplaced during a period of effusive rhyolitic volcanism. The geochemistry of these rocks is consistent with a close relationship to the Mafic to Intermediate Facies Association. The rhyolites may be moderate degree partial melts of basaltic to andesitic material emplaced in the upper crust during the mafic to intermediate phase of magmatism.

The 'continental margin' type magmatism and volcanism expressed by the Agnes Water Volcanics is observed in other volcanic units of possible Late Triassic age. This period is generally regarded as a transition from continental convergent margin magmatism to extension-related magmatism. Further investigation of stratigraphy/volcanic architecture and detailed geochemistry and geochronology are required to understand the timing and dynamics of this event.

Note: All grids and grid references (GR) used throughout this report are based on the Map Grid of Australia, 1994, zone 56.

Keywords: Agnes Water Volcanics, Agnes Water Caldera Complex, volcanology, volcanic stratigraphy, petrography, geochemistry, geochronology, ignimbrite, intracaldera, Late Triassic, Miriam Vale (9249), Rosedale (9248).

INTRODUCTION

Various convergent margin tectonic features associated with numerous phases of advancing and retreating subduction are recorded in the New England Fold Belt (NEFB) of eastern Australia. While the complexities of the Devonian and Carboniferous northern NEFB are still being revealed (*e.g.* Bryan & others, 2001; Murray & Blake, 2005), continental arc magmatism during the Late Permian to middle Triassic, evidenced by the linear distribution and geochemistry of granitoids (*e.g.* Gust & others, 1996), remains fairly well established. Following this period, extensive mafic to silicic volcanics and intrusives were emplaced during the Late Triassic in a broad but roughly linear north-north-east trending belt. This Late Triassic magmatism is generally considered bi-modal and extension-related, marking the earliest phases of Gondwana break-up and a major change in tectonic regime from that of the Permian through Early to Middle Triassic (Stephens, 1991; Gust & others, 1993; Gust & others, 1996; Holcombe & others, 1997; Tang, 2004). Additionally, the low initial Sr ratios of some Late Triassic granites relative to Permo-Triassic intrusives also indicate a major change in source composition (Stephens, 1991; Gust & others, 1996; Murray, 2003). Despite this, the majority of Late Triassic mafic volcanics have subduction-related trace element compositions similar to those of the Early to Middle Triassic (Cranfield & Murray, 1989).

The belt of Late Triassic volcanic and intrusive rocks extends over 500km from northern New South Wales, central Queensland (Figure 1). Major volcanic deposits within this belt include the Agnes Water Volcanics, Native Cat Andesite, Winterbourne Volcanics, Muncon Volcanics, Bobby Volcanics, Aranbanga Volcanic Group and North Arm Volcanic Group. Age constraints on most of these units are poor but most comprise similar lithologies, dominated by mafic-intermediate lavas and silicic ignimbrites and lavas (Table 1). Mineralisation occurs throughout the Late Triassic volcanics, most notably at Mount Rawdon where high-level porphyry Au-Ag mineralisation is hosted in felsic volcaniclastic deposits.

Detailed work within the Late Triassic volcanic sequences is limited to the Aranbanga Volcanic Group (Cranfield, 1989; Stephens, 1991), Winterbourne Volcanics (Murray & others, in preparation —Yarrol Project Report) and part of the North Arm Volcanics (Hutchison, 1992; Chamberlin, 1994). These studies indicate 1) an early period of mafic-intermediate volcanism, 2) development of major silicic caldera systems (Figure 1) associated with emplacement of thick silicic ignimbrites, and 3) effusive eruption of silicic lavas in domes and cryptodomes. The Aranbanga Volcanic Group also features post-caldera eruption of mafic to intermediate lavas. A mafic to silicic-dominated transition is also preserved within basal parts of the Ipswich Basin (Roach, 1996). Detailed work within the Agnes Water Volcanics presented here reveals a similar mafic to silicic sequence and defines another large caldera system.

Previous work within the Agnes Water Volcanics is limited to a descriptive investigation of coastal exposures near Agnes Water (Stevens, 1968) and a general description from early regional mapping work (Ellis & Whitaker, 1976). These studies provide a general framework and highlight the lithological diversity

Table 1. Summary of major Mid- to Late Triassic volcanic units in central and south-east Queensland

Unit/Group	Lithology/Stratigraphy	Age	References
Agnes Water Volcanics	Basaltic to andesitic lavas, minor pyroclastic and epiclastic deposits. Overlain by caldera-forming dacitic ignimbrite then caldera-forming rhyolitic ignimbrite and lavas	228.6±1.7Ma (U-Pb SHRIMP Zircon)	This work; Cross & others, in preparation
Native Cat Andesite	Dominantly adesitic flows, tuff, andesitic to rhyolitic breccia. Minor rhyolitic flows towards top of sequence	Mid- to Late Triassic — stratigraphic relationships, correlation with other units	Murray & others, in preparation (Yarrol Project Report); Kirkegaard & others, 1970
Bobby Volcanics	Basal volcaniclastic deposits dominated by clasts of intermediate to mafic lava. Basaltic to andesitic lavas towards top of sequence. Southern areas include rhyolite and rhyolitic ignimbrite mapped as separate phase — may underlie the intermediate to mafic volcanics.	Mid- to Late Triassic — plant fossils, stratigraphic relationships, correlation with other volcanic units	Murray & others, in preparation (Yarrol Project Report); Dear & others, 1971
Winterbourne Volcanics	Lower Eruption Sequence: Basaltic to andesitic lavas, andesitic breccia, ash, crystal and crystal-lithic tuffs at base. Rhyolitic and trachytic lava and pyroclastic deposits towards top. Upper Eruption Sequence: Rhyolitic ignimbrite, breccias and tuffs, higher proportion of breccia.	218±3Ma (Rb-Sr whole rock)	Murray & others, in preparation (Yarrol Project Report)
Muncon Volcanics	Interbedded volcaniclastic sediments and minor basaltic to andesitic lava in lower part. Basaltic to andesitic lava accompanied by tuffs, volcanic breccia and minor conglomerate in upper part.	Mid- to Late Triassic — plant fossils, stratigraphic relationships, correlation with other units	Murray & others, in preparation (Yarrol Project Report); Dear & others, 1971; Cummings, 1998
Aranbanga Volcanic Group	Rhyolitic ignimbrite and lavas associated with caldera collapse. Basalts and andesites above and below? Rhyolites, extensive late-stage subvolcanic intrusive complex	221±2Ma (Abernethy Basalt K-Ar); 214Ma (Mungore Granite K-Ar); 226.5±1.6Ma (Mungore Granite/g U-Pb SHRIMP Zr)	Cranfield, 1989; Stevens, 1991; Stevens, 1986; Cranfield, 1994; Cross, in preparation
North Arm Volcanic Group	Lower Sequence: Andesitic lavas and debris flows. Middle sequence: rhyolitic ignimbrites and bedded tuffs associated with caldera collapse. Upper sequence: rhyolitic lavas and bedded tuffs	217±2Ma (K-Ar); 213±6Ma (K-Ar)	Ashley & Shaw, 1993; Green & Webb, 1974; Cranfield & Scott, 1993; Chamberlin, 1994; Hutchison, 1992; see Cranfield, 1999 for compilation

preserved within the Agnes Water Volcanics. The opportunity to investigate the Agnes Water Volcanics in more detail arose during the Bundaberg regional mapping project. The results of detailed field investigations, petrography, geochemistry, geochronology and interpretation of geophysical data included in this study provides new mapping and an insight to the internal stratigraphy, development and origin of the Agnes Water Volcanics. These rocks cover a large area and record an important aspect of Late Triassic magmatism in the northern NEFB.

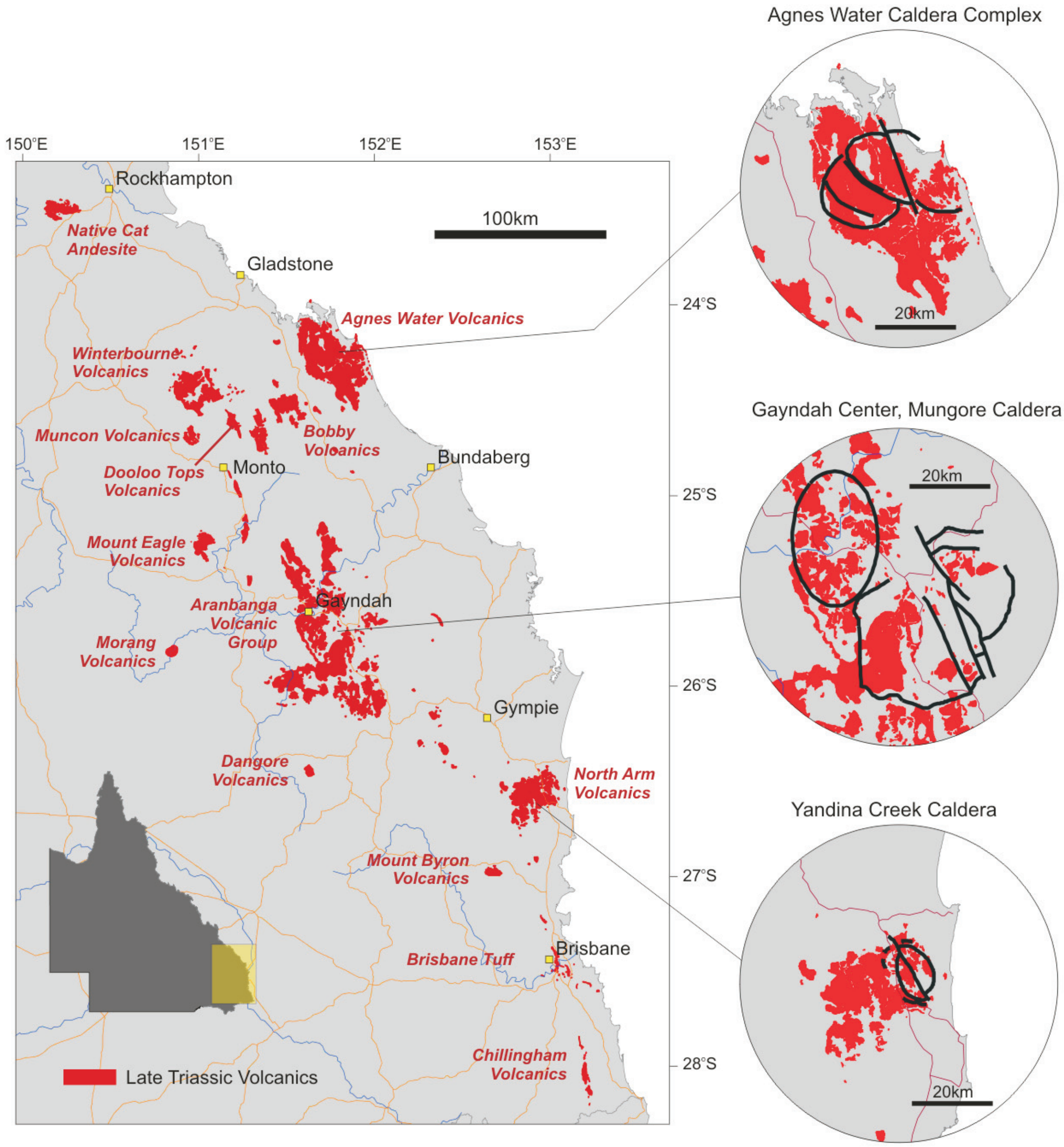


Figure 1. Distribution of Late Triassic Volcanics in central and south-east Queensland. The volcanics form a broad north-north-west trending belt extending for over 500km. Major deposits include the Agnes Water Volcanics, Aranbanga Volcanic Group and North Arm Volcanics. Outlines of three interpreted caldera systems are shown for comparison; Agnes Water Caldera Complex — this study, Gayndah Centre and Mungore Caldera — Stephens, 1991, Yandina Creek Caldera — Chamberlin, 1994; Hutchison, 1992.

REGIONAL MAPPING

Rocks defined as the Agnes Water Volcanics were first described from the excellent coastal exposures in the vicinity of Agnes Water between Round Hill Head and Wreck Rock (Stevens, 1968). That work identified several intermediate to felsic volcanic/sedimentary facies with complex relationships and suggested a Triassic age for the unit (based on the presence of *Dicroidium odontopteroides*). Subsequent regional mapping (Ellis & Whitaker, 1976) defined a large outcrop area and suggested similarities with the Aranbanga Beds (now Aranbanga

Volcanic Group) and Muncon Beds (now divided into several new units — see Murray & others, in preparation — Yarrol Project Report) to the west.

Recent mapping by the Geological Survey of Queensland has refined the distribution of the Agnes Water Volcanics (Figure 2), and defines four major subunits: 1) Rvw_m — Mafic to intermediate lavas and volcaniclastic deposits, 2) Rvw_{id} — Dacitic ignimbrite and volcaniclastic sediments, 3) Rvw_{ir} — Rhyolitic ignimbrite, and 4) Rvw_r — Coherent and autoclastic rhyolite to dacite. Additionally, in collaboration with Geoscience Australia, the Geological Survey of Queensland has obtained a SHRIMP U-Pb zircon crystallisation age of 228.6±1.7Ma for coherent rhyolite collected near Arthurs Seat (Table 2). This rhyolite forms part of a large dome/cryptodome (part of subunit Rvw_r) and represents the latest phases of volcanism associated with the Agnes Water Volcanics.

As currently mapped, the Agnes Water Volcanics cover an area of ~1000km^2 and occupy much of the Miriam Vale 1:100 000 map sheet area. They crop out in a broad north-north-west trending band that extends from Baffle Creek township, north over 60km to Rodds Peninsula, and from the vicinity of Miriam Vale in the west to the coast. Central parts of this region form rugged, heavily vegetated terrain with high relief whereas northern and southern parts have more subdued topography with open grassy pastures.

Throughout this distribution, the Agnes Water Volcanics overlie or are faulted against low-grade metasediments of the Carboniferous Shoalwater Formation as well as various sediments of the Permian Gympie Group and Triassic Brooweena Formation (Figure 1). In a small area between Deepwater Creek and the coastline, ~ 3km SE of Toowong Hill (in vicinity of BB3879 — GR 396055, 7303525), rhyolitic ignimbrite of the Agnes Water Volcanics is overlain by a quartzose sandstone mapped as Late Triassic – Early Jurassic Myrtle Creek Sandstone. Elsewhere, the Agnes Water Volcanics are overlain by Quaternary-age alluvial and marine sediments.

Relationships with the many intrusive units of the region are more difficult to resolve. Recent geochronology (Table 2) indicates high-grade metamorphism at ~275Ma followed by two distinct episodes of intrusive activity. Magmatism associated with the first episode was bimodal and occurred in the Late Permian at ~270Ma to ~260Ma, significantly earlier than deposition of the Agnes Water Volcanics. The second episode was in the Late Triassic at ~225Ma. These later intrusions overlap in age or are slightly younger than the Agnes Water Volcanics and mostly comprise small, high-level (miarolitic), leucocratic, felsic granitoid bodies. Several of these intrusions are spatially (and possibly genetically) associated with the Agnes Water Volcanics (*e.g.* Eurimbula Granite).

In the vicinity of the Bundaberg project region, volcanic units of possible equivalence to the Agnes Water Volcanics include the Mount Whacogo Volcanics, Coulston Volcanics and Bobby Volcanics. The Mount Whacogo Volcanics crop out as small remnants on the Rosedale 1:100 000 map sheet and include a wide variety of coherent and volcaniclastic facies that range in composition from basalt to rhyolite. Rocks mapped as Coulston Volcanics

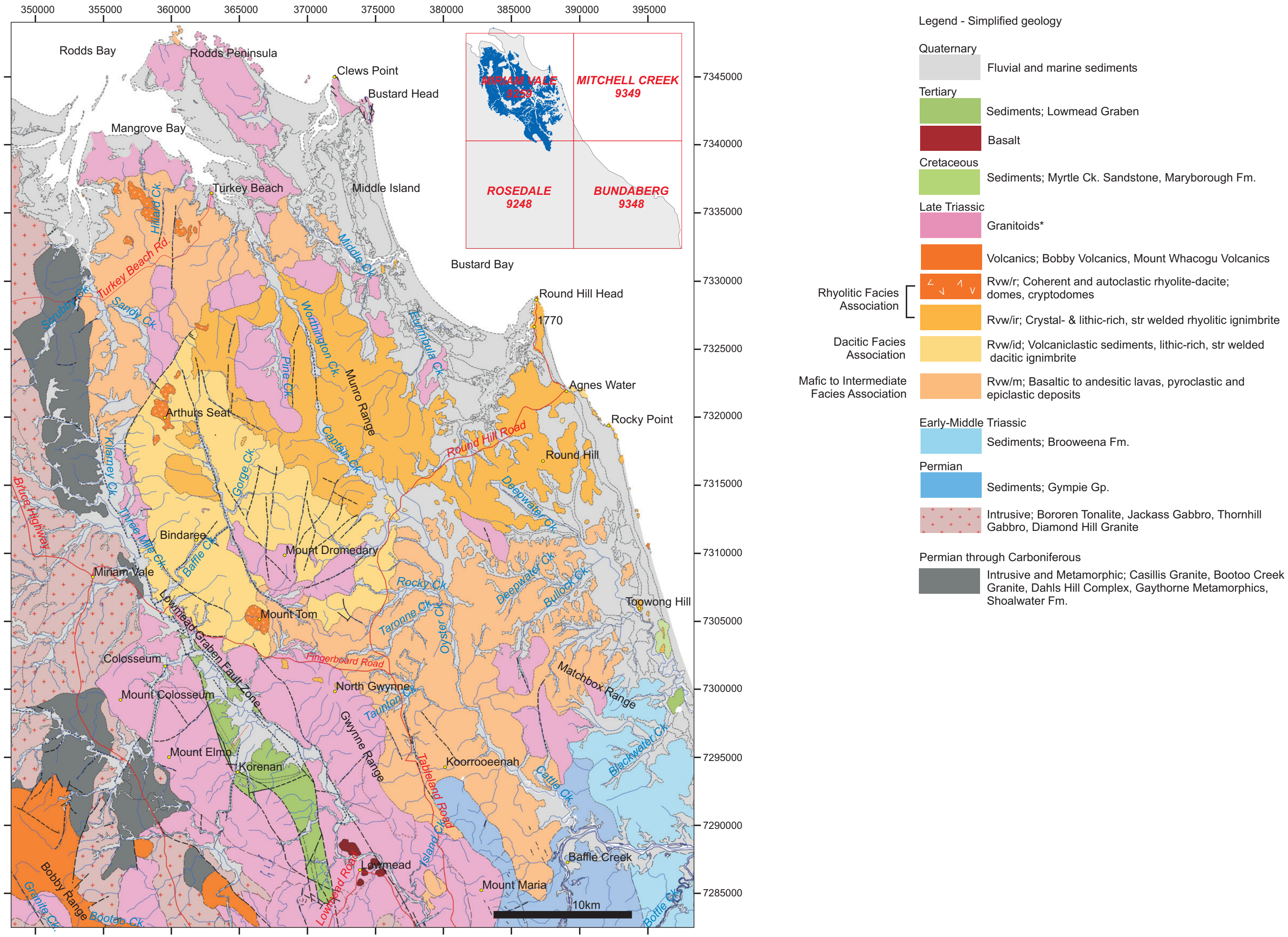


Figure 2. Simplified geology of the Agnes Water – Miriam Vale area. Agnes Water Volcanics are divided into four subunits. Map is simplified from the Miriam Vale (9249) and Rosedale (9248) 1:100 000 map sheets (see inset).
*Late Triassic granitoids include: Bustard head Granodiorite, Colosseum Quartz Monzodiorite, Edinburgh Mountains Granite, Eurimbula Granite, Fingerboard Road Granite, Matchbox Range Granite, Mount Elmo Granite, North Gwynne Granite, Tolson Creek Igneous Complex, Turkey Beach Granite, Ulangool Granite, Rodds Peninsula Granite, Smallcombes Road Granite, Tinami Valley Granodiorite, John Clifford Road Granite, Rosevale Granite, Borilla Granite, Grevillea Granite, Glenelm Granite, Hawthorne Granite, Molangul Granite.

Table 2. Summary of recent zircon U-Pb SHRIMP geochronology from the Agnes Water Volcanics vicinity and Gayndah area

Rock Unit	Lithology sampled	Easting	Northing	Sheet 100k	Age	±	N	Comments	Source
Glen Eva Complex	Massive to weakly foliated biotite-muscovite tonalitic orthogneiss	350102	7265721	Rosedale	276.8	4.6	9	Metamorphism	Carson & others, 2006
Glen Eva Complex	Migmatitic biotite granitic gneiss	354800	7257777	Rosedale	274.9	3.2	11	Metamorphism	Carson & others, 2006
Cassillis Metamorphics	Biotite granitic orthogneiss	356222	7287142	Rosedale	282.4	2.5	1	Metamorphism	Carson & others, 2006
New Moonta Diorite	Equigranular biotite-hornblende-titanite quartz diorite	369895	7228541	Mount Perry	269.2	1.6	28	Magmatic	Carson & others, 2006
Hazeldene Quartz Diorite	Orthopyroxene quartz diorite	357506	7259020	Rosedale	268.7	1.7	18	Magmatic	Carson & others, 2006
Gaeta Diorite	Orthopyroxene (± clinopyroxene?), hornblende, plagioclase (± biotite) diorite	357640	7254885	Rosedale	262.6	2.5	20	Magmatic	Carson & others, 2006
Wolca Granite	Melanocratic biotite granodiorite	357792	7211175	Mount Perry	262.9	1.6	23	Magmatic	Carson & others, 2006
Tenningering Granodiorite	Biotite-muscovite leuco-granodiorite	362711	7213078	Mount Perry	259	2	30	Magmatic	Carson & others, 2006
Moolyung Granodiorite	Massive, hornblende, titanite granodiorite	395696	7257816	Rosedale	227.5	1.5	27	Magmatic	Carson & others, 2006
Moolboolaman Granodiorite	Massive, equigranular, hornblende, biotite granodiorite	377498	7233201	Rosedale	224	1.2	30	Magmatic	Carson & others, 2006
Moolyung Granodiorite (Eastern Pluton)	Medium-grained, porphyritic, miarolitic, clinopyroxene, biotite, hornblende granodiorite	399281	7260692	Bundaberg	225	2	33	Magmatic	Black, unpublished
Colosseum Quartz Monzodiorite	Fine- to medium-grained, hornblende quartz monzodiorite	361737	7300152	Miriam Vale	225	1.8	41	Magmatic	Black, unpublished
Mount Bania Granite	Fine- to medium-grained, granophyric, porphyritic, biotite, hornblende monzogranite	355096	7241250	Rosedale	228.5	2.1	30	Magmatic	Black, unpublished
Captain Osborne Tonalite	Medium-grained, porphyritic, sphene, hornblende, biotite tonalite	363165	7241361	Rosedale	259.8	2.1	35	Magmatic	Black, unpublished
Eurimbula Granite	Granophyric, miarolitic biotite granite	363234	7327774	Miriam Vale	226.4	2.3	17	Magmatic	Cross & others, in preparation
Agnes Water Volcanics/r	Moderately porphyritic, coherent, flow banded rhyolite	358981	7321017	Miriam Vale	228.6	1.7	19	Magmatic	Cross & others, in preparation
Mount Marcella Volcanics	Pyroxene andesite	385951	7139487	Gayndah	230.7	3.2	5	Magmatic — few zircons	Cross, in preparation
Mungore Granite/g	Fine to medium-grained miarolitic, granophyric bt, hbl syenogranite	405177	7172465	Biggenden	226.5	1.6	26	Magmatic	Cross, in preparation

comprise mafic to intermediate volcaniclastic and coherent deposits that crop out in a small area around Mount Coulston ~20km north-west of Miriam Vale. The Bobby Volcanics crop out over a larger area to the south-west of Miriam Vale and comprise thick sequences of volcaniclastic sediments, basaltic to andesitic lavas with extensive autoclastic deposits and in upper parts, more evolved dacitic to rhyolitic pyroclastic and coherent deposits. This unit is the subject of on-going investigations.

STRATIGRAPHY

The Agnes Water Volcanics sequence comprises three broad but clearly separate volcano-sedimentary facies associations. These correspond to the subunits defined in regional mapping work. Subunit Rvw_m represents a basal Mafic to Intermediate Facies Association, subunit Rvw_{id} forms a Dacitic Facies Association and subunits Rvw_{ir} and Rvw_r comprise an upper Rhyolitic Facies Association. Each association comprises various volcanic and sedimentary facies. These are grouped on the basis of composition and stratigraphic position and each represent significant changes in the composition of erupted products, as well as the styles of volcanism and sedimentation during emplacement of the Agnes Water Volcanics.

MAFIC TO INTERMEDIATE FACIES ASSOCIATION

Flat-lying to gently undulating sequences of mafic to intermediate volcanics and volcaniclastics comprise basal parts of the Agnes Water Volcanics sequence. These deposits are widespread, extending from Rodds Peninsula in the north over approximately 60km to the vicinity of Koorrooeenah to the south (Figure 2). They are faulted against (and probably directly overlie) low grade metasediments of the Shoalwater Formation and are overlain by other sub-units of the Agnes Water Volcanics. The thickness of the Mafic to Intermediate Facies Association is difficult to estimate. In relatively high-relief areas, reasonably continuous sequences with no top or bottom exposed reach thicknesses exceeding 150m. However, it should be noted that upon deposition, the thickness of this association probably varied substantially over relatively short distances. A small but continuous sequence of volcaniclastic sediments, ignimbrite and coherent lavas from the Mafic to Intermediate Facies Association is exposed in low hills ~6km southwest of Turkey Beach (in vicinity of BDDP260 — GR 356950, 7333976). The volcanic and sedimentary facies in this sequence (Figure 3) are representative of the Mafic to Intermediate Facies Association.

Lavas

The Mafic to Intermediate Facies Association is dominated by sequences of coalesced lava flows ranging in composition from basalt to andesite. Interflow facies (eg. palaeosol and autoclastic domains) are poorly preserved but individual lava flows are roughly defined by mineralogy and vesicularity changes that correlate with topographic breaks. These indicate that individual flows are generally <10m thick.

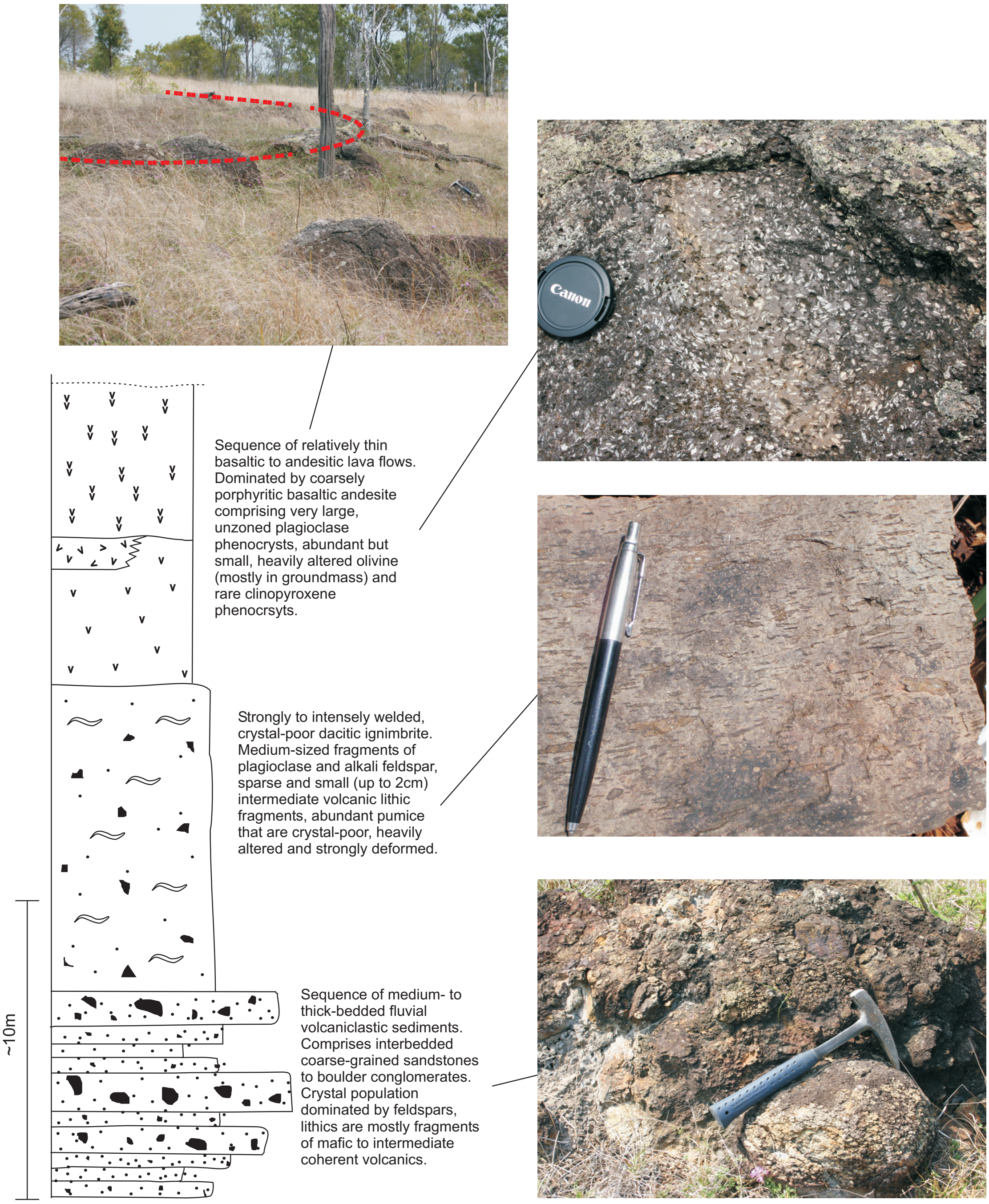


Figure 3. Stratigraphic section for part of the Mafic to Intermediate Facies Association. Base comprises various fluvial volcaniclastic sediments with abundant fragments of coherent mafic to intermediate volcanics. Sediments are overlain by a thin, strongly welded, crystal-poor dacitic ignimbrite. This ignimbrite is quite distinct and locally forms a marker horizon. Upper parts of sequence comprise numerous thin basaltic to andesitic lavas. The coarsely porphyritic lavas here are common throughout the Agnes Water Volcanics subunit Rvw_m and as clasts throughout other subunits. Section crops out in vicinity of BDDP260 — GR 356845, 7333801.

The basaltic to andesitic lavas exhibit a variety of textures ranging from coarsely porphyritic to aphanitic and from massive to highly vesicular (amygdaloidal). The mineralogy of these lavas is also variable but three general types based on major phenocryst phases are defined: 1) plagioclase- and clinopyroxene-rich lavas, 2) plagioclase-rich lavas, and 3) plagioclase- and amphibole-rich lavas. Each lava type is not restricted to particular regions or stratigraphic intervals; the division is made simply for the purposes of description. Most lavas in each type are amygdaloidal although the size and abundance of amygdales vary substantially on small scales. Amygdales are filled with combinations of chlorite, calcite and quartz and in some cases appear stretched.

Plagioclase and clinopyroxene-rich lavas (Figure 4a) cover a broad grouping and represent the most abundant lava type. These are mostly moderately porphyritic and comprise abundant medium-sized plagioclase phenocrysts, varying abundances of medium to small clinopyroxene phenocrysts and plagioclase/clinopyroxene glomocrysts. Groundmass comprises fine plagioclase laths (flow-aligned in many samples), opaque phases and small clinopyroxene. Some lavas with higher clinopyroxene abundance also contain olivine as phenocrysts, or more commonly, microphenocrysts. Plagioclase-rich lavas are generally coarsely porphyritic (Figure 4b) and comprise very large and abundant, unzoned to weakly zoned plagioclase phenocrysts in a groundmass of fine, occasionally flow-aligned plagioclase laths, opaque phases and minor, fine clinopyroxene ± olivine. Most finer-grained lavas are plagioclase-rich and comprise very fine plagioclase laths and possibly minor, very fine pyroxenes either in flow-alignment or a structureless framework. Some plagioclase-rich lavas comprise two or more distinct textural (and probably compositional) domains (Figure 4c). Plagioclase and amphibole-rich lavas are sparse and generally appear more felsic than other lava types. They comprise moderately abundant, large and unzoned plagioclase phenocrysts, varying abundances of highly altered amphibole phenocrysts, plagioclase/amphibole glomerocrysts and rare alkali feldspar phenocrysts. In most cases, amphiboles are completely altered leaving only relict rims. These lavas also show some flow-alignment of very fine plagioclase laths in the groundmass.

The various textural and mineralogical lava types described above form a major lithic component of epiclastic deposits in other parts of the Mafic to Intermediate Facies Association and in parts of the overlying Dacitic and Rhyolitic Facies Associations.

Epiclastic sediments

Epiclastic deposits are locally interspersed with the basaltic to andesitic lavas in the Mafic to Intermediate Facies Association. Epiclastic material preserved in a representative sequence of the Mafic to Intermediate Facies Association (Figure 3) comprises medium- to thickly-bedded fluvial volcaniclastic sediments >7m thick ranging from medium-grained sandstones to boulder conglomerates. These sediments are dominated by sub-angular to sub-rounded fragments of intermediate to mafic coherent volcanics with textures ranging from aphanitic to finely crystalline and coarsely porphyritic (Figure 4d). Fragments of plagioclase crystals are also common in the sediments and moderately vesicular scoriaceous material is present in many samples but highly variable in abundance. Quartz and alkali feldspars are entirely absent and matrix material is generally highly altered (chlorite). The epiclastic sediments are overlain by a dacitic ignimbrite (see below) and mafic to intermediate lavas. These sediments represent re-working of mafic to intermediate coherent volcanics and therefore do not represent the base of the sequence (*i.e.* they must be preceded by mafic-intermediate volcanism).

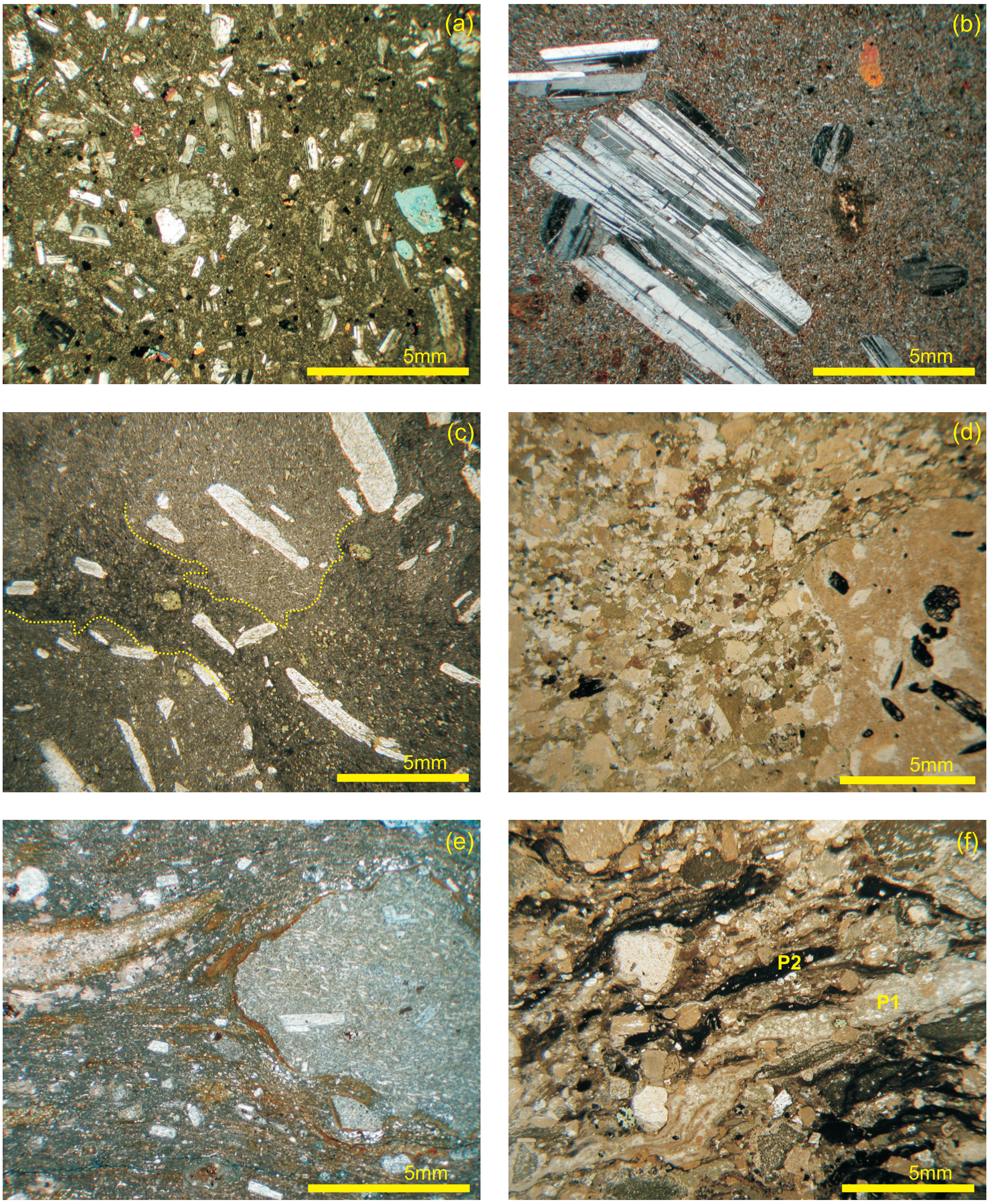


Figure 4. Petrography of the Mafic to Intermediate Facies Association.
a) Plagioclase and clinopyroxene-rich lava comprises moderately abundant, medium-sized plagioclase and clinopyroxene phenocrysts in fine-grained matrix (x-polars, sample BDDP117 — GR 361492, 7328450),
b) Plagioclase-rich lava comprises very large and abundant, unzoned plagioclase phenocrysts and less abundant and much smaller clinopyroxene and altered olivine as small phenocrysts and matrix phases (x-polars, sample BDDP248 — GR 356846, 7333471),
c) Plagioclase-rich lava with two distinct textural/compositional domains (ppl, sample QFG5100B — GR 374534, 7303898),
d) Epiclastic sandstone comprising sub-angular fragments of mafic to intermediate volcanics (including one large fragment) and fragments of plagioclase — no quartz (ppl, sample BDDP260a — GR 356950, 7333976),
e) Crystal-poor, strongly welded dacitic ignimbrite. Comprises scattered, small fragments of plagioclase and alkali feldspar, small but abundant, strongly deformed, crystal-poor pumice and one porphyritic mafic-intermediate lithic fragment (x-polars, sample BDDP258 — GR 357107, 7334382),
f) Strongly welded, crystal- and pumice-rich dacitic to andesitic ignimbrite. Note two distinctly different pumice types — light P1 and dark P2 (ppl, sample BDDP250 — GR 354142, 7339554).

In southern regions, epiclastic deposits are also common but individual sequences are poorly constrained due to limited exposure. These sediments range in grainsize up to boulder conglomerates and comprise abundant sub-rounded to sub-angular clasts of mafic to intermediate coherent lavas.

Pyroclastic deposits

A relatively thin (~10m), intensely welded, ash- to pumice-rich (Figure 5) ignimbrite crops out in northern regions amongst epiclastic sediments and lavas as discussed above (Figure 3). This ignimbrite is highly altered but comprises abundant strongly deformed, crystal-poor relict pumice clasts, sparse plagioclase phenocryst fragments and rare mafic volcanic lithic clasts (Figure 4e). Although dacitic in composition, this ignimbrite is clearly part of the Mafic to Intermediate Facies Association and is overlain by a variety of relatively thin basaltic lavas.

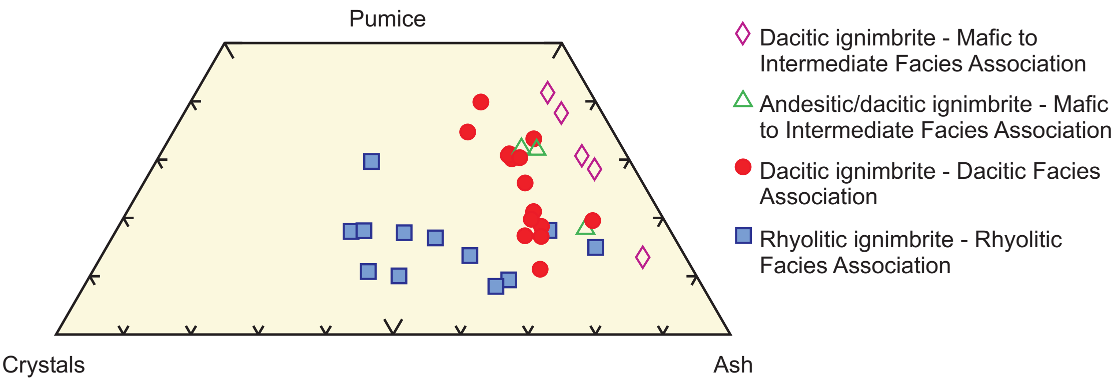


Figure 5. Agnes Water Volcanics ignimbrite components. Data for each facies association exhibit scatter in pumice/ash content. Ignimbrite from Rhyolitic Facies Association is relatively crystal-rich. Ignimbrite from the Mafic to Intermediate Facies Association is crystal-poor. Data from point counting ~800 points/thin section representing a spacing of ~1.5mm.

Higher parts of the sequence in this area also include relatively mafic (probably andesitic to dacitic), lithic- and crystal-rich, scoriaceous ignimbrite. This ignimbrite is highly altered and has a phenocryst assemblage dominated by plagioclase and alkali feldspar, although some evidence (*e.g.* secondary oxide- and chlorite-rich patches) exists for former presence of mafic phases. It contains varying proportions of two distinct juvenile components. One is light in colour, sparsely porphyritic (plagioclase) and thoroughly devitrified, the other is dark in colour, aphanitic to weakly porphyritic, moderately to poorly vesicular and highly altered (Figure 4f). Lithic clasts are abundant in the ignimbrite and include various mafic to intermediate, finely crystalline to coarsely porphyritic (plagioclase) and amygdaloidal coherent volcanics.

In southern regions, a poorly outcropping deposit that appears to comprise irregularly-shaped poorly vesiculated juvenile fragments crops out in the vicinity of epiclastic deposits and coherent lavas (BDDP215 — GR 380587, 7296246). This may represent a spatter-type facies.

DACITIC FACIES ASSOCIATION

The dacitic facies association comprises epiclastic sediments, ignimbrite and coherent to autoclastic dacite. These primarily crop out in the Baffle Creek headwaters region on Bindaree Station (Figure 2) where they directly overlie lavas of the Mafic to Intermediate Facies Association. However, this lower contact and the upper contact with rhyolitic ignimbrite are complex. In the Westwood Range, just north of Bindaree Homestead, the Dacitic Facies Association probably exceeds 250m thickness, almost all of which comprises lithic-rich dacitic ignimbrite. Isolated exposures of dacitic ignimbrite also crop out to the east of this main body in the Round Hill and Workmans Beach areas. These exposures are probably part of the same unit and represent erosional remnants.

Epiclastic sediments

In many places the base of the Dacitic Facies Association is marked by packages of fluvial sediments. These range from medium-bedded, medium- to coarse-grained sandstones (Figure 6a) and pebbly sandstones through to massive cobble and boulder conglomerates. All sediments contain high proportions of sub-angular volcanic lithic clasts dominated by fragments of coherent dacite (Figure 6b). These clasts are sparsely porphyritic (feldspar) and generally have formerly glassy, spherulitic, micropoikiolitic or granophyric groundmass textures. Many exhibit perlitic fracturing and fine flow banding. Clasts of porphyritic and finely crystalline coherent mafic to intermediate lavas are also common but subordinate to dacitic clasts. Most sediments also comprise high proportions of angular feldspar fragments, quartz is very rare or entirely absent and pumaceous clasts are relatively sparse. Relict glass shards are evident in the matrix of some sediments.

An extensive sequence of volcaniclastic sediments at the top of the Dacitic Facies Association crops out in the Workmans Beach area near Agnes Water (Appendix 1). This sequence unconformably overlies dacitic ignimbrite and is dominated by poorly sorted, volcanic lithic-rich, bouldery conglomerates. These deposits form thick (10s of metres) sequences, commonly with diffuse stratification defined by minor grainsize and/or fabric variation. Although poorly defined, individual strata mostly appear <1m thick. Clasts within most deposits are sub-angular to sub-rounded and range up to several meters in diameter. Towards the base, clasts are almost exclusively dacitic ignimbrite but compositions become more variable and include abundant fragments of coherent dacite and mafic to intermediate volcanics and volcaniclastics, higher in the sequence. The largest clasts, including one block ~25m in length, are always dacitic ignimbrite, identical to that in adjacent exposures. Matrix material comprises medium- to coarse-grained sand and most deposits are matrix supported

Relatively thin packages of sandstone, pebbly sandstone and carbonaceous siltstone are interbedded with breccias at several intervals. At one location, these finer-grained sediments contain plant remains (Figure 6c) including tree stumps and roots, possibly in growth position, and various leaf material including

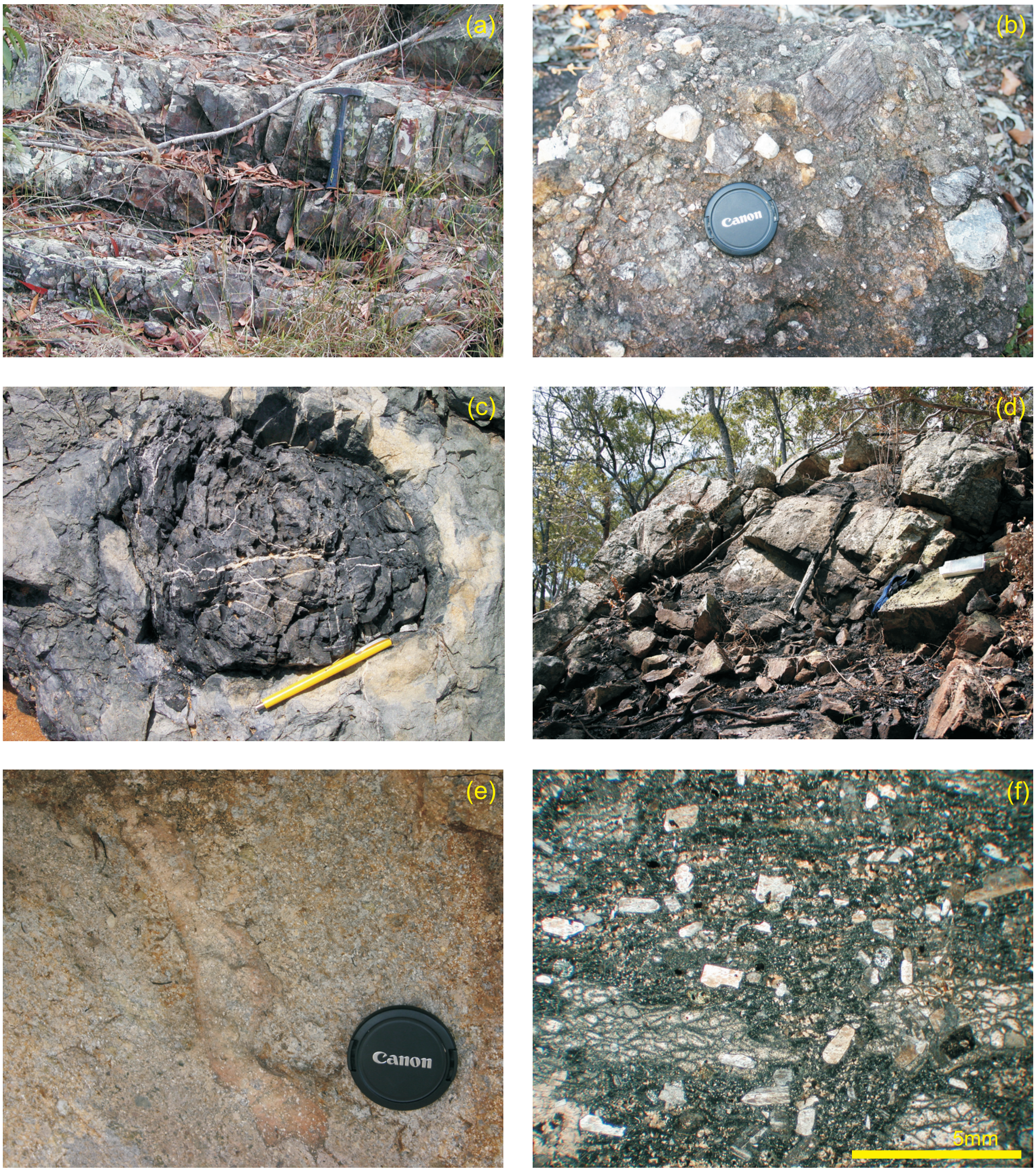


Figure 6. Examples of deposits from the Dacitic Facies Association.
a) Well-bedded fine- to medium-grained volcaniclastic sandstone from basal part of the association. Rocks in this sequence vary down to siltstone. The shallow dip is typical of the Agnes Water Volcanics (BDDP164 — GR 365680, 7316598),
b) Cobble conglomerate from basal part of the Dacitic Facies Association. Most clasts are flow banded fragments of coherent dacite (BDDP289 — GR 361838, 7310833),
c) Woody plant remains amongst volcaniclastic sediments in coastal exposures near Workmans Beach, Agnes Waters,
d) Large blocky outcrop of lower part of dacitic ignimbrite (BDDP288 — GR 362213, 7311752),
e) Close up of BDDP288 (Figure 6d) showing large, deformed pumice fragment,
f) Photomicrograph of dacitic ignimbrite. Note moderately abundant, small fragments of feldspars and medium-sized, devitrified pumice fragments exhibiting perlitic fracture (x-polars, sample BDDP158 — GR 363560, 7316407).

specimens of *Dicroidium odontopteroides* and *Heidiphyllum elongatum* (Dr. Stephen McLoughlin, personal communication). Soft sediment deformation is commonly observed in these coastal exposures and strongly affects finer-grained beds. Further details regarding the stratigraphy of coastal exposures near Agnes Water are presented in Appendix 1.

Dacitic ignimbrite

Through the main outcropping region, dacitic ignimbrite directly overlies epiclastic sediments and forms a major component of the Agnes Water Volcanics. This ignimbrite is dominantly crystal- to lithic-rich (Figure 5), strongly to intensely welded and roughly columnar jointed. Typical dacitic ignimbrite is shown in outcrop, hand sample and thin section in Figures 6d to 6f. Variable style and extent of alteration and variable lithic clast content give the ignimbrite different appearances, but the modal mineralogy remains fairly consistent throughout. Assemblages are dominated by unzoned plagioclase and weakly embayed alkali feldspar. These generally occur as small to medium-sized broken fragments but appear larger and more euhedral within larger pumice clasts. Evidence for highly altered mafic phases including small biotite and amphibole is present in some fresher samples of the ignimbrite. These are replaced by opaque oxides and chlorite and comprise a minor component of the mineral assemblage.

Pumice clasts are moderately abundant and easily identifiable in fresher samples of the dacitic ignimbrite. They range up to ~25cm x 4cm (Figure 6e) but most are small (<~3cm), deformed and relatively crystal poor (Figure 6f). Pumice glass is thoroughly devitrified and textures vary between samples. Spherical and axiolitic spherulites are common and the interior parts of some pumice exhibit granophyric recrystallisation textures. Some pumice and possibly some glassy groundmass domains exhibit perlitic fracture (Figure 6f). One sample from the base of the dacitic ignimbrite where it directly overlies fluvial sediments (BDDP165 — GR 365556, 7316722) contains pumices that display two distinct devitrification styles possibly reflecting two pumice populations (compositions). All other dacitic ignimbrite samples contain only one pumice type. The groundmass of fresher dacitic ignimbrite samples is very rich in moderately to strongly welded relict glass shards, small pumice fragments and small crystal fragments.

Lithic clasts generally form a major component of the dacitic ignimbrite and range in size up to ~3m, although most are <10cm in diameter. Two major clast types are present in most ignimbrite samples: 1) sparsely porphyritic or aphanitic, occasionally flow banded, coherent dacite with formerly glassy, devitrified groundmass or less commonly very finely crystalline groundmass, and 2) various mafic to intermediate coherent volcanic fragments ranging from aphanitic and highly amygdaloidal to finely crystalline and porphyritic. Coherent dacite fragments are generally larger and more abundant than mafic to intermediate fragments and lithic clasts in general may be larger in areas closer to Bindaree Homestead.

Coherent and autoclastic dacite to rhyolite

Coherent and autoclastic dacite to rhyolite appears relatively uncommon within the Dacitic Facies Association and is restricted to isolated bodies in the vicinity of Workmans Beach near Agnes Water and syndepositional intrusions in the Bindaree Station area. However, the abundance of coherent dacite lithic clasts within epiclastic sediments and ignimbrite highlights the close association between coherent and clastic dacite facies.

At the south-eastern end of Workmans Beach, a partially effusive dacitic cryptodome intrudes volcaniclastic sediments (Appendix 1). This coherent dacite is sparsely porphyritic and intricately flow banded. It comprises sparse, small to medium-sized, euhedral alkali feldspar and lesser plagioclase phenocrysts in a devitrified groundmass that exhibits some micropoikiolitic texture (possibly representing originally glassier bands). Small, non-flow banded inclusions with similar modal mineralogy to the coherent dacite are relatively abundant. Volcaniclastic sediments immediately adjacent to the dome show evidence for some disruption during dome emplacement. Debris from the dome forms a major component of coarse volcaniclastic deposits in the vicinity suggesting that it formed a significant topographic high. Similar flow banded coherent dacites with autoclastic margins also crop out along the rocky coastline immediately south of Workmans Beach and overlie coarse volcaniclastic sediments.

Further west, on Bindaree Station in the vicinity of Gorge Creek, and also near the junction of Baffle Creek and Tolson Creek, coherent dacite to rhyolite occurs in both blocky and fluidal peperite exposures (Figure 7). Coherent domains of these deposits comprise aphanitic to sparsely porphyritic dacite to rhyolite. Clastic domains comprise epiclastic sediments that represent the base of the Dacitic Facies Association and/or dacitic ignimbrite.

RHYOLITIC FACIES ASSOCIATION

The Rhyolitic Facies Association forms the uppermost preserved parts of the Agnes Water Volcanics sequence and comprises widespread rhyolitic ignimbrite and coherent to autoclastic rhyolite. It has a complex lower contact and overlies deposits from both the Dacitic Facies Association and the Mafic to Intermediate Facies Association.

Rhyolitic ignimbrite

Rhyolitic ignimbrite is the major deposit of the Rhyolitic Facies Association and represents a large component of the Agnes Water Volcanics. It crops out extensively through central and eastern regions and all exposures of rhyolitic ignimbrite are considered part of the same deposit. In the Edinburgh Mountains area south of Turkey Beach Road, >300m thickness of rhyolitic ignimbrite may be preserved. Significantly lesser thicknesses are preserved elsewhere. Examples and important features of the rhyolitic ignimbrite are displayed in Figure 8.

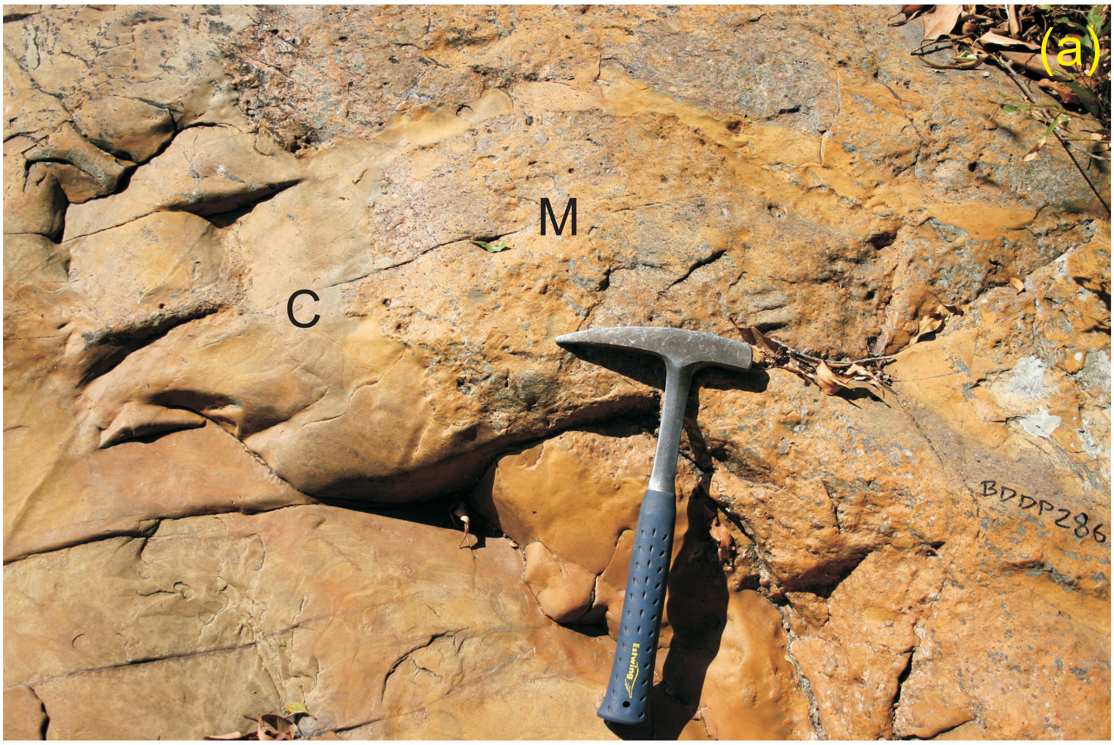


Figure 7. Peperite from base of Dacitic Facies Association.
a) Outcrop of peperite. Coherent domain (c) comprises locally flow banded rhyolite to dacite, clastic material from mixed domain (m) comprises volcaniclastic pebbly sandstone (BDDP286 — GR 364219, 7311937),
b) Close-up of mixed domain in peperite at BDDP286 showing blocky, irregular-shaped coherent fragments (*e.g.* arrow) amongst volcaniclastic matrix.

Figure 8. Features of ignimbrite from the Rhyolitic Facies Association.
a) The rhyolitic ignimbrite generally crops out quite well and forms rugged topography. The best exposures are along the coast on the western side of Round Hill Head (BDDPR1 — GR 386670, 7328667),
b) Detail of outcrop at BDDPR1 showing medium-sized crystal-rich pumice (P), mafic volcanic lithic fragment (L), and overall crystal-rich nature of the ignimbrite,
c) Unvesiculated juvenile fragment (J) with abundant, large, euhedral phenocrysts in rhyolitic ignimbrite at BDDPR1,
d) Rough columnar jointing is common in the rhyolitic ignimbrite. This well-developed column is from lower parts of the ignimbrite (BDDP273 – GR 363379, 7327254),
e) Photomicrograph showing large, embayed alkali feldspar (F) and very large, very heavily embayed quartz (Q), these are very common in the rhyolitic ignimbrite (x-polars, BDDPW6 — GR 390826, 7320562) ,
f) Photomicrograph of typical rhyolitic ignimbrite. Note the crystal-rich pumice fragments (P), large, embayed quartz (Q) and overall crystal-rich character of the ignimbrite (x-polars, BDDPR1).

The rhyolitic ignimbrite is crystal- to lithic-rich (Figure 5), strongly to intensely welded and exhibits little variation throughout the mapped extent. Mineral assemblages are dominated by conspicuously large and very heavily embayed quartz (Figure 8e) and medium-sized unzoned to weakly zoned plagioclase fragments. Alkali feldspar fragments, occasionally exhibiting embayment (Figure 8e) are less common, and deformed and heavily altered biotite is a minor phase. Pumice clasts (Figure 8f) are generally small but moderately abundant and strongly deformed. These have similar phenocryst assemblages to the remainder of the rock but are generally preferentially altered. They exhibit micropoikiolitic and granophyric recrystallisation textures and relicts of spherical and axiolitic spherulites are preserved in places.

Lithic clasts within the rhyolitic ignimbrite are moderately abundant and range up 40cm in diameter, although most are <5cm. The most abundant clasts are coherent felsic volcanics, with micropoikiolitic (*i.e.* formerly glassy) or finely crystalline and sparsely porphyritic textures. Mafic to intermediate volcanic clasts are also common and generally comprise fine plagioclase laths and altered pyroxenes. Plutonic clasts, generally granitic in composition, are rare except in breccia/ignimbrite towards the base of the sequence to the north (*e.g.* at BDDP273 — GR 363379, 7327254). Upper parts of the ignimbrite in the vicinity of Round Hill Head also contain coarsely porphyritic, non-vesicular juvenile fragments up to ~8cm in diameter (Figure 8c). These have similar mineralogy to the host ignimbrite and probably represent early-crystallised portions of the erupting magma (*i.e.* cognate).

The rhyolitic ignimbrite groundmass comprises small crystal fragments, small, strongly deformed pumice fragments and strongly deformed glass shards. In some cases, micropoikiolitic and granophyric recrystallisation textures replace these original welded, glassy groundmass features. Columnar jointing is observed throughout the rhyolitic ignimbrite and is very well developed in places (Figure 8d).

Epiclastic Sediments

Epiclastic deposits that may form part of the Rhyolitic Facies Association are only observed in coastal exposures at Round Hill Head (Figure 9). These sediments comprise moderately well-bedded fine sandstones to massive boulder conglomerates rich in felsic to intermediate volcanic lithic fragments. Soft sediment deformation is severe and the package of sediments overall has an unusual ‘wedge-like’ geometry cropping out between rhyolitic ignimbrite and a rhyolitic lava. It is uncertain if the sediments were emplaced above rhyolitic ignimbrite or if the package was ‘pushed’ into place by the overlying rhyolitic lava.

Coherent to autoclastic rhyolite

Coherent rhyolitic lavas, domes and syn-volcanic intrusions along with associated autoclastic facies are widely distributed throughout the Agnes Water Volcanics. These represent the last preserved phase of volcanism. The most prominent exposures are in the vicinity of Arthurs Seat where coherent rhyolite forms large

Figure 9. Complex relationships exposed at Round Hill Head. Rhyolitic ignimbrite is overlain? by a package of volcaniclastic sediments with ‘wedge’ geometry and extreme soft sediment deformation (inset) possibly related to loading from the overlying rhyolitic lava. Photo taken from area adjacent to Round Hill Head car park, looking north.

cliffs (Figure 10a) of intricately flow banded and spherulitic lava (Figure 10b). Elsewhere, coherent and autoclastic rhyolite generally forms small, roughly circular, isolated bodies that overlie/intrude rhyolitic ignimbrite, dacitic ignimbrite, mafic volcanics and various epiclastic deposits. Some coherent rhyolite facies (*e.g.* at Round Hill Head — Figures 9, 10c,d) clearly overlie older clastic units and represent subaerially-erupted domes/laterally restricted flows. Others, including lower exposures of coherent rhyolite near Arthurs Seat appear to disrupt bedding of surrounding volcanics and probably represent partly effusive cryptodomes. Rhyolitic dykes of varying thickness are abundant in areas surrounding larger coherent rhyolite bodies (*e.g.* Arthurs Seat and Mount Tom).

Most coherent rhyolites exhibit rough columnar jointing and variably contorted flow banding. Phenocrysts are variable in abundance but generally comprise a minor component (<20%) of the whole rock. Typical assemblages comprise highly embayed quartz, unzoned plagioclase, alkali feldspar and minor highly altered biotite. Plagioclase also occurs in small glomerocrysts in some samples. In

Figure 10. Examples of coherent and autoclastic rhyolite from the Rhyolitic Facies Association.
a) Cliff exposure of rhyolitic lava dome at Arthurs Seat (GR 359519, 7320031). Lower parts of this body may be partially intrusive,
b) Flow banding and large spherulites in rhyolite lava at Arthurs Seat,
c) Intricate flow banding in rhyolite lava at Round Hill Head (BDDPR2 – GR 386700, 7328800). This body also exhibits columnar jointing,
d) Rhyolite autobreccia associated with coherent lava at BDDPR2,
e) Photomicrograph of typical rhyolitic lava. Scattered feldspar and embayed quartz phenocrysts in a formerly glassy matrix that now comprises abundant small spherical spherulites (sample QFG5212 — GR 359551, 7320015),
f) Complex phenocryst textures such as this overgrown and embayed feldspar are found in many rhyolite lavas (x-polars, sample BDDPR2).

rhyolite at Round Hill Head (BDDPR2 — GR 386700, 7328800), plagioclase and alkali feldspar phenocrysts have rims of alkali feldspar that are subsequently strongly embayed (Figure 10e). The groundmass of most rhyolites is thoroughly devitrified (formerly glassy) and exhibits spherulitic, granophyric or micropoikiolitic textures. Spherical spherulites (Figure 10f) are abundant and particularly well developed/preserved within thicker rhyolite bodies where they range up to several centimetres in diameter. Axiolitic spherulites are well developed around the margins of large quartz phenocrysts in several samples.

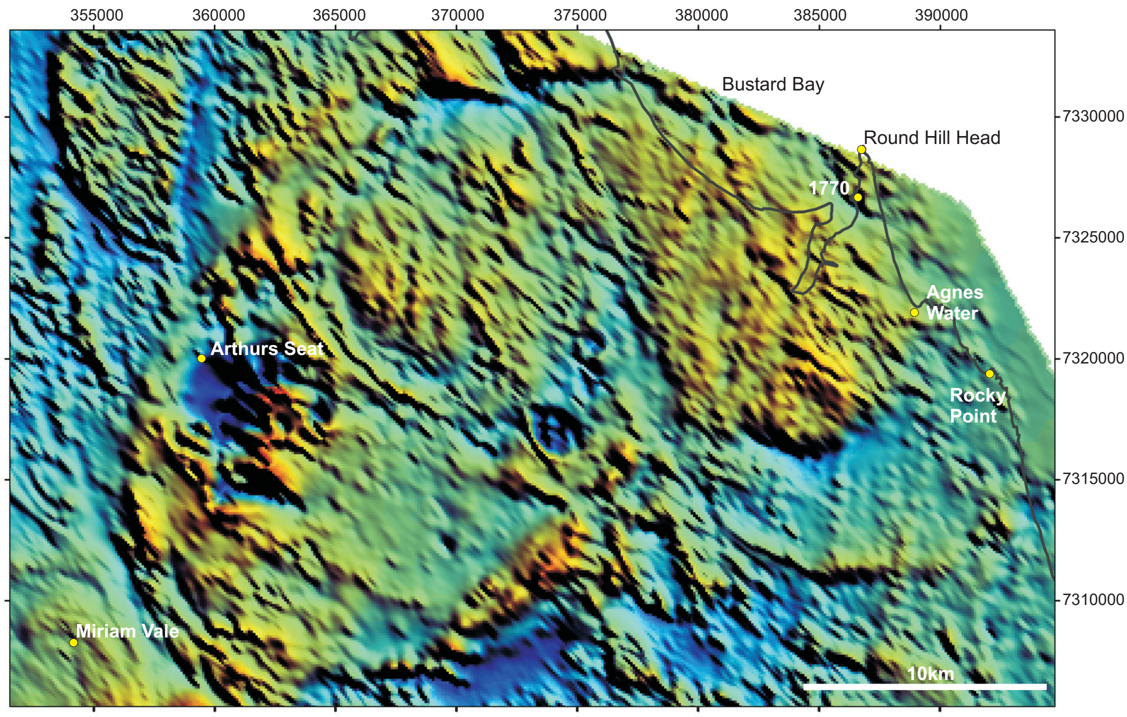
STRUCTURE

Bedding, indicated by grainsize variations in epiclastic deposits, eutaxitic texture in ignimbrites and stretching of vesicles in lavas, suggests that the Agnes Water Volcanics are flat-lying to gently undulating throughout. The sequence is dissected by several north-north-west trending faults highlighted by sharp, straight drainages. These have minimal displacement and may be relatively young, possibly associated with development of the Tertiary Lowmead Graben. Extensions of the Lowmead Graben Fault Zone form the western boundary of the Agnes Water Volcanics and the overall north-north-west trending geometry of the unit may be associated with this activity and subsequent erosion rather than original deposition.

Extensive curvilinear features that may be more closely associated with accumulation of the Agnes Water Volcanics are revealed in regional magnetic images (Figure 11). These features broadly enclose the main outcrop extents of ignimbritic subunits Rvw_{id} and Rvw_{ir} and are interpreted as caldera structural margins within a nested caldera complex — the Agnes Water Caldera Complex. Although not obviously defined in the field, these features appear to be preferential sites of rhyolite dome emplacement, high-level granitoid emplacement (*e.g*. Smallcombes Road Granite, Fingerboard Road Granite, Tolson Creek Igneous Complex and parts of the Eurimbula Granite) and possibly increased dyke abundance. The westernmost curvilinear feature, interpreted as the caldera margin associated with eruption of dacitic ignimbrite (Rvw_{id}), has a maximum diameter of 20km. This feature is truncated to the east by another caldera margin associated with eruption of rhyolitic ignimbrite (Rvw_{ir}). This feature has a maximum diameter exceeding 30km and probably extends offshore. It is offset by a north-north-west trending fault in the central region.

GEOCHEMISTRY

Major and trace element contents of the Agnes Water Volcanics were determined by XRF at the Queensland Government Chemical Laboratory, Archerfield, Brisbane or ICP-AES (major elements) and ICP-MS (trace elements) at ALS Chemex laboratories, Stafford, Brisbane. Representative analyses are presented in Table 3 (see Appendix 2 for the full data set). Prior to this work, geochemistry of the Agnes Water Volcanics was limited to analyses of a rhyolitic ignimbrite and trachyte and six SiO_2 determinations of rocks in coastal exposures around Agnes Water (Stevens, 1968).



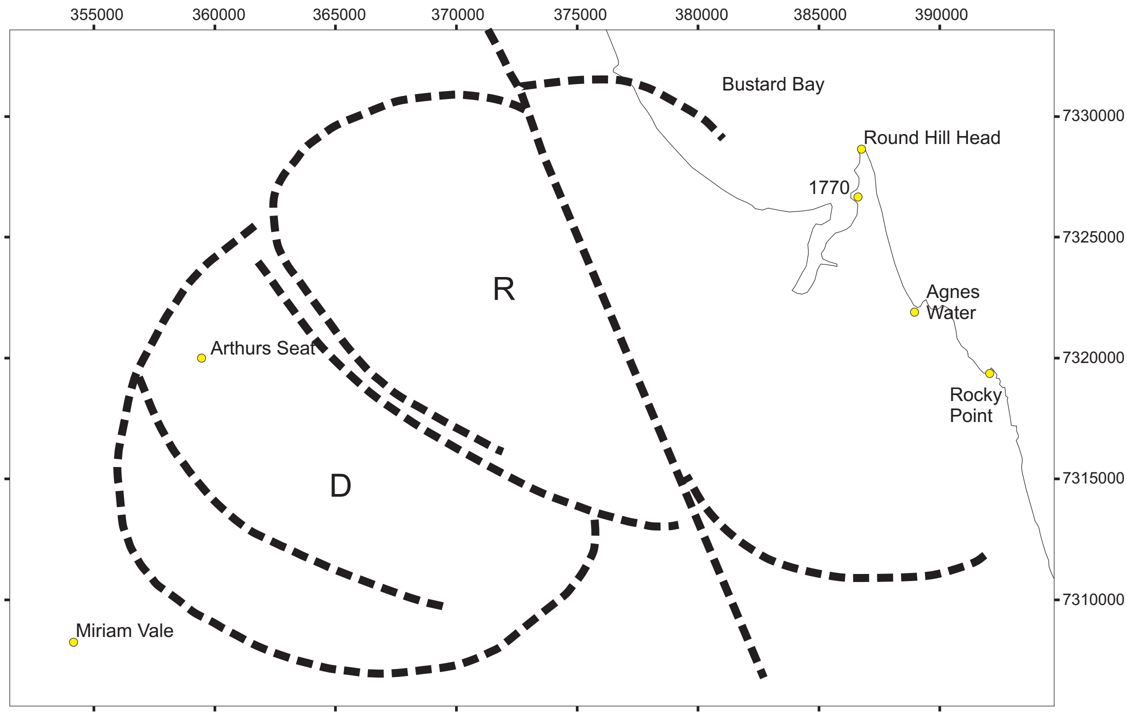


Figure 11. Definition of the Agnes Water Caldera Complex. Regional total magnetic intensity images reveal distinct curvilinear features dissecting the Agnes Water Volcanics. These roughly correspond to boundaries between facies associations and are interpreted as structural caldera margins, together defining a nested caldera complex. Westernmost caldera (D) is associated with the Dacitic Facies Association, larger caldera to the east (R) is associated with the Rhyolitic Facies Association, this is slightly offset by a NNW-trending fault.

Table 3. Representative geochemical analyses from the Agnes Water Volcanics

Sample	BDDP264	BDDP280a	BDDP117	BDDP258	BDDP158	BDDP165	BDDP279	BDDPR1	BDDPR2	QFG5212
Unit	Rvw_m	Rvw_m	Rvw_m	Rvw_m	Rvw_{id}	Rvw_{id}	Rvw_{ir}	Rvw_{ir}	Rvw_r	Rvw_r
Comm	Lava	Lava	Lava	Ignimbrite	Ignimbrite	Ignimbrite	Ignimbrite	Ignimbrite	Lava	Dome
Easting	360302	365147	361493	357108	363560	365556	365195	386670	386700	359552
Northing	7331046	7317737	7328461	7334393	7316418	7316733	7318186	7328667	7328800	7320026
Method	icp	icp	icp	xrf	icp	icp	icp	icp	icp	icp
SiO_2	53.4	50.6	61.1	70.2	71.6	71.3	74.5	74.6	77.1	75.8
TiO_2	1.25	1.36	1.08	0.48	0.4	0.4	0.25	0.27	0.09	0.17
Al_2O_3	18	17.9	16.1	14.4	14.7	14.9	13.55	13.4	12.65	13.3
Fe_2O_3T	9.84	9.19	6.31	2.2	2.16	2.22	1.78	1.88	1.02	1.2
Fe_2O_3				1.4						
FeO				0.7						
MnO	0.38	0.18	0.12	0.06	0.1	0.12	0.04	0.08	<0.01	0.02
MgO	1.6	4.87	2.44	0.7	0.45	0.47	0.3	0.37	0.12	0.06
CaO	4.23	9.21	4.93	1	0.93	0.88	0.98	0.72	0.11	0.15
Na_2O	6.17	3.12	3.89	4.6	5.22	4.69	4.14	4.38	3.9	4.22
K_2O	0.8	1	2.59	3.24	3.78	3.22	3.76	3.44	4.01	4.25
P_2O_5	0.29	0.32	0.28	0.08	0.02	0.07	0.05	0.02	0.02	0.06
LOI	3.89	2.04	1.01	2.92	0.4	1.5	0.6	0.76	0.93	0.74
Total	99.85	99.79	99.85	99.88	99.76	99.77	99.95	99.92	99.95	99.97
Ba	153.5	351	642	910	733	765	785	749	647	739
Ce	32.1	36.8	59.9	75	90.4	94.5	66.7	69.3	29.2	72
Co	43.9	43.1	63.3		57.4	111.5	46.7	44.7	65.8	62
Cr	130	100	10	-10	<10	<10	<10	<10	<10	<10
Cs	0.83	2.72	2.6		2.38	2.67	2.21	3.86	1.7	3.39
Cu	37	45	18	15	<5	<5	5	<5	<5	<5
Dy	5.07	5.3	6.73		9	9.82	6.43	6.03	8.28	5.64
Er	2.96	3.1	4.13		5.7	6.09	4.11	3.93	5.92	3.98
Eu	1.62	1.71	1.83		2.63	2.76	1.45	1.42	0.55	0.9
Ga	19.2	21.4	20.3	18	19.9	20.5	17.5	18.4	16.8	16.1
Gd	5.19	5.7	6.99		9.51	10.35	6.81	6.62	4.6	5.94
Hf	3.5	3.9	6.7	9	11	11.7	5.6	5.8	7	5
Ho	1.04	1.08	1.38		1.92	2.04	1.33	1.28	1.88	1.21
La	13.5	17	27.4	35	41.7	42.1	33	35.8	14	34.1
Lu	0.42	0.44	0.63		0.9	0.93	0.66	0.65	0.92	0.64
Mo	<2	<2	2	-1	<2	3	2	2	<2	2
Nb	3.2	5.4	7.8	11	13.1	14	7.7	8.7	9.5	9.2
Nd	19.3	21.8	29.3	42	43.5	47.4	31	30.9	12.9	30.8
Ni	36	41	12	-1	<5	<5	5	5	<5	<5
Pb	8	5	17	16	15	14	12	12	9	11
Pr	4.26	4.84	6.98		10.4	11.35	7.86	7.92	3.42	8.32
Rb	25.4	27.5	94.2	94	108	94.7	122	117.5	132	121.5

Table 3 (continued)

Sample	BDDP264	BDDP280a	BDDP117	BDDP258	BDDP158	BDDP165	BDDP279	BDDPR1	BDDPR2	QFG5212
Unit	Rvw_m	Rvw_m	Rvw_m	Rvw_m	Rvw_{id}	Rvw_{id}	Rvw_{ir}	Rvw_{ir}	Rvw_r	Rvw_r
Comm	Lava	Lava	Lava	Ignimbrite	Ignimbrite	Ignimbrite	Ignimbrite	Ignimbrite	Lava	Dome
Easting	360302	365147	361493	357108	363560	365556	365195	386670	386700	359552
Northing	7331046	7317737	7328461	7334393	7316418	7316733	7318186	7328667	7328800	7320026
Method	icp	icp	icp	xrf	icp	icp	icp	icp	icp	icp
Sm	4.66	5.26	6.45	10	9.29	10.05	6.35	6.29	3.08	5.89
Sn	2	2	3	-5	4	4	3	2	3	3
Sr	413	542	354	250	145.5	176	120	120	48.6	60.2
Ta	<0.1	0.2	0.5		0.8	0.9	0.5	1.6	1.6	0.7
Tb	0.94	0.99	1.24		1.68	1.82	1.18	1.14	1.19	1.08
Th	2.36	2.1	8.62	10	10.6	11.15	10.5	10.25	11.5	12.5
Ti	<0.5	<0.5	0.5		0.6	0.5	<0.5	1.7	1.8	0.7
Tm	0.42	0.43	0.59		0.83	0.9	0.62	0.58	0.87	0.58
U	0.79	0.55	2.54	2	3.06	3.08	2.45	2.78	2.62	2.82
V	230	263	135	10	17	6	46	83	10	17
W	70	73	321		431	820	343	350	399	442
Y	28.4	30.2	40.4	55	55.6	58.6	39.2	36.6	53.1	38.2
Yb	2.81	2.94	4.04	5	5.87	6.16	4.35	4.12	6.1	4.15
Zn	91	92	77	70	73	85	50	60	44	25
Zr	123	139	240	430	430	444	185	195	197	151

Data presented here represent the spatial distribution and compositional diversity of the Agnes Water Volcanics. These range from ~49–77wt% SiO_2 but have a roughly bimodal distribution on a TAS classification scheme (Figure 12a). Rocks from the early-erupted Mafic to Intermediate Facies Association form a grouping around the basalt/trachy-basalt to andesite/trachy-andesite fields. Two ignimbrite samples from this association are more felsic and plot in the dacite and rhyolite field. On most major element versus silica variation diagrams, the Mafic to Intermediate Facies Association form broad linear trends of decreasing major elements (excluding Na_2O and K_2O) with increasing silica (Figure 12b,c,d). Na_2O and K_2O both broadly increase with increasing silica (Figure 12e,f). The scatter exhibited in these variation diagrams and the relatively high LOI (up to 6 wt%) probably reflects variable alteration. Obtaining fresh, and in particular, amygdale-free samples of these rocks is extremely difficult.

In addition to the effects of alteration, some variation within the Mafic to Intermediate Facies Association may relate to magmatic processes; MgO contents are variable but generally low (~1.5–6wt%) and many lavas have negative Eu anomalies and LREE-enriched REE patterns (Figure 13a). The most primitive lavas from the Mafic to Intermediate Facies Association have moderately enriched REE patterns, negative Nb anomalies and positive Pb anomalies on MORB-normalised spider diagrams (Figure 13b). Although the overall slope of REE patterns remains fairly similar (Figure 13c), more evolved lavas have higher overall REE contents and larger negative Eu anomalies (Figure 13d). The

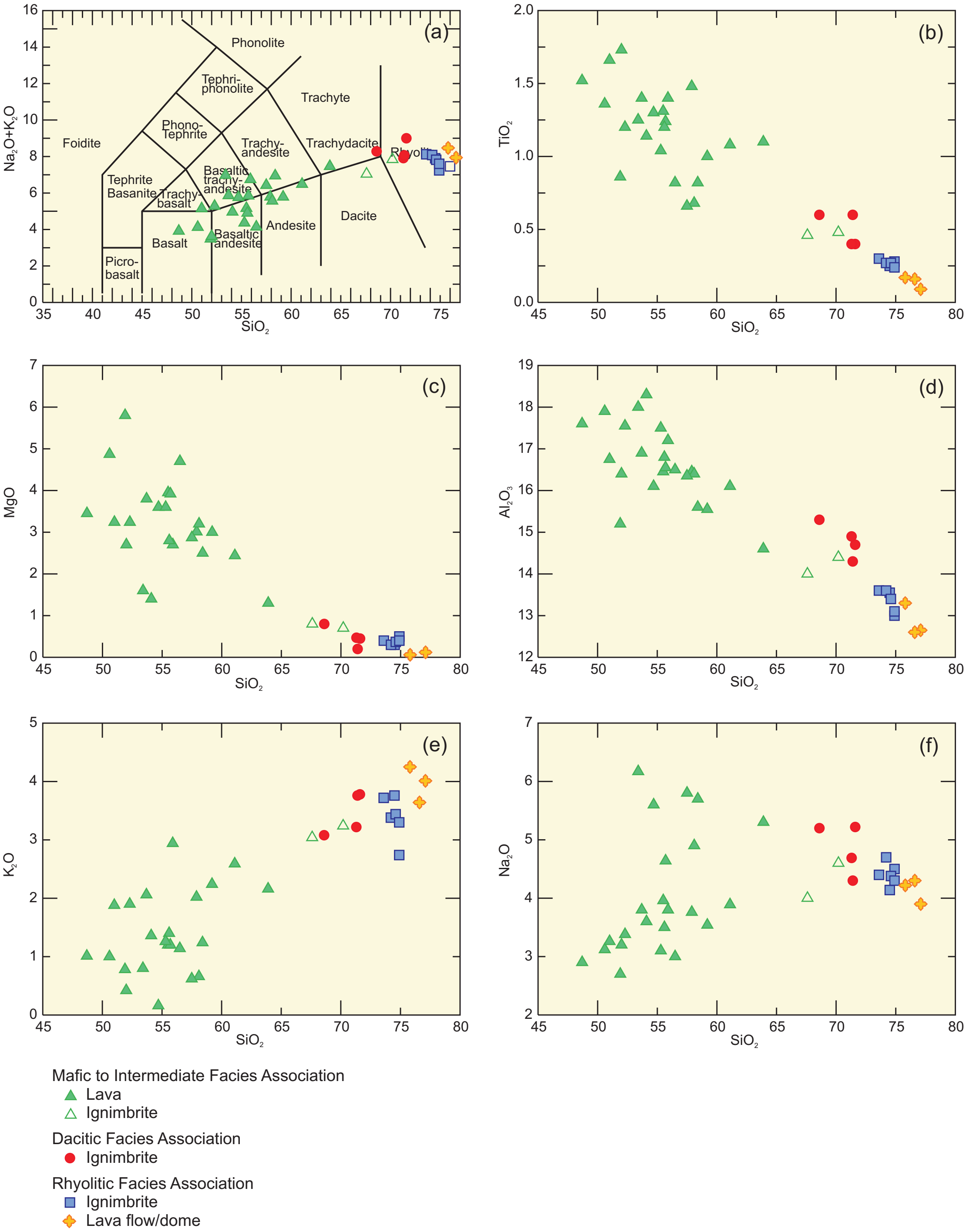


Figure 12. Major element geochemistry of the Agnes Water Volcanics.
a) TAS classification scheme — data form two distinct groupings (fields from Le Bas, 1986),
b–d) Data form broad linear trends of decreasing major elements with increasing silica,
e) Broad trend of increasing K_2O with increasing Silica,
f) Na_2O increases with increasing silica for basaltic to andesitic rocks and decreases with increasing silica for more felsic rocks.

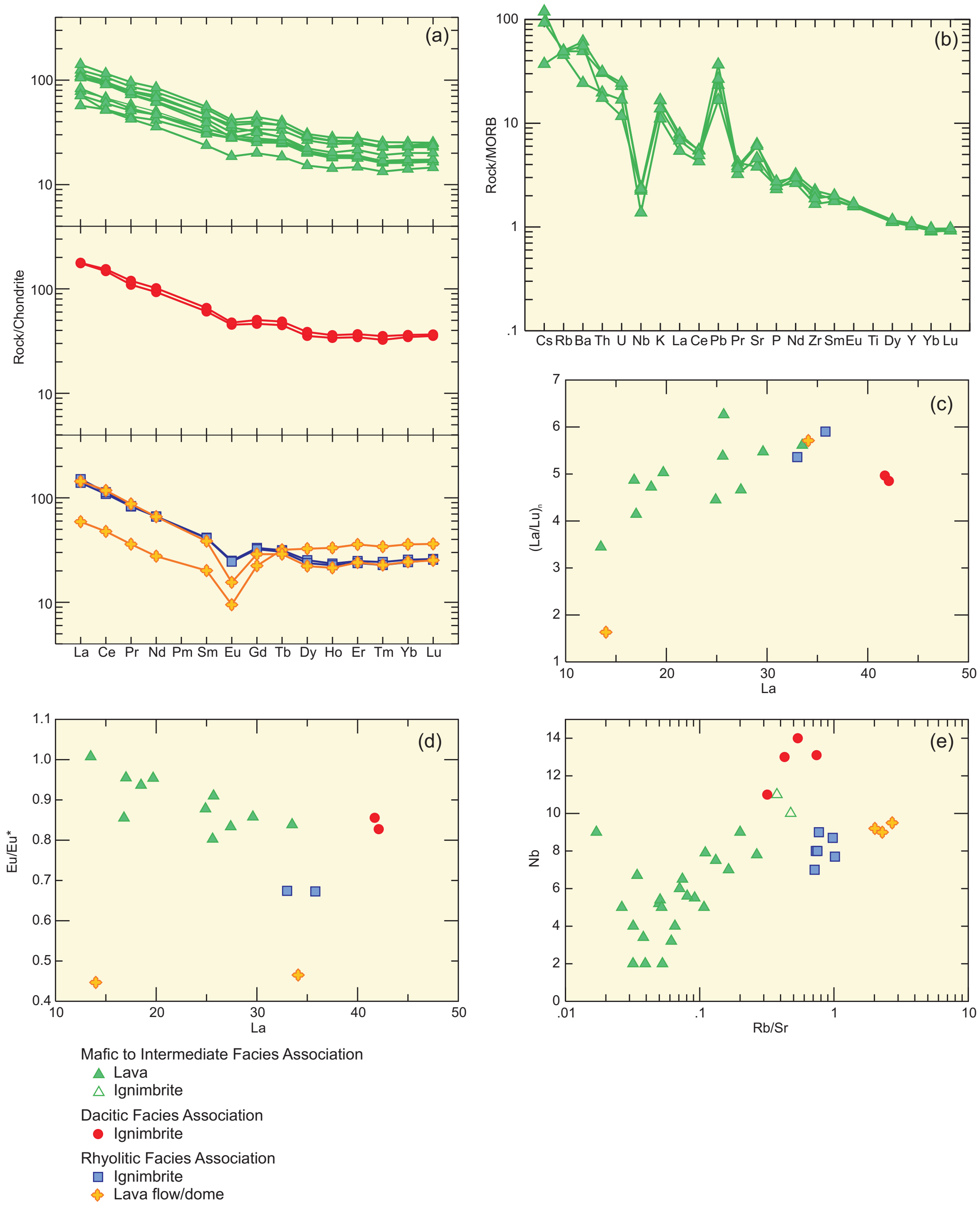


Figure 13. Trace element geochemistry of the Agnes Water Volcanics (all normalizing values from Sun & McDonough, 1989).
a) Chondrite normalized REE patterns — Mafic to Intermediate Facies Association rocks have variable but generally enriched patterns, Dacitic Facies Association ignimbrites have relatively high REE contents and minimal Eu anomaly, Rhyolitic Facies Association rocks have LREE-enriched patterns, significant negative Eu anomalies and flat HREE patterns,
b) MORB-normalised spider diagram for least evolved basalts from the Mafic to Intermediate Faces Association — note the marked Nb depletion and Pb enrichment,
c) Plot of La vs La/Lu — note that rocks from the Dacitic Facies Association plot adjacent to the main data trend,
d) Plot of La vs Eu/Eu* (magnitude of Eu anomaly) — again rocks from the Dacitic Facies Association plot separately to the main data trend,
e) Plot of Rb/Sr vs Nb — rocks from the Rhyolitic Facies Association have significantly lower Nb (as well as Zr, Y and REEs) than those of the Dacitic Facies Association.

variation observed within the Mafic to Intermediate Facies Association does not appear to relate to the mineralogical groups discussed above or geographical location.

Only four samples from the Dacitic Facies Association were selected for analysis due to the lithic-rich nature of volcanics in this association. All four samples are ignimbrites. Three are from a central area in the headwaters of Baffle Creek, the other is from coastal exposures near Agnes Water. This sample does not vary significantly from the other three and although data is limited, these rocks overall have a fairly restricted compositional range (*e.g.* SiO_2 ~69–72wt%). The samples are classified as trachydacite to rhyolite according to a TAS classification scheme (Figure 12a). On most major element versus silica variation diagrams (Figure 12) as well as plots utilising high field strength elements (Figure 13e), these ignimbrites plot along the broad trends defined by the Mafic to Intermediate Facies Association. These similarities may suggest some close genetic relationship, however, some inconsistences exist in the concentrations of large ion lithophile elements, in particular, rare earth elements (Figure 13a,c,d). Interestingly, these dacites exhibit similar REE patterns (slopes) and similar negative Eu anomaly to lavas from the Mafic to Intermediate Facies Association, yet are much higher in SiO_2, Rb/Sr, and total REE content.

Similarly to the Dacitic Facies Association, some difficulties are experienced in obtaining relatively lithic-poor and unaltered samples from the Rhyolitic Facies Association. Data presented here comprise six ignimbrite samples and three coherent lava samples. All samples are rhyolites and (excluding Na_2O) plot along the broad trends formed by data from the Mafic to Intermediate and Dacitic Facies Associations on major element versus silica variation diagrams (Figure 12). In these rocks, Na_2O broadly decreases with increasing silica. Coherent lava samples are very high-silica and have very low abundance of all major elements excluding SiO_2, Na_2O and K_2O. In contrast to rocks of the Mafic to Intermediate and Dacitic Facies Associations, these rhyolites have significantly lower Nb, Zr, Y, and REEs, defining a clearly separate grouping (Figure 13e). Excluding sample BDDPR2, the REE patterns of the Rhyolitic Facies Association ignimbrites and lavas are quite similar (Figure 13a). These are LREE-enriched and have relatively flat HREE patterns and significant negative Eu anomalies, which is more pronounced in coherent lava samples. Sample BDDPR2 is unusual in that it has a similar LREE slope but dramatically lower overall LREE concentrations and higher HREE concentrations.

Detailed investigation of Late Triassic granitoids in the Agnes Water/Bundaberg area is beyond the scope of this study and should form the basis of further work. However, some points based on initial observations of geochemical data should be made: 1) Granitoids considered to be Late Triassic in age form tight linear trends on plots of major elements (Figure 14a,b). These trends are the same as those more diffusely defined by the Agnes Water Volcanics, 2) At least two distinct groupings of data emerge on plots utilising high field strength elements. This division is particularly clear for granitoids that appear closely associated with the Agnes Water Volcanics (Figure 14c). One group is characterised by high Nb and parallels/extends trends of data for the Dacitic Facies Association. The other, lower Nb group forms a distinct trend along with data from the Rhyolitic

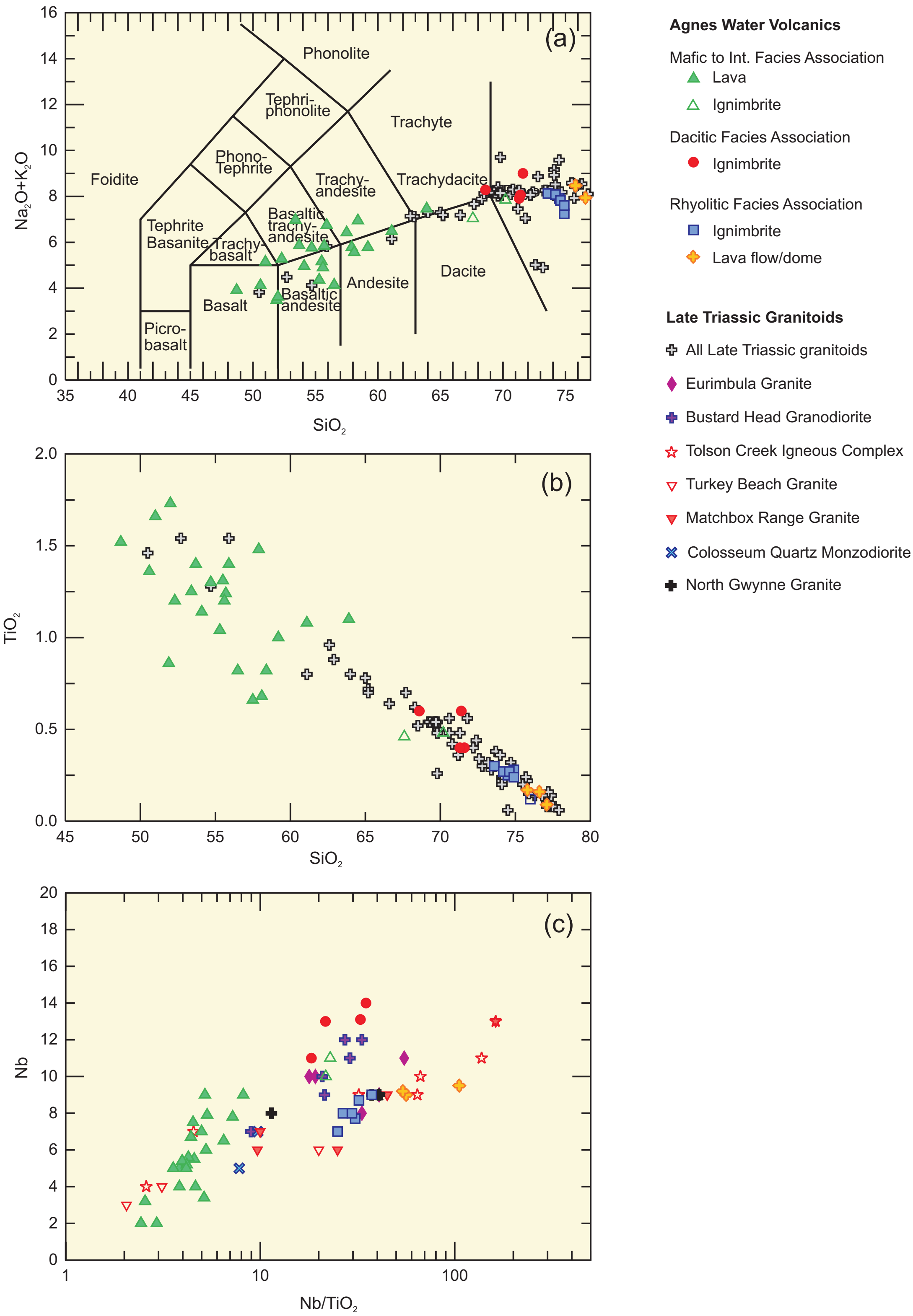


Figure 14. Geochemistry of Late Triassic granitoids relative to the Agnes Water Volcanics.
a) Granitoids have similar major element composition to the Agnes Water Volcanics — TAS classification scheme, Le Bas, 1986,
b) SiO_2 vs TiO_2. Granitoids form remarkably tight linear trends (similar to those from the Agnes Water Volcanics) for some major elements,
c) Nb/TiO_2 vs Nb showing at least two groupings of data. One group is characterised by high Nb similar to trends for the Dacitic Facies Association. The other, lower Nb group forms a distinct trend with data from the Rhyolitic Facies Association. Some units (*e.g.* Eurimbula Granite) are divided between the high-Nb and low-Nb groups. All data is from the Geological Survey of Queensland.

Facies Association. Interestingly, analyses for some units (*e.g.* Eurimbula Granite) are divided between the high-Nb and low-Nb groups.

INTERPRETATIONS

STYLES AND ENVIRONMENTS OF VOLCANISM AND SEDIMENTATION

The Agnes Water Volcanics comprise a diversity of volcanic, volcaniclastic and sub-volcanic facies. These are divided into three distinct sequences (facies associations) marked by changes in the composition of products and the styles of volcanism and sedimentation. The lack of pillow lavas, hyaloclastite deposits and marine sedimentary interbeds throughout the Agnes Water Volcanics, as well as the presence of plant remains including large stumps possibly in growth position, indicate a terrestrial depositional environment for the unit.

Mafic to Intermediate Facies Association

The earliest phase of volcanism within the Agnes Water Volcanics was dominated by effusive eruption of relatively thin basaltic to andesitic lava flows in sub-aerial environments (Figure 15a). The presence of thin ignimbrites in the Mafic to Intermediate Facies Association (Figure 3) indicates that effusive eruptions were interspersed with relatively minor explosive eruptions of slightly more evolved magmas resulting in generation of pyroclastic flows. Both coherent and clastic material was also reworked into laterally constrained fluvial systems during this time.

The lateral confinement of individual facies and the variety of products generated during this early period are characteristic of environments dominated by stratovolcanoes (Cas & Wright, 1987) and high-relief terrain. In particular, the dominance of coherent lava flows throughout the Mafic to Intermediate Facies Association may be more consistent with a medial to proximal environment as opposed to distal ring plain type environment where primary volcanics are rare or absent (Cas & Wright, 1987; Fisher & Schminke, 1984; Vessell & Davies, 1981; Davidson & De Silva, 2001). The lateral extent of the Mafic to Intermediate Facies Association (~60km) is within the range of stratovolcano basal diameters (Pike & Clow, 1981) and it is possible that the currently exposed deposits were associated with one volcanic centre.

Dacitic Facies Association

A significant change in magma composition is marked at the base of the Dacitic Facies Association. Fluvial systems during this time were still strongly controlled by topography developed during the earlier mafic to intermediate phase of volcanism. However, lithic populations suggest that fluvial systems sourced coherent dacite (Figure 6b), presumably originating from one or more large dacitic domes, in addition to surrounding mafic to intermediate lavas. The angularity, large-size and abundance of coherent dacite fragments further suggests that dome growth immediately preceded or was contemporaneous with sedimentation. Peperites (Figure 7) associated with some of these sediments confirm ongoing magmatism during this time.

Fluvial sedimentation and dacite dome growth was immediately followed by a major explosive eruption and widespread deposition of a thick dacitic ignimbrite. Similarly to underlying sediments, this ignimbrite comprises abundant fragments of coherent dacite and mafic to intermediate volcanics. In the main outcropping area on Bindaree Station, the dacitic ignimbrite has characteristics indicating intracaldera deposition; it is thick (>200m), lithic- to crystal-rich, strongly welded and generally massive (Figure 6). Major curvilinear features revealed in magnetic images at or near the boundaries of dacitic ignimbrite in this area probably represent the structural margins of a large caldera. These define a truncated, roughly circular area approximately 20km in diameter (Figure 11).

Dacitic ignimbrite that outcrops further east near Agnes Water has the same mineralogy and assemblage of lithic clasts but appears finer-grained and relatively lithic-poor. This may represent outflow facies of the same ignimbrite.

Prior to the next major phase of volcanism, dacitic ignimbrite and mafic to intermediate volcanics and volcaniclastics were severely eroded (Figure 15b). In at least one major fluvial system (preserved at Workmans Beach — Appendix 1), reworked material was deposited as thick sequences of coarse sedimentary breccias and minor intervals of sandstone, pebbly sandstone and siltstone. The voluminous sedimentary breccias have characteristics of volcaniclastic debris flow deposits (Smith & Lowe, 1991; McPhie & others, 1993); they are diffusely stratified, poorly sorted and have sandy matrix. The major soft sediment deformation and the presence of huge clasts within the volcaniclastic sequence at Workmans Beach are probably related to loading from rapidly accumulating debris flow deposits, occasional debris avalanches or slide/slumps and ongoing seismic activity. Ongoing magmatism is recorded by several dacitic domes and cryptodomes. These relatively high-relief features provided some debris to adjacent fluvial systems. Some finer-grained deposits in these coastal exposures are carbonaceous and contain large woody tree material, occasionally in growth position, indicating that steady conditions occasionally prevailed.

Rhyolitic Facies Association

Accumulation of the Rhyolitic Facies Association (Figure 15c) began with a second major explosive eruption resulting in emplacement of a thick and widespread rhyolitic ignimbrite. This ignimbrite directly overlies a variety of deposits and appears to have blanketed a deeply eroded and probably high-relief terrain. An intracaldera depositional environment appears most appropriate for characteristics of this ignimbrite (Figure 8). It is very thick, strongly to intensely welded, relatively dense (crystal-rich), columnar jointed and exhibits only minor variation throughout. A second set of major curvilinear features revealed on magnetic images may represent structural margins of the caldera. These features intercept those associated with the earlier dacitic ignimbrite and define a very large elliptically-shaped area with a maximum dimension >30km and a minimum dimension of ~20km. Together, these two large calderas represent a significant nested caldera complex (Figure 11).

Effusive rhyolitic volcanism followed this major caldera-forming event. Numerous rhyolitic domes, cryptodomes and lava flows (Figure 10) were emplaced throughout the Agnes Water Volcanics in what was probably an extensive dome field environment. These features are the youngest preserved deposits in the Agnes Water Volcanics.

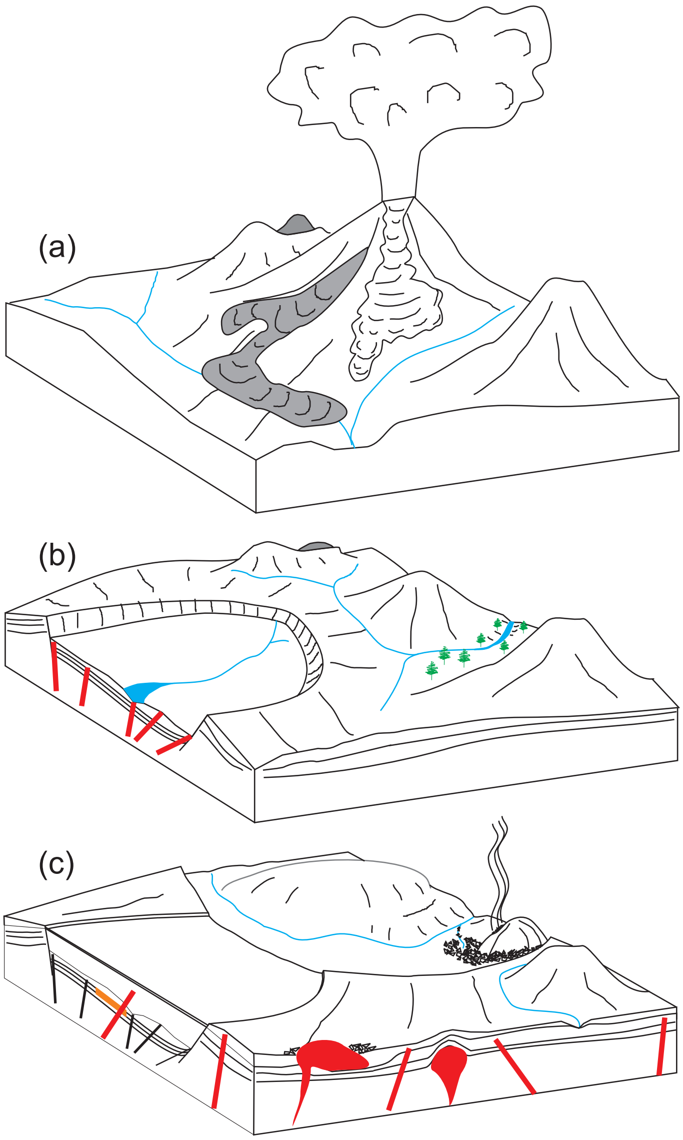


Figure 15. Schematic volcanic evolution of the Agnes Water Volcanics.
a) Initial phases of activity produced thin lavas flows and occasional pyroclastic deposits in a high-relief terrain dominated by stratovolcanoes. Volcanic material was reworked in laterally constrained fluvial systems,
b) Major change in volcanism marked by eruption of dacitic ignimbrite and formation of large caldera. Erosion and reworking of the dacitic ignimbrite and underlying mafic to intermediate volcanics continues,
c) Second major explosive eruption deposits thick rhyolitic ignimbrite and a second, larger caldera is formed. Continuing magmatism produces scattered rhyolite domes, cryptodomes and resurgence of the caldera.

MAGMATIC EVOLUTION

Thorough investigation of the Agnes Water Volcanics magma system and magmatic evolution would require a more extensive data set, possibly including more whole rock analyses, mineral chemistries, isotopic determinations and fluid inclusion studies. However, from the geochemical data and petrographic observations presented here, several preliminary and general points may be made. Firstly, the most mafic rocks from the Agnes Water Volcanics (lavas from the basal Mafic to Intermediate Facies Association) have trace element characteristics similar to those of continental margin basalts. These include strong Nb depletion and Pb enrichment. However, it should be noted that many of the mafic lavas sampled in this study have low MgO, LREE-enriched REE patterns and mild negative Eu anomalies indicating that they are not primary basalts. The broad linear trends that these rocks form on major and trace element variation diagrams hint at some kind of continuous evolution, on occasion culminating in the production of relatively highly evolved dacite to rhyolite magma batches that erupt explosively to produce ignimbrites. However, petrographic observations indicate that magma mingling was also an important process in their petrogenesis; some lavas comprise two distinct textural and mineralogical domains (Figure 4c) and two distinct pumice compositional populations are observed in some pyroclastic deposits (Figure 4f).

The caldera-forming dacitic to rhyolitic ignimbrite of the Dacitic Facies Association represents accumulation of a large volume of felsic magma and therefore a major change in magmatic, volcanic, and possibly tectonic processes. Accordingly, the Dacitic Facies Association also appears to have a different origin. Although these rocks plot at the ‘evolved’ end of trends delineated by rocks of the Mafic to Intermediate Facies Association on most major and trace element variation diagrams, REE data suggest that they are not genetically related via fractional crystallisation. Such a process, involving pyroxene, amphibole and feldspars (the observed mineralogy) would produce steeper REE slopes (LREE enrichment) and larger negative Eu anomalies. Although the overall REE contents of the Dacitic Facies Association are slightly greater, La/Sm, Gd/Yb and La/Yb ratios as well as Eu/Eu* are all within the range of those of the Mafic to Intermediate Facies Association (Figure 13), despite an SiO_2 difference of >5wt%.

Ignimbrites and lavas from the Rhyolitic Facies Association vary significantly in high field strength element content from rocks of the Dacitic and Facies Association. This suggests that they are not closely genetically related and is consistent with the large time interval and volcanic hiatus inferred between the Dacitic Facies Association caldera forming event and this larger rhyolitic event. This allowed accumulation of a very large volume of silicic magma now represented by the widespread and thick, crystal-rich rhyolitic ignimbrite.

Phenocryst textures including feldspar overgrowth and embayment and advanced quartz embayment (Figure 8e) indicate instability in the rhyolitic magma system prior to eruption. However, the overall homogeneity of geochemistry, mineralogy and texture through stratigraphy and lateral distribution of this ignimbrite indicates that any late-stage magmatic processes were chamber-wide and/or the chamber was well stirred prior to or during eruption.

Excluding the unusual sample BDDPR2, rhyolitic lavas from the Rhyolitic Facies Association have very similar major and trace element geochemistry to rhyolitic ignimbrites. Minor feldspar fractionation of the de-gassed, unerupted rhyolitic ignimbrite magma could account for the larger negative Eu anomaly, lower crystal content and effusive eruption of the rhyolite lavas, with sample BDDPR2 representing a more advanced stage of this process. Alternatively, remelting/remobilisation of the unerupted rhyolitic ignimbrite magma or expulsion of liquid from the unerupted rhyolitic ignimbrite magma mush may produce similar rhyolitic lavas. Phenocrysts in some rhyolitic lavas (Figure 10f) have similar growth/resorption textures to those in rhyolitic ignimbrites possibly supporting a remobilisation hypothesis.

An interesting aspect of REE patterns from the Rhyolitic Facies Association is their apparent similarity or continuity with those of the Mafic to Intermediate Facies Association. The elevated LREE content, steepening in LREE slopes, larger negative Eu anomalies and flattening of HREE slopes from the mafic rocks to the Rhyolitic Facies Association (Figure 13) are typical of magmatic processes that involve plagioclase, pyroxene and amphibole (the observed mineralogy of some Mafic to Intermediate Facies Association rocks). This apparent link may be explained by two alternate hypotheses: 1) Following the Dacitic Facies Association caldera forming eruption, mafic to intermediate magmatism continued. However, these magmas stalled in the crust (possibly due to the presence of felsic magma associated with the Dacitic Facies Association) allowing accumulation and differentiation (*i.e.* fractional crystallisation of a plag + cpx + hbl assemblage) to produce the large volume Rhyolitic Facies Association magma. 2) Alternatively, the Rhyolitic Facies Association magma may represent remelting of partly or wholly solidified basaltic to andesitic magmas in the crust that were emplaced during the earlier Mafic to Intermediate Facies Association stage of magmatism.

Simplistic models utilising the modal batch partial melting equation and Rayleigh fractionation equation (Rollinson, 1993, equations 4.10 and 4.18) along with appropriate partition coefficients (Rollinson, 1993), show that both processes can produce melts similar in REE composition to the Rhyolitic Facies Association from a Mafic to Intermediate Facies Association lava. Modal batch partial melting models require ~30% melting of a Mafic to Intermediate Facies Association lava starting material with a plagioclase-rich + cpx +hbl mineral assemblage (Figure 16a). A Rayleigh fractional crystallisation model would involve moderate fractionation (~40%) and a fractionating assemblage rich in plagioclase with varying proportions of plag, cpx and hbl (Figure 16b).

These processes and other possible links between the Mafic to Intermediate Facies Association and the Rhyolitic Facies Association clearly require further investigation. However, the suggestions raised here and simple REE geochemistry plots highlight the irregularity of the Dacitic Facies Association in the Agnes Water Volcanics sequence. These rocks form the middle part of the sequence yet appear to have a significantly different origin.

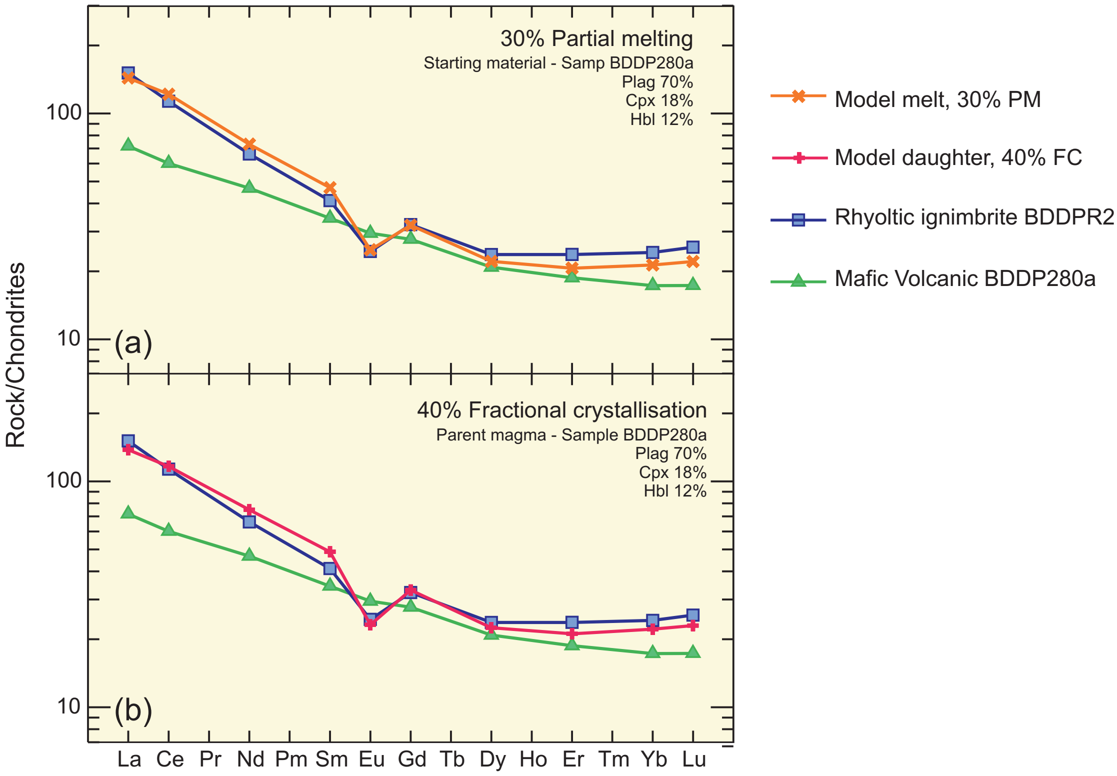


Figure 16. Simple partial melting and fractional crystallisation models for rhyolitic ignimbrite of the Agnes Water Volcanics.
a) 30% Batch modal partial melting of a Mafic to Intermediate Facies Association starting material produces melt with similar composition to ignimbrite from the Rhyolitic Facies Association,
b) Similar results are achieved via 40% Rayleigh fractional crystallization of a Mafic to Intermediate Facies Association parent magma. Partition co-efficient used in modelling are from Rollinson, 1993.

REGIONAL COMPARISONS

Volcanic rocks considered to be Late Triassic in age are scattered throughout a broad belt that extends from central Queensland to northern New South Wales (Figure 1). Although detailed mapping and petrogenetic investigations are limited, most Late Triassic units comprise similar rock types to the Agnes Water Volcanics (Table 1). Many units include significant periods of voluminous silicic magmatism and development of large caldera systems. These are defined in the Aranbanga Volcanic Group (Mungore Cauldron and Gayndah Center — Stephens, 1991), North Arm Volcanics (Yandina Creek Caldera — Hutchison, 1992; Chamberlin, 1994) and possibly the Winterbourne Volcanics (Kroombit Tops Cladera — Murray & others, in preparation — Yarrol Project Report). These caldera systems are of similar dimension to those defined here in the Agnes Water Volcanics (Figure 1) and each was preceded by mafic to intermediate volcanism.

Geochemical similarities also exist between mafic rocks from the Agnes Water Volcanics and other Mid- to Late Triassic Units (Figure 17). In the southern Yarrol Province area, mafic volcanics from the Late Triassic Native Cat Andesite, Muncon Volcanics, Bobby Volcanics and Coulston Volcanics all have geochemical characteristics similar to the Agnes Water Volcanics. They are calc-alkalic and have trace element signatures with strong resemblance to rocks from the Andean Southern Volcanic Zone (Murray & others, in preparation — Yarrol Project Report). Further south, andesitic rocks from the Aranbanga

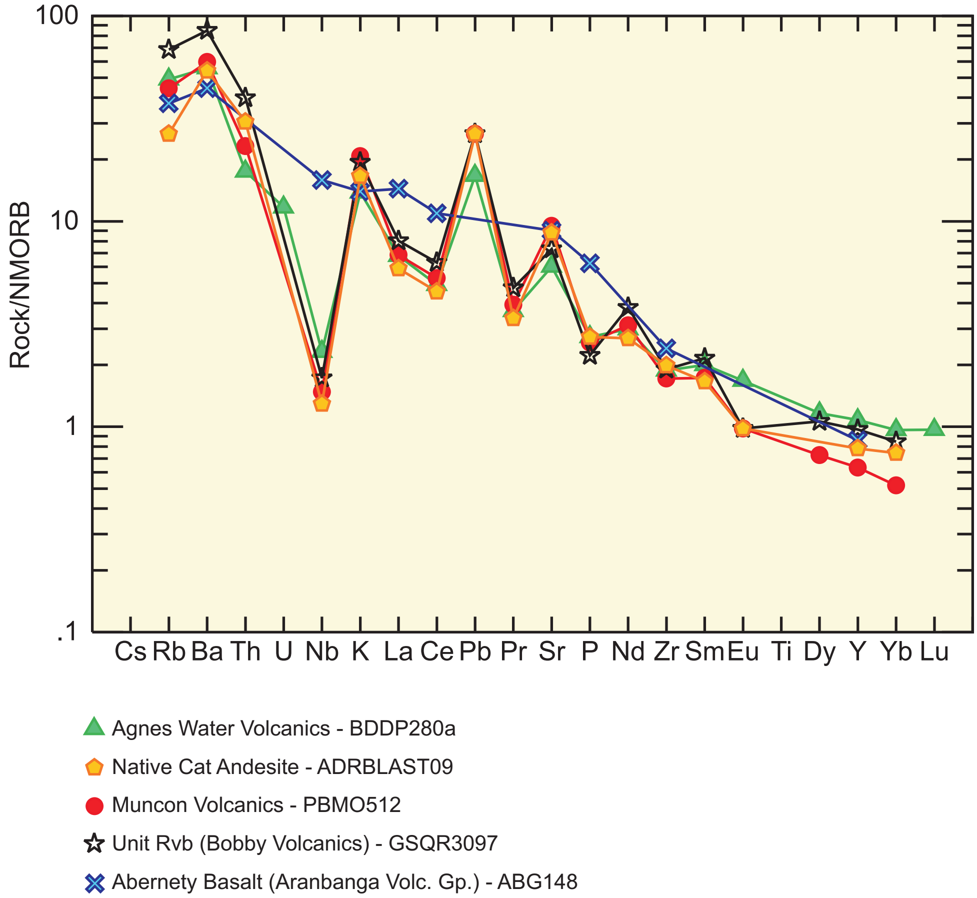


Figure 17. Comparison of Late Triassic basalts and basaltic andesites. Native Cat Andesite, Muncon Volcanics and Unit Rvb (equivalent to Bobby Volcanics) all have very similar trace element patterns to the Agnes Water Volcanics. Abernethy Basalt from the Aranganba Volcanic Group lacks Nb depletion and has 'within plate' type pattern. Normalising values from Sun & McDonough, 1989. All data is from the Geological Survey of Queensland.

Volcanic Group have similar compositions but this unit also includes some basalt with 'within-plate' characteristics, indicating a different origin (Cranfield & Murray, 1989). Data for other units in the southern areas (*e.g.* North Arm Volcanics, Mount Byron Volcanics) is very limited.

Late Triassic volcanics and granitoids in Queensland are generally thought to be bi-modal and extension-related, representing the earliest phases in the transition from a convergent continental margin to an extensional margin (Stephens, 1991; Gust & others, 1993; Gust & others, 1996; Holcombe & others, 1997; Tang, 2004). A bi-modal scenario indicates contemporaneous mafic and silicic magmatism. In comparison, the mapping work presented here shows that the Agnes Water Volcanics record a transition from mafic/intermediate-dominated to silicic-dominated volcanism. Along with geochemical characteristics such as Nb depletion and LREE enrichment exhibited by mafic rocks from the Agnes Water Volcanics, this is consistent with a continental convergent margin origin (or at least a continental margin signature) as is more commonly suggested for Early to Middle Triassic Volcanics (*e.g.* Buck, 2008; Gust & others, 1996; Holcombe & others, 1997; Campbell, 2005).

This prevailing hypothesis of Early–Middle Triassic continental convergent margin magmatism followed by Late Triassic extension-related magmatism is being tested by early results from ongoing expansion of the geochronology database. Two new U-Pb zircon SHRIMP dates from Triassic volcanics near Gayndah are both within error of that obtained for the Agnes Water Volcanics (228.6±1.7Ma). In the Gayndah area, the Toogoolawah Group, which includes the Mount Marcella Volcanics, are considered to represent Early to Mid-Triassic subduction-related magmatism whereas the Aranbanga Volcanic Group and associated Mungore Granites are considered to represent Late Triassic extension-related magmatism. New dates of 230.7±3.2Ma (tentative) for the Mount Marcella Volcanics, and 226.5±1.6Ma for the Mungore Granite (Table 2) are slightly younger and older respectively in comparison to previous K-Ar dates (see Cranfield, 1994 for compilation). Although more work in these sequences is required, these new data narrow the time gap between what many workers consider subduction-related volcanism and extension-related volcanism.

The Triassic volcanics of central and south-east Queensland clearly require more detailed work focussing on comparison of geochemistry, volcanic and magmatic evolution and, most importantly, geochronology. This will build a more detailed understanding of this interesting period in the development of the eastern Australian margin.

CONCLUSIONS

Recent regional mapping has refined the distribution the Agnes Water Volcanics and identified four subunits: 1) Mafic to intermediate lavas and volcaniclastic deposits (Rvw_{m}), 2) Dacitic ignimbrite and volcaniclastic sediments (Rvw_{id}), 3) Rhyolitic ignimbrite (Rvw_{ir}), and 4) Coherent and autoclastic rhyolite to dacite (Rvw_{r}). The results of this work, combined with more detailed studies of individual sequences, petrography, geochemistry and geochronology gives a clearer understanding of the volcanic and magmatic evolution associated with this extensive unit. Important conclusions from this work are:

1. The Agnes Water Volcanics sequence comprises three stratigraphic and compositionally distinct volcano-sedimentary facies associations: a) a basal Mafic to Intermediate Facies Association comprising sequences of coalesced basaltic to andesitic lava, thin dacitic pyroclastic deposits and fluvial volcaniclastic sediments, b) a Dacitic Facies Association dominated by thick dacitic to rhyolitic ignimbrite and minor sediments, and 3) an upper Rhyolitic Facies Association comprising thick, crystal-rich rhyolitic ignimbrite and scattered rhyolitic domes and cryptodomes.

2. A rhyolite dome from the Rhyolitic Facies Association has a crystallisation age of 228.6±1.7Ma.

3. Distinct curvilinear features revealed on regional magmatic images broadly correspond to boundaries between major ignimbrite units and may represent the structural margins of calderas associated with emplacement of the Agnes Water Volcanics. These broadly define the Agnes Water Caldera Complex.

4. The volcanic and sedimentary evolution of the Agnes Water Volcanics progressed through several stages: a) early effusive eruption of basaltic to andesitic lavas in a relatively high relief terrain dominated by stratovolcanoes with minor explosive eruptions of more evolved magmas and reworking of volcanic products, b) large-scale explosive eruption, caldera formation and emplacement of dacitic ignimbrite, c) a major period of erosion and sedimentation, d) a second major explosive eruption producing a larger caldera and very thick and extensive rhyolitic ignimbrite, and e) effusive eruption of rhyolite domes, cryptodomes and lava flows.

5. Rocks from the Mafic to Intermediate Facies Association have compositions similar to other continental arc basalts and exhibit variation consistent with fractionation processes. However, evidence for magma mingling also exists.

6. Following mafic volcanism, a major change in tectonic and/or magmatic processes allowed the accumulation of large volumes of silicic magma bodies.

7. Ignimbrite from the Dacitic Facies Association has REE patterns that are inconsistent with a genetic relationship to either the Mafic to Intermediate Facies Association or Rhyolitic Facies Association.

8. The composition of rocks from the Rhyolitic Facies Association is consistent with derivation via partial melting of rocks produced during the mafic to intermediate facies phase of magmatism, or they at least share a very similar source.

9. The rocks exposed in the Agnes Water Volcanics are of similar type and composition to most other Late Triassic volcanic units. However, the Agnes Water Volcanics record a transition from mafic magmatism to silicic magmatism rather than contemporaneous mafic and silicic magmatism as suggested for other Late Triassic units. More geochronology is required.

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REFERENCES

ASHLEY, P.M. & SHAW, S.E., 1993: Apparent ages of hydrothermal alteration zones in the North Arm Volcanics, south-east Queensland. *Australian Journal of Earth Sciences*, **40**, 415–421.

BRYAN, S.E., HOLCOMBE, R.J. & FIELDING, C.R., 2001: Yarrol terrane of the northern New England Fold Belt: forearc or backarc? *Australian Journal of Earth Sciences*, **48**, 293–316.

BUCK, A., 2008: The Mount Marcella Volcanics: Middle Triassic convergent margin volcanism in south-east Queensland. MSc Thesis, Queensland University of Technology, Brisbane.

CAMPBELL, L.M., 2005: Basin analysis and tectonic evolution of the Esk Trough in south-east Queensland. PhD Thesis, University of Queensland, Brisbane.

CARSON, C.J., von GNIELINSKI, F.E. & BULTITUDE, R.J., 2006: Results of the joint GSQ-GA geochronology project, New England Orogen, ROSEDALE, MOUNT PERRY and GLADSTONE 1:100 000 Sheet areas March 2006 – December 2006. *Queensland Geological Record* **2006/01**.

CAS, R.A.F. & WRIGHT, J.V., 1987: *Volcanic successions: modern and ancient*. Unwin Hyman, London.

CHAMBERLIN, R.M., 1994: Indications of a faulted and mineralised Late Triassic caldera margin near Eumundi, south-eastern Queensland. *Queensland Government Mining Journal*, **95**(1108), 20–37.

CRANFIELD, L.C., 1989: New and revised Mesozoic stratigraphic units in the Maryborough 1:250 000 sheet area, south-east Queensland. *Queensland Government Mining Journal*, **90**(1049), 163–174.

CRANFIELD, L.C., 1994: Maryborough. *Queensland 1:250 000 Geological Series - Explanatory Notes*. Geological Survey of Queensland, Department of Minerals and Energy.

CRANFIELD, L.C., 1999: *Gympie Special Sheet 9445, Part 9545, Queensland 1:100 000 Geological Map Commentary*. Queensland Department of Mines and Energy, Brisbane.

CRANFIELD, L.C. & MURRAY, C.G., 1989: Geochemistry of basaltic rocks from the Gayndah region in the Maryborough 1:250 000 sheet area, south-east Queensland. *Queensland Government Mining Journal*, **90**(1055), 469–480.

CRANFIELD, L.C. & SCOTT, M., 1993: Geology of the Gympie 1:100 000 Special area (9445, 9545), south-east Queensland. *Queensland Geological Record* **1993/20**.

CROSS, A.J., PURDY, D.J., BULTITUDE, R.J., DHNARAM, C. & von GNIELINSKI, F.E., 2009: Summary of results of the Joint GSQ-GA geochronology project, New England Orogen and Drummond Basin, 2008. *Queensland Geological Record*, **2009/03**.

CUMMINGS, A.M., 1998: Geology of the Cania Region, western Yarrol Province, southern central Queensland. Honours Thesis, University of Queensland, Brisbane.

DAVIDSON, J. & DE SILVA, S., 2001. Composite Volcanoes. *In:* Sigurdsson, H., Houghton, B., Rymer, H., Stix, J. & McNutt, S.R., (Editors): *Encyclopedia of volcanoes*. Elsevier Academic Press, 663–681.

DEAR, J.F., McKELLAR, R.G. & TUCKER, R.M., 1971: Geology of the Monto 1:250 000 Sheet area. *Geological Survey of Queensland Report*, **46**.

ELLIS, P.L. & WHITAKER, W.G., 1976: Geology of the Bundaberg 1:250 000 Sheet area. *Geological Survey of Queensland Report*, **90**.

FISHER, R.V. & SCHMINKE, H.U., 1984: *Pyroclastic rocks*. Springer-Verlag, Berlin.

GUST, D., BLEVIN, P., CHAPPELL, B. & STEPHENS, C., 1996: Early Mesozoic magmatism of the New England Orogen: space, time and compositional relationships. *Mesozoic Geology of the Eastern Australia Plate Conference — Extended Abstracts*. Geological Society of Australia, Brisbane, 224–227.

GUST, D.A., STEPHENS, C.J. & GRENFELL, A.T., 1993: Granitoids of the northern NEO: their distribution in time and space and their tectonic implications. *1993 NEO Field Conference*. Geological Society of Australia, 565–571.

HOLCOMBE, R.J., STEPHENS, C.J., FIELDING, C.R., GUST, D.A., LITTLE, A., SILWA, R., KASSAN, J., McPHIE, J. & EWART, A., 1997: Tectonic evolution of the northern New England Fold Belt: the Permian-Triassic Hunter-Bowen event. *In:* Ashley, P.M. & Flood, P.G., (Editors): Tectonics and Metallogenesis of the New England Orogen. *Geological Society of Australia, Special Publication* **19**, 52–65.

HUTCHISON, N.A., 1992: The Triassic Yandina Creek Caldera of the North Arm Volcanics, south-east Queensland. Honours Thesis, University of Southern Queensland.

KIRKEGAARD, A.G., SHAW, R.D. & MURRAY, C.G., 1970: Geology of the Rockhampton and Port Clinton 1:250 000 sheet area. *Geological Survey of Queensland Report*, **38**.

LE BAS, M.J., LE MAITRE, R.W., STRECKEISEN, A. & ZANETTIN, B., 1986: A chemical classification of volcanic rocks based on the total alkali-silica diagram. *Journal of Petrology*, **27**, 745–750.

McPHIE, J., DOYLE, M. & ALLEN, R., 1993: *Volcanic textures: a guide to the interpretation of textures in volcanic rocks*. Centre for Ore Deposit and Exploration Studies, University of Tasmania, Hobart.

MURRAY, C.G., 2003. Granites of the Northern New England Orogen. *In:* Blevin, P., Jones, M. & Chappell, B., (Editors): Magmas to Mineralisation: The Ishihara Symposium. *Geoscience Australia, Record* **2003/14**, 101–108.

MURRAY, C.G. & BLAKE, P.R., 2005: Geochemical discrimination of tectonic setting for Devonian basalts of the Yarrol Province of the New England Orogen, central coastal Queensland: an empirical approach. *Australian Journal of Earth Sciences*, **52**, 993–1034.

PIKE, R.J. & CLOW, G.D., 1981: Revised classification of terrestrial volcanoes and a catalog of topographic dimensions with new results on edifice volume. United States Geological Survey open-file report, 81-1038.

ROACH, A., 1996: Late Triassic volcanism of the Ipswich Basin. *Mesozoic Geology of the Eastern Australia Plate Conference - Extended Abstracts*. Geological Society of Australia, Brisbane, 476–484.

ROLLINSON, H., 1993: *Using geochemical data: evaluation, presentation, interpretation. Geochemistry series*. Longman Group Limited, Essex.

SMITH, G.A. & LOWE, D.R., 1991: Lahars: Volcano-hydrologic events and deposition in the debris flow - hyperconcentrated flow continuum. *In:* Fisher, R.V. & Smith, G.A., (Editors): Sedimentation in volcanic settings. *Special Publications. SEPM (Society for Sedimentary Geology)*, Tulsa, Oklahoma, 59–70.

STEPHENS, C., 1986: Late Triassic silicic volcanism near Gayndah. *In:* Willmott, W.F., (Editor): *1986 Field Conference, the South Burnett District.* Geological Society of Australia, Queensland Division, Brisbane, 32–38.

STEPHENS, C., 1991: The Mungore Cauldron and Gayndah Centre: Late Triassic large-scale silicic volcanism in the New England Fold Belt near Gayndah, south-east Queensland. PhD Thesis, University of Queensland, Brisbane.

STEVENS, N.C., 1968: Triassic Volcanic Rocks of Agnes Water. Queensland. *University of Queensland Papers*, **6**, 147-155.

SUN, S.-S. & McDONOUGH, W.F., 1989: Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. *In:* Saunders, A.D. & Norry, M.J., (Editors): Magmatism in the ocean basins. *Geological Society, London, Special Publications*, 313–345.

TANG, J., 2004: The petrogenesis of the Station Creek Igneous Complex and associated volcanics, northern New England Orogen. PhD Thesis, Queensland University of Technology, Brisbane.

VESSELL, R.K. & DAVIES, D.K., 1981: Nonmarine sedimentation in an active forearc basin. *In:* Ethridge, F.G. & Flores, R.M., (Editors): Recent and ancient nonmarine depositional environments: models for exploration. *Special Publication. Society of Economic Paleotologists and Mineralogists*, Tulsa, Oklahoma, U.S.A., 31–45.

WITHNALL, I.W., HUTTON, L.J., BULTITUDE, R.J., von GNIELINSKI, F.E. & RIENKS, I.P., 2009: Geology of the Auburn Arch, Southern Connors Arch and adjacent parts of the Bowen Basin and Yarrol Province, Central Queensland. *Queensland Geology*, **12**.

Appendix 1

Introducing the Agnes Water Volcanics: Key exposures at
Workmans Beach, Fenre Point and Round Hill Head
Poster presented at Australian Earth Sciences Convention 2006

Introducing the Agnes Water Volcanics

Key exposures at Workmans Beach, Fence Point and Round Hill Head

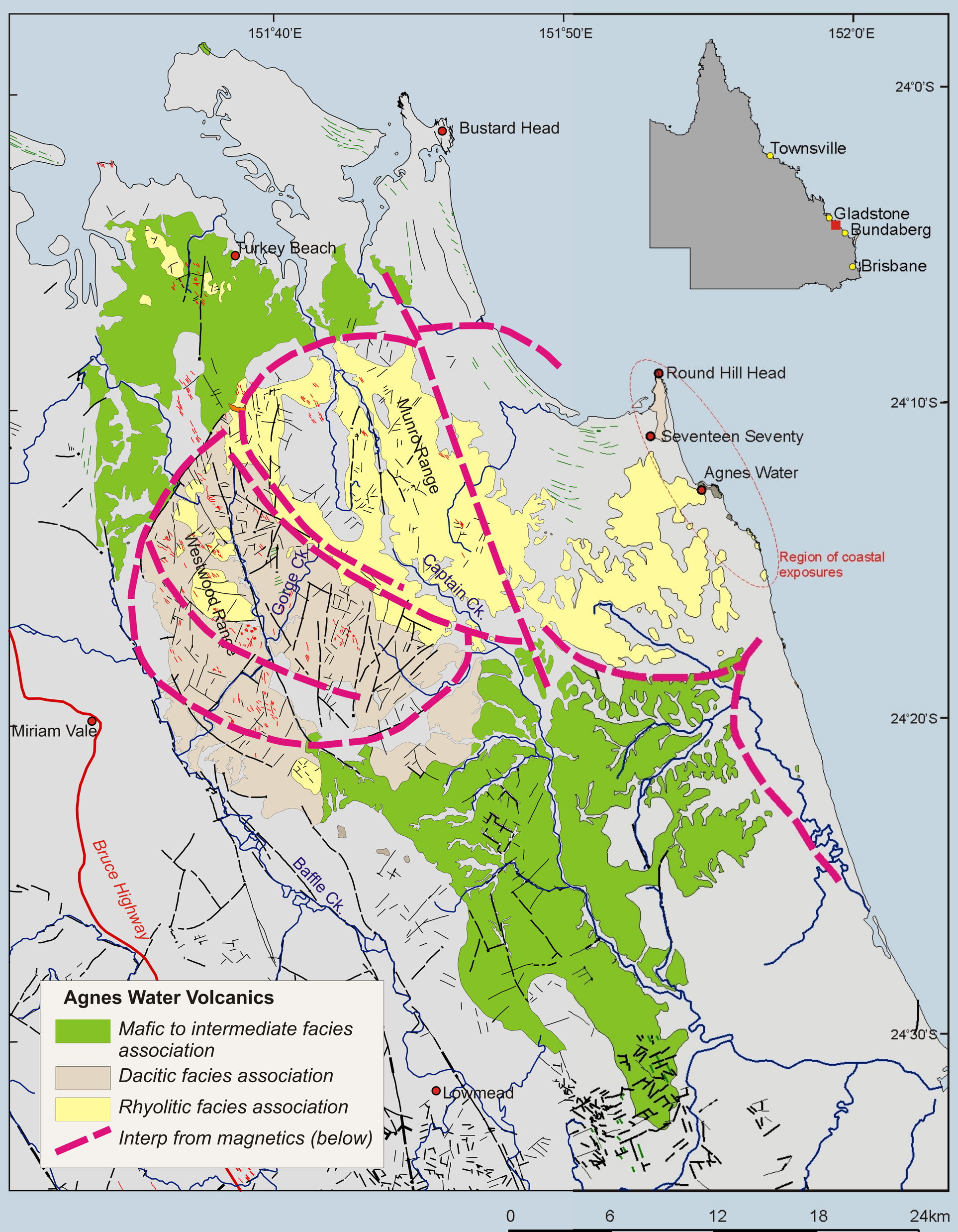
Dave Purdy - Geological Survey of QLD, Department of Natural Resources, Mines and Water, 80 Meiers Rd. Indooroopilly QLD 4068 <david.purdy@nrm.qld.gov.au> +61 7 3362 9359

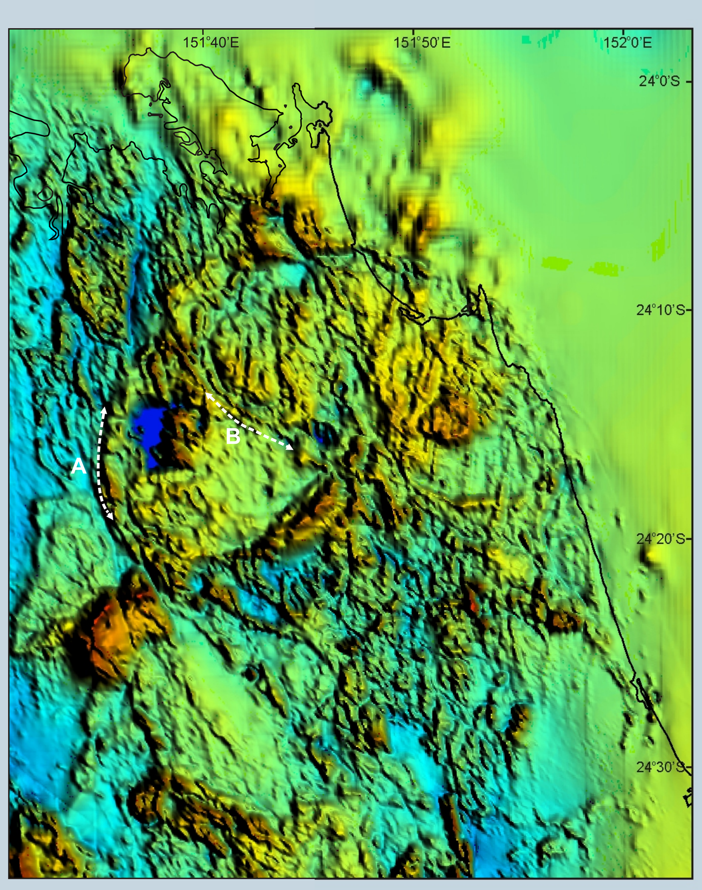
Background

Numerous phases of volcanism and various volcanic and sub-volcanic environments are preserved within the Late Triassic Agnes Water Volcanics in Queensland. Recent detailed mapping within this unit reveals three major volcano-sedimentary facies associations. From oldest to youngest these are 1) a basal Mafic to Intermediate Facies Association dominated by basaltic to andesitic lavas and interbedded volcaniclastic deposits, 2) a Dacitic Facies Association comprising thick, strongly welded dacitic ignimbrite, minor sediments and coherent dacite, and 3) a Rhyolitic Facies Association dominated by a widespread, very thick, strongly welded rhyolitic ignimbrite and scattered rhyolitic domes and cryptodomes. Additionally, interpretation of regional magnetic images reveals several large, curvilinear features throughout the main outcropping area of the Agnes Water Volcanics. These features roughly correlate with boundaries between facies associations and may represent structural margins of a large nested caldera complex.

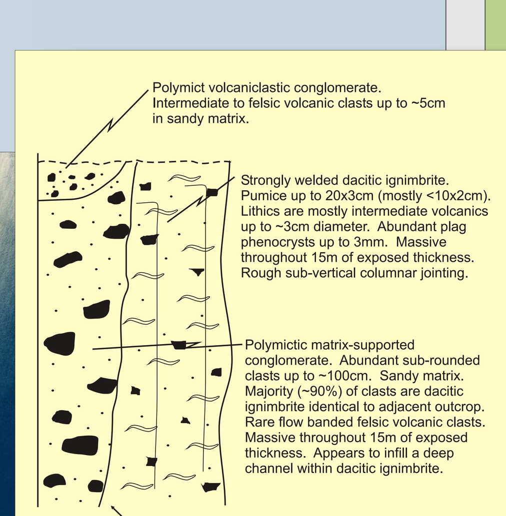
Relationships within and between facies associations are complex and indicate significant relief and/or periods of major erosion following emplacement of each association. Several facies belonging to the dacitic and rhyolitic associations are exposed in coastal outcrops between Round Hill Head and Rocky Point along the Agnes Water coastline. The quality and three-dimensionality of these exposures provides an excellent opportunity to establish relationships between facies that may be applicable across the Agnes Water Volcanics.

These exposures record an interesting sequence that involves; 1) erosion of welded dacitic ignimbrite, 2) rapid accumulation of coarse debris flow deposits, and minor finer-grained fluvial sediments, 3) emplacement of dacitic domes and cryptodomes, 4) deposition of thick rhyolitic ignimbrite, 5) emplacement of rhyolitic lavas, and 6) intrusion of felsic and later mafic dykes.

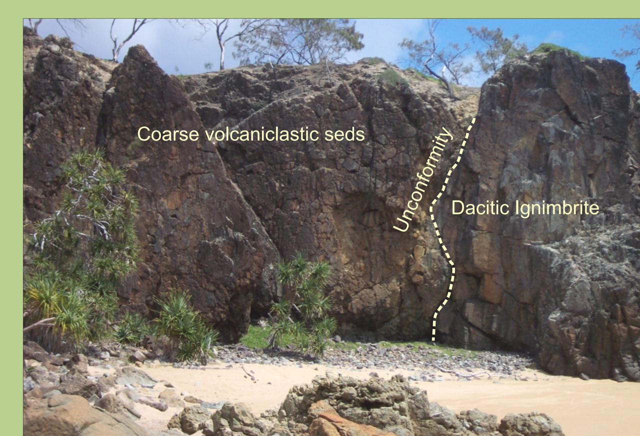


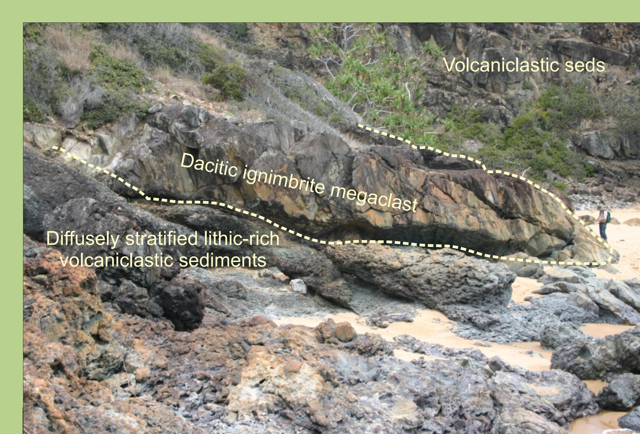


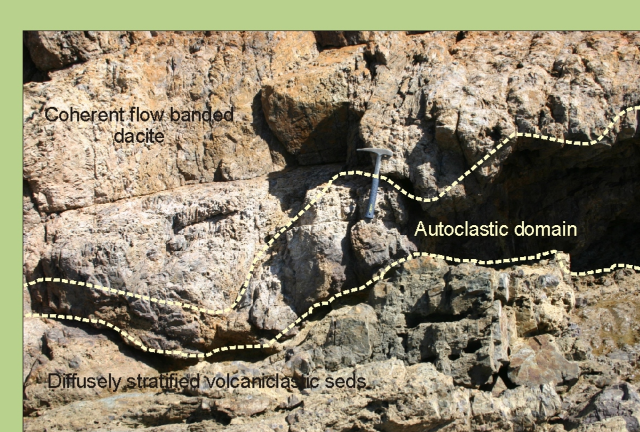
Geophysical images such as this total magnetic intensity colour drape (reduced to the pole) highlight intersecting curvilinear features that broadly align with boundaries between major facies associations. One major curvilinear feature (A), which borders the dacitic facies association is truncated by another major feature (B), which borders the younger rhyolitic facies association. Image extent is the same as the geological map above.

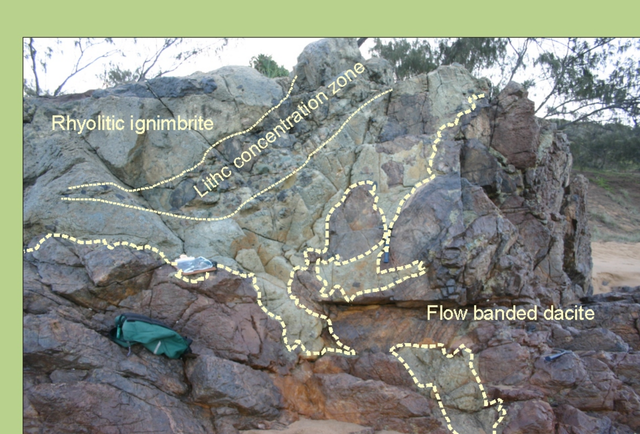


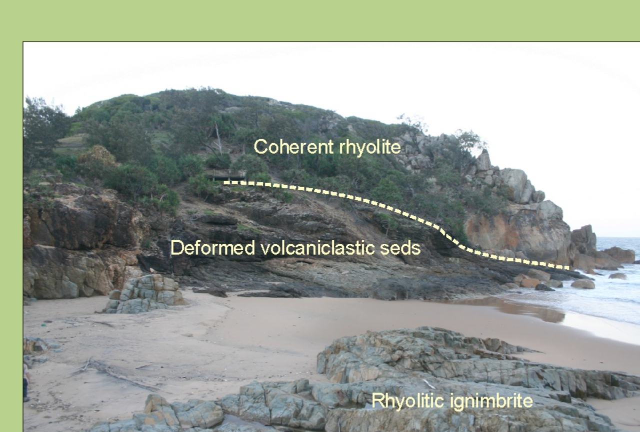
Key Exposures

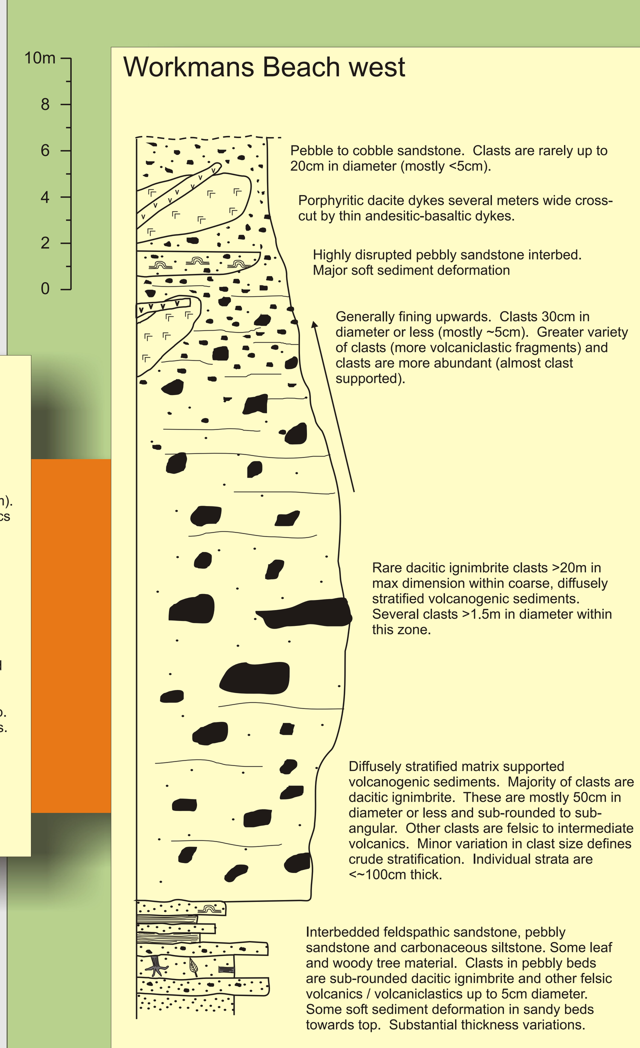


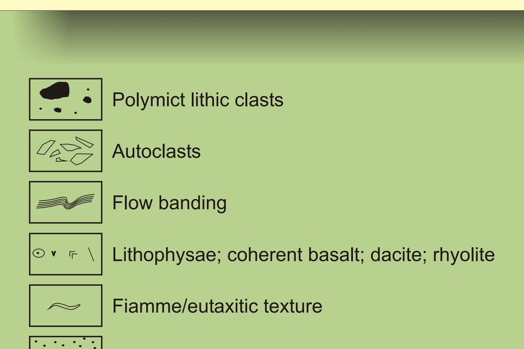












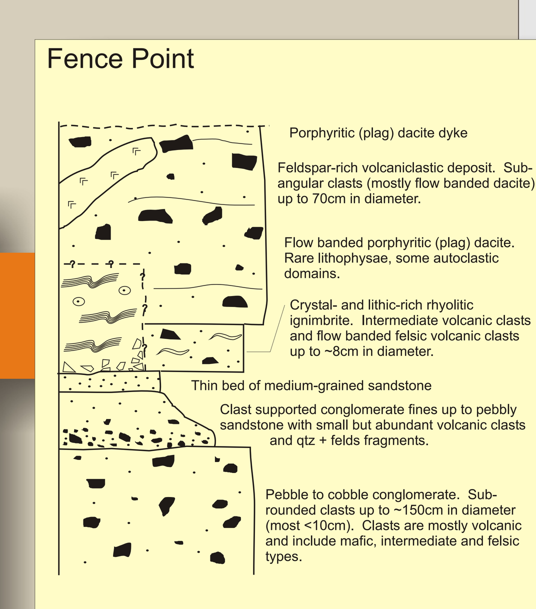
Facies

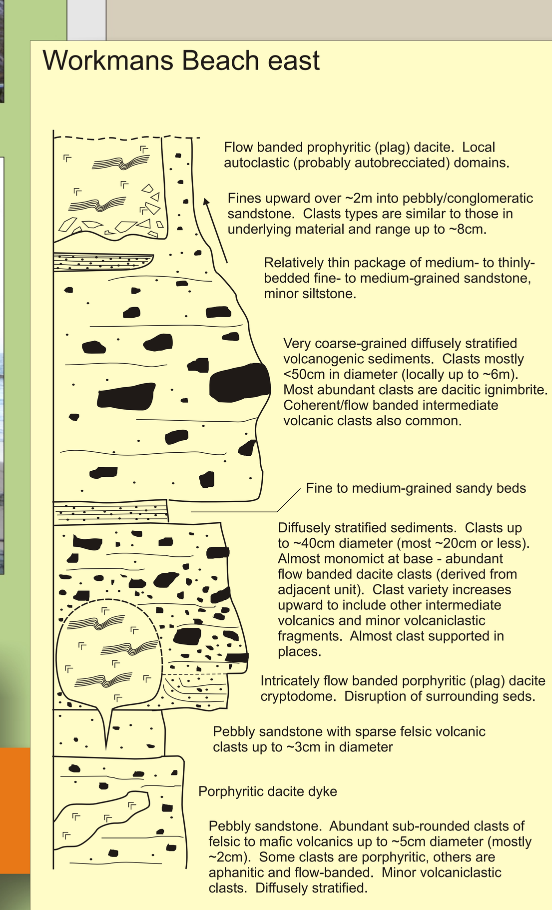
Dacitic Ignimbrite
Exposure of dacitic ignimbrite in this coastal region is limited to a small headland northwest of Workmans Beach. The ignimbrite is maroon/brown in colour, crystal-rich and strongly welded. It comprises abundant plagioclase and alkali feldspar fragments, strongly deformed pumice clasts and small angular fragments of intermediate volcanics. The groundmass appears thoroughly welded. Throughout 15m of exposure the ignimbrite is relatively massive and exhibits rough columnar jointing. It has a near-vertical unconformable relationship with adjacent (overlying) breccia that contains abundant clasts of the ignimbrite. Similar dacitic ignimbrite forms a major component of the Agnes Water Volcanics, particularly in the upper Baffle Creek and Westwood Range vicinity. In these areas, dacitic ignimbrite overlies deposits of the mafic to intermediate facies association occasionally separated by a sequence of coarse volcaniclastic deposits rich in fragments of coherent dacite.

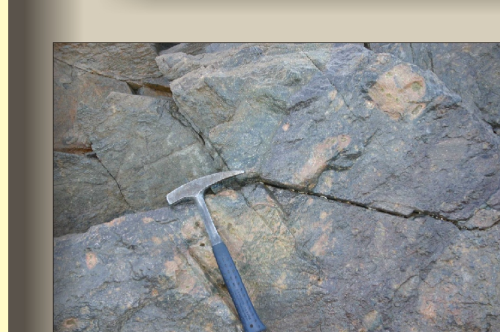
Volcanogenic sediments
Sequences of volcanogenic sedimentary deposits are common throughout the Agnes Water Volcanics and, in particular, form a major component of the Workmans Beach to Fence Point exposures. The most abundant volcanogenic sediments along this coastline are poorly-sorted, volcanic lithic-rich, bouldery conglomerates. These deposits form thick (10's of meters) sequences, commonly with diffuse stratification defined by minor grainsize and/or fabric variation. Although poorly defined, individual strata mostly appear <1m thick. Lithic clasts in most deposits exhibit at least some rounding and range up to several meters in diameter. Clast variety increases upward through the sequence from almost exclusively dacitic ignimbrite fragments near the base to include various mafic to intermediate coherent volcanics as well as other felsic volcanics and volcaniclastics. Throughout the sequence the largest clasts are always dacitic ignimbrite identical to that in adjacent exposures. Matrix material is mostly medium- to coarse-grained sand and most deposits are matrix supported.

Some finer-grained volcanogenic sediments are interspersed throughout the sequence. West of Workmans Beach, a relatively thin sequence of carbonaceous siltstones, sandstones and pebbly sandstones contains fossilised leaves and woody plant material (some of which may be in growth position). Throughout the sequence volcanogenic sedimentary deposits (particularly finer-grained deposits) show significant local thickness variations and major soft sediment deformation. This is particularly severe at Round Hill Head possibly due to loading from rhyolitic lava.

Rhyolitic Ignimbrite
Strongly-welded, crystal- to lithic-rich rhyolitic ignimbrite is exposed within the Round Hill Head and Fence Point to Rocky Point sections. The base of this ignimbrite crops out south of Fence Point where it has a highly irregular contact with coherent dacite. In this basal area, the ignimbrite comprises abundant fragments of plagioclase, alkali feldspar, large, heavily embayed quartz and minor deformed biotite. Lithic clasts are abundant and mostly comprise flow banded dacite and other intermediate volcanic fragments. Pumice clasts are relatively sparse, green in colour and moderately to strongly deformed. Up-sequence, clasts become smaller and flow banded fragments become less abundant. The top of this ignimbrite is exposed at Round Hill Head where it is overlain by coarse volcanogenic sediments and a rhyolitic lava. Ignimbrite in the upper section is very crystal-rich and contains sparse cognate lithic clasts. Further west, the ignimbrite is exposed in the Munro Range and Captain Creek areas where it overlies mafic to intermediate volcanics, dacitic ignimbrite and basement granitoids. In these areas the ignimbrite exceeds 150m thickness. It is columnar jointed and exhibits little variation in mineralogy and componentry.

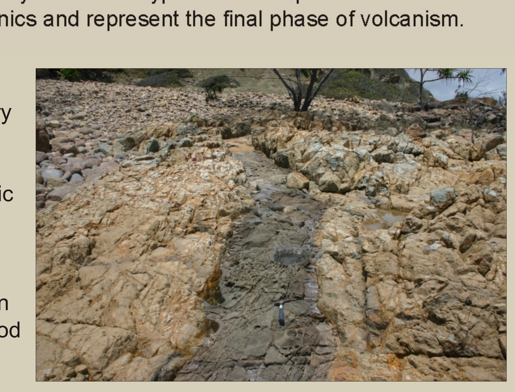






Coherent and autoclastic dacite
Coherent dacitic lavas and cryptodomes are common along the Agnes Water coastline and generally form resistant headlands. At the southern end of Workmans Beach a partially effusive? dacitic cryptodome intrudes and disrupts bedding in a sequence of volcaniclastic sediments. This coherent dacite is intricately flow banded and sparsely porphyritic with small to medium-sized alkali feldspar and plagioclase phenocrysts in a devitrified micropoikiolitic groundmass. Similar flow banded coherent dacite with locally abundant lithophysae crop out higher in the sequence, south of Workmans Beach. These dacites have locally preserved autoclastic margins and overlie coarse volcaniclastic sediments. Dacitic lavas and domes are generally sparse throughout the remainder of the Agnes Water Volcanics. However, dacitic dykes, which in some cases appear contemporaneous with sedimentation, are abundant. Other parts of the Agnes Water Volcanics record an additional period of dacitic dome growth prior to emplacement of dacitic ignimbrite.

Coherent and autoclastic rhyolite
A subaerial rhyolite lava flow/dome crops out at the northern end of Round Hill Head. This unit exhibits contorted flow banding, rough columnar jointing and locally exposed autoclastic (probably autobrecciated) domains. The rhyolite is moderately porphyritic with common feldspar and heavily embayed quartz phenocrysts. It directly overlies rhyolitic ignimbrite and strongly deformed volcanogenic sedimentry deposits and forms the stratigraphically highest exposure along this coastline. Several rhyolitic domes and partially extrusive cryptodomes crop out at scattered localities throughout the Agnes Water Volcanics and represent the final phase of volcanism.



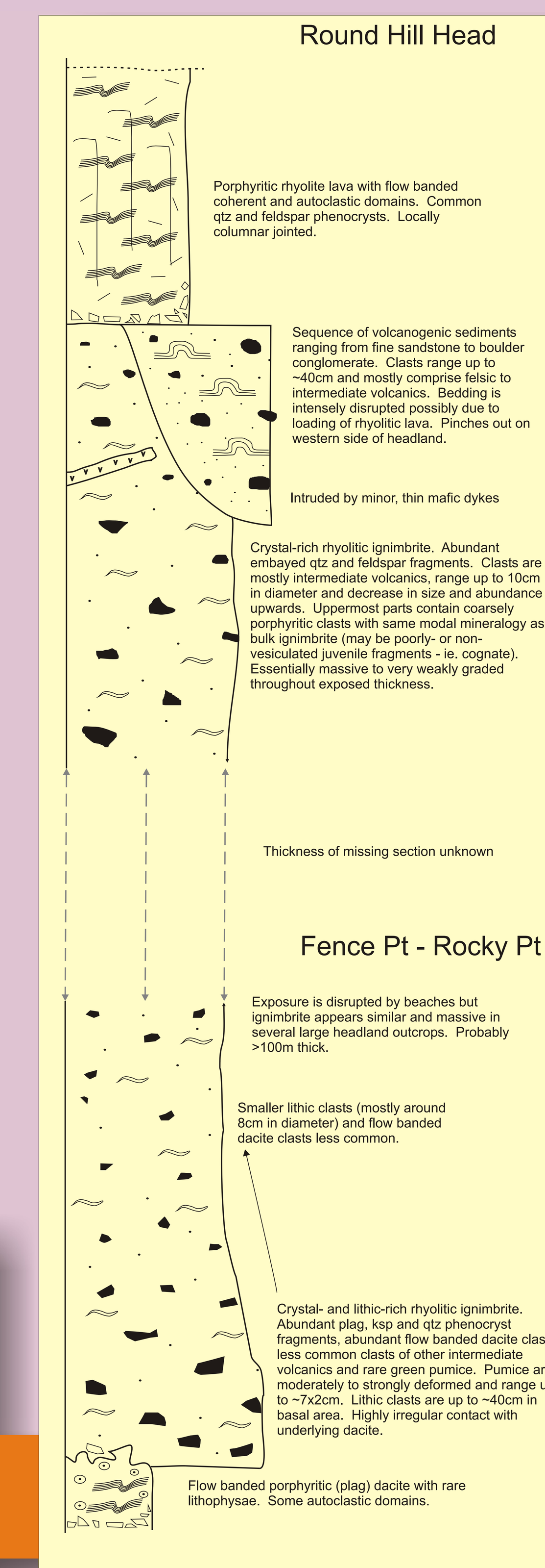
Dykes
Along this coastline the volcanic/sedimentary sequence is intruded by several felsic and mafic dykes. Cross-cutting relationships indicate that felsic dykes are older than mafic dykes. Felsic dykes are abundant in most other areas of Agnes Water Volcanics and many appear contemporaneous with sedimentation/volcanism. Peperites occur in the Gorge Creek, Baffle Creek and Westwood Range areas.

Sequence

Reasonably complete sequences are preserved in the coastal exposures near Agnes Water. Although interrupted by sandy beaches, individual sequences can be roughly correlated to produce a somewhat generalised stratigraphy for the coastal region.

Despite being fairly widespread, deposits of the mafic to intermediate facies association do not crop out along the Agnes Water coastline; they are only evident in this area as fragments within coarse-grained volcaniclastic deposits. Instead, the base of this coastal sequence comprises strongly welded dacitic ignimbrite (limited to a small headland exposure). Elsewhere within the Agnes Water Volcanics, dacitic ignimbrite that occupies a similar stratigraphic position forms thick, strongly-welded, lithic-rich deposits that represent a major explosive eruption and possibly intracaldera deposition. Dacitic ignimbrite at the base of the Agnes Water coastal sequence has similar mineralogy and assemblage of lithic clasts but appears generally finer-grained and may represent an outflow facies of the same ignimbrite.

In the coastal sequence, dacitic ignimbrite is overlain by thick volcanogenic sediments. The contact between these deposits is a near-vertical unconformity, indicating a significant period of erosion and development of a major fluvial system prior to the next phase of volcanism. During this time, voluminous reworked material was deposited as thick sequences of coarse conglomerates and minor intervals of sandstone, pebbly sandstone and siltstone. The coarser deposits are diffusely stratified and may represent debris flow deposits that accumulated rapidly and violently with significant disruption/deformation of underlying deposits. Some finer-grained deposits are carbonaceous and contain woody tree material,



some of which may be in growth position suggesting that quiet, steady conditions occasionally prevailed.

Reworked material initially comprised dacitic ignimbrite fragments up to 25m in diameter, highlighting significant relief during this time. Further sedimentation sourced material from the mafic to intermediate facies association indicating that these deposits were either still exposed or re-exposed.

Within the Agnes Water coastal sequence, coherent dacite is exposed amongst volcanogenic sediments indicating that sedimentation was accompanied by effusive dacitic volcanism. This volcanism produced domes and cryptodomes that also provided debris to adjacent fluvial systems.

The thick sequences of volcanogenic sediments and coherent dacites are directly overlain by a strongly-welded, crystal-rich rhyolitic ignimbrite. The base of the ignimbrite directly overlies coherent dacite in the Fence Point to Rocky Point area. The top of the rhyolitic ignimbrite is also exposed in coastal outcrops at Round Hill Head. Unfortunately, the overall thickness of the ignimbrite (between the base exposure and top exposure) is unknown. However, the ignimbrite is confidently correlated with rhyolitic ignimbrite in other areas of the Agnes Water Volcanics where it is probably significantly greater than 150m thick. In other areas the rhyolitic ignimbrite directly overlies basement granitoids and deposits from the dacitic and mafic to intermediate facies associations implying that it blanketed a relatively high-relief environment. Within coastal exposures near Agnes Water and throughout the Agnes Water Volcanics, this rhyolitic ignimbrite shows little variation in mineralogy and componentry. It is crystal- and lithic-rich, strongly welded, thick and columnar jointed; features that may indicate intracaldera deposition.

The top of the coastal sequence is exposed at Round Hill Head. Here, rhyolitic ignimbrite is overlain by both a thin sequence of volcanogenic sediments and coherent rhyolite. The volcanogenic sediments are strongly deformed and the sequence overall has a wedge-shaped geometry. These features probably relate to loading and displacement caused by the overlying coherent rhyolite which appears to comprise a subaerially-erupted lava flow. Some basal parts of the rhyolite are autobrecciated whereas internal zones are columnar jointed.

Although detailed work is limited, other Late Triassic units in south east Queensland show similar transitions from extensive mafic to intermediate, dominantly effusive volcanism to eruption of widespread silicic ignimbrites and development of major caldera systems (eg. Mungore Cauldron, Stephens, 1991; Yandina Creek Caldera, Chamberlin 1994). The mafic to silicic-dominated transition is also preserved within basal parts of the Ipswich Basin (Roach, 1996).

Acknowledgements:
Early investigations by N.C. Stevens (1968) highlighted the complexity and variety of deposits preserved along part of the Agnes Water coastline. Fred von Gnielinski (GSQ), Bob Bultitude (GSQ) and David Gust (QUT) are thanked for useful discussions while on the outcrops.

References:
Chamberlin, R.M., 1994. Indications of a faulted and mineralised late Triassic caldera margin near Eumundi, south-eastern Queensland. Queensland Government Mining Journal, 95: 20-37.

Roach, A., 1997. Late Triassic volcanism of the Ipswich Basin. Mesozoic Geology of the Eastern Australia Plate Conference, Extended Abstracts. Geological Society of Australia, Brisbane, pp. 476-484.

Stephens, C.J., 1991. The Mungore Cauldron and Gayndah Centre, late Triassic large-scale silicic volcanism in the New England Fold Belt near Gayndah, southeast Queensland. Unpublished Phd thesis, University of Queensland, Brisbane.

Stevens, N.C., 1968. Triassic rocks of Agnes Water, Queensland. University of Queensland Papers, 6: 147-155.

Appendix 2

Geochemical analyses of the Agnes Water Volcanics
and adjacent granitoids

Appendix 2: Geochemical analyses of the Agnes Water Volcanics and adjacent granitoids

SAMPNO	BDDP107	BDDP117	BDDP151	BDDP157A	BDDP158	BDDP165	BDDP227	BDDP248	BDDP258	BDDP260c	BDDP261	BDDP263	BDDP264	BDDP272	BDDP279	BDDP280A
Unit	Rvw$_m$	Rvw$_m$	Rvw$_{ir}$	Rvw$_m$	Rvw$_{id}$	Rvw$_{id}$	Rvw$_m$	Rvw$_m$	Rvw$_m$	Rvw$_m$	Rvw$_m$	Rvw$_m$	Rvw$_m$	Rvw$_{ir}$	Rvw$_{ir}$	Rvw$_m$
Comments	Lava	Lava	Ignimbrite	Lava	Ignimbrite	Ignimbrite	Lava	Lava	Ignimbrite	Ignimbrite	Lava	Lava	Lava	Ignimbrite	Ignimbrite	Lava
Easting_94	358888	361493	360754	360903	363560	365556	379224	356847	357108	356951	361240	360586	360302	363375	365195	365147
Northing_94	7335322	7328461	7317162	7331966	7316418	7316733	7297039	7333482	7334393	7333987	7330282	7330864	7331046	7325965	7318186	7317737
Method	xrf	icp	xrf	xrf	icp	icp	xrf	icp	xrf	xrf	icp	icp	icp	xrf	icp	icp
SiO_2	55.90	61.10	74.90	54.70	71.60	71.30	51.90	52.30	70.20	67.60	55.50	55.70	53.40	73.60	74.50	50.60
TiO_2	1.40	1.08	0.28	1.30	0.40	0.40	0.86	1.20	0.48	0.46	1.31	1.24	1.25	0.30	0.25	1.36
Al_2O_3	17.20	16.10	13.00	16.10	14.70	14.90	15.20	17.55	14.40	14.00	16.45	16.55	18.00	13.60	13.55	17.90
Fe_2O_3T	8.60	6.31	2.30	7.90	2.16	2.22	7.60	7.66	2.20	2.30	7.37	7.17	9.84	2.00	1.78	9.19
Fe_2O_3	4.30		0.70	2.10			3.20		1.40	1.50				1.00		
FeO	3.90		1.40	5.20			4.00		0.70	0.70				0.90		
MnO	0.16	0.12	0.08	0.12	0.10	0.12	0.16	0.15	0.06	0.10	0.13	0.12	0.38	0.06	0.04	0.18
MgO	2.70	2.44	0.50	3.60	0.45	0.47	5.80	3.24	0.70	0.80	3.95	3.92	1.60	0.40	0.30	4.87
CaO	4.80	4.93	0.70	6.70	0.93	0.88	9.40	8.26	1.00	3.10	6.86	6.55	4.23	0.80	0.98	9.21
Na_2O	3.80	3.89	4.50	5.60	5.22	4.69	2.70	3.38	4.60	4.00	3.96	4.64	6.17	4.40	4.14	3.12
K_2O	2.94	2.59	2.74	0.16	3.78	3.22	0.78	1.90	3.24	3.04	1.20	1.20	0.80	3.72	3.76	1.00
P_2O_5	0.56	0.28	0.06	0.32	0.02	0.07	0.24	0.57	0.08	0.08	0.29	0.27	0.29	0.06	0.05	0.32
SO_3	-0.02		-0.02	-0.02			-0.02		-0.02	-0.02				-0.02		
CO_2	-0.10		0.10	1.40			4.20		0.50	2.40				-0.10		
H_2O	0.33		0.25	0.49			0.16									
LOI	2.06	1.01	1.26	4.39	0.40	1.50	5.86	3.59	2.92	4.70	2.89	2.44	3.89	0.97	0.60	2.04
Total	100.12	99.85	100.32	100.89	99.76	99.77	100.50	99.80	99.88	100.18	99.91	99.80	99.85	99.91	99.95	99.79
Ag		<1			<1	<1		<1			<1	<1	<1		<1	<1
As	8		2	5			8		5	4				2		
Ba	760	642	590	44	733	765	270	629	910	700	311	385	153.5	730	785	351
Ce	65	59.9	45	30	90.4	94.5	35	58.7	75	70	41.4	40.7	32.1	60	66.7	36.8
Co		63.3			57.4	111.5		33.8			39.9	31.9	43.9		46.7	43.1
Cr	-10	10	-10	20	<10	<10	220	120	-10	-10	30	30	130	-10	<10	100
Cs		2.6			2.38	2.67		1.2			0.26	0.65	0.83		2.21	2.72
Cu	90	18	10	40	<5	<5	60	135	15	10	27	32	37	10	5	45
Dy		6.73			9	9.82		5.38			5.17	5.08	5.07		6.43	5.3
Er		4.13			5.7	6.09		3.1			3.18	2.97	2.96		4.11	3.1
Eu		1.83			2.63	2.76		2.04			1.68	1.61	1.62		1.45	1.71
Ga	21	20.3	15	20	19.9	20.5	18	21.6	18	18	20.4	19.5	19.2	15	17.5	21.4
Gd		6.99			9.51	10.35		6.63			5.71	5.47	5.19		6.81	5.7
Hf	5	6.7	5	4	11	11.7	5	5.4	9	9	4.3	4.2	3.5	7	5.6	3.9
Ho		1.38			1.92	2.04		1.07			1.09	1.02	1.04		1.33	1.08
La	30	27.4	25	20	41.7	42.1	15	25.7	35	30	18.5	19.7	13.5	25	33	17
Li	33		18	23			8		7	7				8		
Lu		0.63			0.9	0.93		0.44			0.42	0.42	0.42		0.66	0.44
Mo	1	2	-1	-1	<2	3	-1	2	-1	2	2	<2	<2	-1	2	<2
Nb	7	7.8	7	5	13.1	14	4	5.5	11	10	5.6	5.2	3.2	8	7.7	5.4
Nd	44	29.3	28	22	43.5	47.4	18	33.2	42	44	23.4	21.7	19.3	32	31	21.8
Ni	13	12	4	18	<5	<5	120	47	-1	1	7	19	36	-1	5	41
Pb	14	17	16	6	15	14	6	16	16	16	7	11	8	10	12	5
Pr		6.98			10.4	11.35		7.49			5.5	5.09	4.26		7.86	4.84
Rb	92	94.2	79	5	108	94.7	16	57.5	94	81	27.6	28	25.4	110	122	27.5
Sc	18		14	20			24		8	8				6		
Sm	10	6.45	8	8	9.29	10.05	6	7.09	10	12	5.27	4.87	4.66	10	6.35	5.26
Sn	-5	3	-5	-5	4	4	-5	3	-5	-5	1	2	2	-5	3	2
Sr	560	354	110	190	145.5	176	500	627	250	170	342	563	413	150	120	542
Ta		0.5			0.8	0.9		0.2			0.3	0.2	<0.1		0.5	0.2
Tb		1.24			1.68	1.82		1.06			0.92	0.96	0.94		1.18	0.99
Th	9	8.62	10	5	10.6	11.15	5	10.1	10	10	3.65	3.74	2.36	10	10.5	2.1
Ti		0.5			0.6	0.5		<0.5			0.9	<0.5	<0.5		<0.5	<0.5
Tm		0.59			0.83	0.9		0.43			0.43	0.41	0.42		0.62	0.43
U	-1	2.54	2	-1	3.06	3.08	-1	3.04	2	2	1.07	1.15	0.79	3	2.45	0.55
V	200	135	110	180	17	6	170	210	10	8	207	215	230	14	46	263
W		321			431	820		74			123	66	70		343	73
Y	44	40.4	40	31	55.6	58.6	22	30.2	55	56	28.9	30.3	28.4	37	39.2	30.2
Yb	5	4.04	4	4	5.87	6.16	2	2.93	5	4	2.94	2.75	2.81	3	4.35	2.94
Zn	87	77	46	82	73	85	70	95	70	64	77	77	91	49	50	92
Zr	300	240	160	180	430	444	140	193	430	430	166	154	123	180	185	139

SAMPNO	BDDP290	BDDP299	BDDP308B	BDDPR1	BDDPR2	BDDPW1	QFG5100B	QFG5116A	QFG5184C	QFG5185A	QFG5191B	QFG5200	QFG5201	QFG5210
Unit	Rvw$_m$	Rvw$_{ir}$	Rvw$_m$	Rvw$_{ir}$	Rvw/r	Rvw$_{id}$	Rvw$_m$	Rvw$_{ir}$	Rvw$_m$	Rvw$_m$	Rvw$_m$	Rvw$_m$	Rvw$_m$	Rvw$_r$
Comments	Lava	Ignimbrite	Lava	Ignimbrite	Lava	Ignimbrite	Lava	Ignimbrite	Lava	Lava	Lava	Lava	Lava	Lava
Easting_94	380239	361270	363038	386670	386700	389405	374534	376402	387410	385638	359566	356996	357353	359266
Northing_94	7301293	7314310	7313646	7328667	7328800	7322318	7303909	7331493	7292582	7290953	7323207	7328280	7329346	7320538
Method	icp	xrf	xrf	icp	icp	xrf	icp	xrf	xrf	icp	xrf	xrf	icp	xrf
SiO_2	48.70	74.20	52.00	74.60	77.10	71.40	51.00	74.90	56.50	59.20	63.90	55.60	57.90	76.60
TiO_2	1.52	0.27	1.73	0.27	0.09	0.60	1.66	0.24	0.82	1.00	1.10	1.20	1.48	0.16
Al_2O_3	17.60	13.60	16.40	13.40	12.65	14.30	16.75	13.10	16.50	15.55	14.60	16.80	16.45	12.60
Fe_2O_3T	9.41	2.00	9.70	1.88	1.02	2.90	10.35	1.90	7.80	6.13	6.00	6.80	7.76	1.20
Fe_2O_3		1.40	3.00			2.60		0.60	2.70		2.30	3.40		1.20
FeO		0.50	6.00			0.30		1.20	4.60		3.30	3.10		-0.10
MnO	0.17	0.08	0.22	0.08	<0.01	0.08	0.15	0.12	0.12	0.11	0.12	0.14	0.13	0.02
MgO	3.45	0.30	2.70	0.37	0.12	0.20	3.24	0.40	4.70	3.00	1.30	2.80	3.01	-0.10
CaO	9.81	0.80	8.20	0.72	0.11	1.10	7.28	1.10	8.10	5.94	3.10	8.40	5.91	0.10
Na_2O	2.90	4.70	3.20	4.38	3.90	4.30	3.26	4.30	3.00	3.54	5.30	3.50	3.76	4.30
K_2O	1.01	3.38	0.42	3.44	4.01	3.76	1.88	3.30	1.14	2.24	2.16	1.40	2.02	3.64
P_2O_5	0.52	0.06	0.46	0.02	0.02	0.14	0.55	0.04	0.22	0.23	0.40	0.26	0.40	-0.02
SO_3		-0.02	-0.02			-0.02		-0.02	-0.02		-0.02	-0.02		-0.02
CO_2		-0.10	2.80			-0.10		0.10	-0.10		1.20	1.70		-0.10
H_2O		0.31	0.22					0.10	0.19		0.17	0.32		0.28
LOI	4.59	1.09	5.00	0.76	0.93	0.87	3.56	1.15	2.17	2.69	2.52	3.79	1.13	1.02
Total	99.68	100.48	100.03	99.92	99.95	99.65	99.68	100.55	101.07	99.63	100.50	100.69	99.95	99.52
Ag	<1			<1	<1		<1			<1			<1	
As		4	2			3		1	-1		3	2		-1
Ba	460	800	260	749	647	850	574	720	560	949	480	380	503	690
Ce	65.4	60	55	69.3	29.2	75	70.8	50	45	55.6	65	40	55.4	65
Co	35.3			44.7	65.8		47.7			53.9			63.2	
Cr	30			<10	<10	-10	30	-10	50	80	-10	20	10	-10
Cs	0.63			3.86	1.7		1.83			1.43			0.65	
Cu	102	-5	50	<5	<5	10	126	5	70	22	15	55	23	5
Dy	7.2			6.03	8.28		7.77			5.65			7.35	
Er	4.12			3.93	5.92		4.63			3.56			4.32	
Eu	2.29			1.42	0.55		2.42			1.63			2.16	
Ga	22.4	16	20	18.4	16.8	18	23	16	18	20.4	18	19	24.2	15
Gd	8.25			6.62	4.6		9.14			6.46			7.94	
Hf	6.7	6	6	5.8	7	9	7.1	5	3	6.2	6	3	5.9	6
Ho	1.48			1.28	1.88		1.6			1.15			1.49	
La	29.6	25	25	35.8	14	35	33.5	25	15	25.6	25	20	24.9	30
Li		16	34			4		18	27		16	10		3
Lu	0.58			0.65	0.92		0.64			0.51			0.6	
Mo	2	-1	-1	2	<2	-1	2	-1	-1	<2	-1	-1	2	-1
Nb	6.7	8	9	8.7	9.5	13	7.5	9	2	6.5	9	5	7.9	9
Nd	35.9	30	36	30.9	12.9	46	39.5	26	26	28.6	38	24	31.7	34
Ni	27	-1	14	5	<5	-1	28	1	20	30	-1	11	11	-1
Pb	11	10	8	12	9	10	10	12	10	13	6	4	8	16
Pr	8.24			7.92	3.42		9.09			6.9			7.34	
Rb	19.4	98	8	117.5	132	90	54.8	85	35	54.5	60	25	56.9	110
Sc		6	24			8		6	24		16	20		2
Sm	8.08	6	12	6.29	3.08	12	8.52		6	5.97	8	6	7.13	10
Sn	3	-5	-5	2	3	-5	3	-5	-5	3	-5	-5	3	-5
Sr	567	130	470	120	48.6	210	416	110	890	733	300	480	517	48
Ta	0.2			1.6	1.6		0.4			0.5			0.5	
Tb	1.38			1.14	1.19		1.51			1.07			1.39	
Th	7.2	11	5	10.25	11.5	9	7.6	10	6	10.55	9	4	5.33	13
Ti	<0.5			1.7	1.8		0.5			0.6			0.5	
Tm	0.58			0.58	0.87		0.65			0.49			0.59	
U	2.01	2	-1	2.78	2.62	2	2.14	3	-1	3.05	2	1	1.64	2
V	263	10	260	83	10	20	306	14	200	163	60	170	237	4
W	64			350	399		136			246			271	
Y	40.9	39	42	36.6	53.1	57	44.7	36	19	33.5	47	29	41.7	39
Yb	3.87	6	4	4.12	6.1	7	4.31			3.42			3.96	
Zn	100	200	260	60	44	60	107	51	74	72	83	74	104	34
Zr	249	33	94	195	197	400	271	180	140	229	280	180	233	140

SAMPNO	QFG5212	QFG5225	QFG5227	QFG5284A	QFG5297A	QFG5299	QFG5304D	QFG5407M	BDDP271	QFG5115	QFG5117	QFG5503	QFG5994
Unit	Rvw$_r$	Rvw$_m$	Rvw$_m$	Rvw$_m$	Rvw$_m$	Rvw$_m$	Rvw$_{id}$	Rvw$_m$	Eurimbula Granite	Eurimbula Granite	Eurimbula Granite	Eurimbula Granite	Eurimbula Granite
Comments	Lava	Lava	Lava	Lava	Lava	Lava	Ignimbrite	Lava	gran	gran	gran	gran	gran
Easting_94	359552	363919	369436	378561	356118	356551	362178	377515	362660	378419	375007	366103	362675
Northing_94	7320026	7331953	7334008	7292702	7322306	7322075	7311345	7296538	7328500	7323007	7326485	7320944	7327720
Method	icp	xrf	xrf	xrf	xrf	icp	xrf	xrf	xrf	xrf	xrf	xrf	xrf
SiO_2	75.80	55.30	53.70	58.10	54.10	57.50	68.60	58.40	69.60	74.10	75.60	75.80	70.60
TiO_2	0.17	1.04	1.40	0.68	1.14	0.66	0.60	0.82	0.52	0.24	0.20	0.22	0.56
Al_2O_3	13.30	17.50	16.90	16.40	18.30	16.35	15.30	15.60	15.10	13.50	13.20	12.90	14.80
Fe_2O_3T	1.20	7.30	8.60	6.30	6.50	5.90	3.00	6.50	2.90	1.80	1.10	1.40	2.20
Fe_2O_3		1.90	3.60	2.50	2.90		1.30	4.10	2.70	0.90	0.90	1.10	1.50
FeO		4.90	4.50	3.40	3.20		1.50	2.20	0.20	0.80	0.20	0.30	0.60
MnO	0.02	0.10	0.12	0.12	0.10	0.12	0.12	0.12	0.06	0.06	0.06	0.08	0.08
MgO	0.06	3.60	3.80	3.20	1.40	2.87	0.80	2.50	0.50	0.40	0.20	0.30	0.60
CaO	0.15	6.70	6.70	5.20	7.90	5.00	1.90	4.20	1.20	1.40	0.40	0.30	1.80
Na_2O	4.22	3.10	3.80	4.90	3.60	5.80	5.20	5.70	5.00	4.10	4.60	4.40	5.70
K_2O	4.25	1.26	2.06	0.66	1.36	0.62	3.08	1.24	3.40	3.96	3.96	4.06	2.48
P_2O_5	0.06	0.28	0.44	0.14	0.32	0.23	0.12	0.18	0.12	0.06	0.02	0.04	0.12
SO_3		-0.02	0.04	-0.02	-0.02		-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
CO_2		2.00	0.20	1.70	2.90		-0.10	2.10	-0.10	-0.10	-0.10	-0.10	-0.10
H_2O		0.29	0.22	0.43	0.22		0.23	0.82	0.57	0.20	0.30	0.62	0.41
LOI	0.74	4.60	2.08	4.48	4.71	4.93	1.07	5.20	1.53	0.65	0.75	1.13	1.21
Total	99.97	100.78	99.60	100.18	99.43	99.98	99.79	100.46	99.93	100.27	100.09	100.63	100.15
Ag	<1					<1							
As		1	2	2	5		2	7	-1	1	-1	-1	-1
Ba	739	500	450	130	370	224	630	460	660	480	720	750	500
Ce	72	35	50	20	45	31.5	70	30	70	50	60	65	60
Co	62					35.9							
Cr	<10	40	70	60	20	40	-10	60	-10	-10	-10	-10	-10
Cs	3.39					0.97							
Cu	<5	50	90	35	50	29	10	40	15	-5	-5	5	15
Dy	5.64					3.87							
Er	3.98					2.44							
Eu	0.9					1.08							
Ga	16.1	20	20	16	20	20	18	16	17	16	14	15	17
Gd	5.94					4.11							
Hf	5	3	5	1	5	3.5	8	3	10	5	6	5	9
Ho	1.21					0.81							
La	34.1	15	20	10	20	16.8	30	10	30	15	25	25	25
Li		44	14	22	12		14	13	5	19	6	9	6
Lu	0.64					0.37							
Mo	2	-1	-1	-1	-1	<2	-1	-1	2	-1	2	-1	-1
Nb	9.2	4	5	2	6	3.4	11	2	10	8	11	9	10
Nd	30.8	24	30	12	24	16.7	40	18	36	26	36	34	30
Ni	<5	33	59	33	19	16	4	37	2	-1	-1	-1	-1
Pb	11	10	4	4	8	8	10	8	8	16	12	14	8
Pr	8.32					4.03							
Rb	121.5	34	56	15	34	19.9	86	19	93	140	120	130	70
Sc		18	20	20	16		10	18	6	6	4	4	8
Sm	5.89	4	8	4	6	3.63	10	6	8				
Sn	3	-5	-5	-5	-5	1	-5	-5	-5	-5	-5	-5	-5
Sr	60.2	520	520	470	480	523	270	360	160	130	55	65	170
Ta	0.7					0.2							
Tb	1.08					0.69							
Th	12.5	5	6	3	7	4.04	9	3	10	15	10	10	7
Ti	0.7					<0.5							
Tm	0.58					0.34							
U	2.82	1	2	-1	2	1.34	2	-1	1	3	3	3	2
V	17	190	230	150	180	173	28	150	26	18	2	4	28
W	442					123							
Y	38.2	29	34	17	28	22.7	50	18	43	43	43	47	38
Yb	4.15					2.39			4	7	8	7	9
Zn	25	91	82	76	68	72	75	60	41	25	25	85	64
Zr	151	170	220	94	190	121	370	120	330	130	170	160	350

SAMPNO	QFG5435A	QFG5437A	QFG5442	QFG5451A	QFG5452	QFG5455	QFG5891A	QFG5892	QFG5389	QFG5390	QFG5397A	QFG5397B	BDDP081	QFG5101	QFG5889	QFG5112	QFG5424A	QFG5425	QFG5426B	QFG5427	QFG6261	QFG6265	BDDP086A	BDDP086B	BDDP250
Unit	Bustard Head Granodiorite	Bustard Head Granodiorite	Bustard Head Granodiorite	Bustard Head Granodiorite	Bustard Head Granodiorite	Bustard Head Granodiorite	Colosseum Granite	Colosseum Granite	Matchbox Range Granite	Matchbox Range Granite	Matchbox Range Granite	Matchbox Range Granite	Matchbox Range Granite?	North Gwynne Granite	North Gwynne Granite	Tolson Creek Igneous Complex/g	Tolson Creek Igneous Complex/g	Tolson Creek Igneous Complex/g	Tolson Creek Igneous Complex/g	Tolson Creek Igneous Complex/g	Tolson Creek Igneous Complex/g	Tolson Creek Igneous Complex/g	Turkey Beach Granite	Turkey Beach Granite	Turkey Beach Granite
Comments	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran	gran
Easting_94	371867	371707	371854	374257	374370	373744	360307	358749	384028	384116	387450	387450	383132	367534	367650	372250	369990	370040	369730	370243	367738	370356	354335	354335	354037
Northing_94	7343256	7344064	7344792	7341505	7341402	7343110	7300834	7302645	7299976	7299846	7296849	7296849	7311264	7302130	7287587	7308240	7307372	7307341	7307285	7309878	7308529	7306661	7340700	7340700	7339379
Method	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf	xrf
SiO_2	70.60	65.00	70.80	72.40	73.70	74.00	66.60	65.20	67.70	68.30	75.50	74.20	77.30	65.20	74.10	73.40	55.90	77.60	77.40	76.30	75.90	52.70	50.50	72.80	54.70
TiO_2	0.48	0.78	0.42	0.44	0.38	0.36	0.64	0.72	0.70	0.62	0.20	0.24	0.08	0.70	0.22	0.28	1.54	0.08	0.08	0.14	0.15	1.54	1.46	0.30	1.28
Al_2O_3	14.50	15.90	14.50	13.80	13.00	12.90	15.60	15.70	14.90	15.10	13.10	13.70	12.30	15.90	14.10	13.70	16.30	12.00	11.90	13.00	12.90	17.00	16.70	14.20	15.60
Fe_2O_3T	2.60	4.30	2.40	2.10	2.00	1.90	4.00	4.50	3.70	3.50	1.00	1.40	0.70	4.40	1.40	1.90	8.80	1.30	1.40	1.10	1.40	8.40	9.90	2.30	8.90
Fe_2O_3	1.50	2.40	1.50	1.20	1.30	1.30	1.80	1.80	1.80	1.70	0.90	0.60	0.70	1.70	1.10	1.00	3.50	1.30	1.20	0.90	1.00	1.70	1.80	1.20	2.00
FeO	1.00	1.70	0.80	0.80	0.60	0.50	2.00	2.40	1.70	1.60	0.10	0.70	-0.10	2.40	0.30	0.80	4.80	-0.10	0.20	0.20	0.40	6.00	7.30	1.00	6.20
MnO	0.10	0.14	0.12	0.10	0.08	0.08	0.08	0.06	0.10	0.08	0.02	0.06	0.04	0.06	0.06	0.06	0.14	-0.02	0.02	0.04	0.08	0.14	0.18	0.02	0.16
MgO	0.70	1.50	0.60	0.50	0.50	0.40	1.60	1.80	1.10	1.00	0.20	0.40	-0.10	1.70	0.30	0.30	3.40	-0.10	-0.10	0.10	0.20	4.50	7.20	0.30	5.30
CaO	1.60	3.70	1.30	1.00	0.70	0.60	3.20	3.50	2.50	2.50	0.30	0.80	0.30	3.60	0.60	1.00	6.50	0.10	0.10	0.20	0.40	9.70	10.00	1.20	8.60
Na_2O	5.00	4.90	5.20	4.80	4.50	4.60	4.70	4.70	4.10	4.30	4.00	3.90	4.10	4.80	5.20	4.80	4.20	5.10	4.40	4.40	4.30	3.70	3.10	4.50	3.20
K_2O	3.08	2.40	3.10	3.38	3.72	3.78	2.48	2.46	3.56	3.58	4.58	4.62	4.40	2.38	3.96	3.46	1.62	3.08	4.14	4.14	4.18	0.78	0.72	4.36	0.92
P_2O_5	0.12	0.26	0.10	0.10	0.06	0.06	0.18	0.20	0.20	0.20	0.02	0.04	-0.02	0.18	0.04	0.04	0.34	-0.02	-0.02	-0.02	0.02	0.36	0.18	0.04	0.16
SO_3	-0.02	-0.02	-0.02	0.12	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	0.10	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	0.14	-0.02	-0.02
CO_2	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.03	0.30	-0.10	-0.10	-0.10	-0.10	-0.10	0.40	-0.03	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	0.10	0.20	0.10
H_2O	0.42	0.33	0.52	0.48	0.46	0.50	0.24	0.34	0.40	0.40	0.35	0.30	0.40	0.28	0.25	0.35	0.36	0.46	0.45	0.56	0.42	0.13	0.06	0.15	0.08
LOI	1.02	1.04	1.42	1.10	0.97	1.06	1.39	1.60	1.62	1.46	0.99	0.91	0.86	1.66	0.56	0.97	1.88	0.69	0.61	1.08	0.98	1.06	0.84	0.52	0.97
Total	99.80	99.92	99.96	99.72	99.61	99.74	100.47	100.44	100.18	100.64	99.91	100.27	99.96	100.58	100.54	99.91	100.62	99.81	99.93	100.48	100.51	99.88	100.78	100.54	99.79
Ag																									
As	2	-1	-1	-1	-1	-1	1	5	-1	-1	-1	-1	-1	3	-1	3	-1	-1	-1	-1	2	-1	-1	-1	-1
Ba	670	400	570	610	630	610	440	440	730	730	480	540	82	430	770	620	350	120	110	640	630	180	92	460	150
Ce	75	60	65	85	90	80	50	55	65	60	75	60	60	40	95	80	45	40	70	60	70	35	15	50	25
Co																					30	50			
Cr	-10	-10	-10	-10	-10	-10	10	10	-10	-10	-10	-10	-10	10	-10	-10	-10	-10	-10	-10			170	-10	80
Cs																									
Cu	10	10	10	5	5	10	15	20	15	15	5	5	-5	20	5	5	35	-5	5	-5	-5	45	60	10	30
Dy																									
Er																									
Eu																									
Ga	17	18	17	16	16	16	17	19	16	17	15	15	16	19	14	16	19	19	16	15	14	19	18	19	18
Gd																									
Hf	9	7	7	9	9	8	7	9	6	7	6	5	4	9	7	6	3	9	9	5	5	2	3	10	5
Ho																									
La	40	20	30	35	40	35	20	20	25	35	30	30	30	20	65	40	15	10	30	25	35	10	10	20	10
Li	9	10	9	11	8	8	13	21	15	16	2	6	5	22	49	14	9	13	1	6	10	10	9	6	7
Lu																									
Mo	-1	-1	-1	1	3	5	-1	-1	1	-1	-1	3	-1	-1	-1	-1	-1	-1	-1	2	-1	-1	-1	-1	-1
Nb	10	7	9	12	11	12	5	7	7	6	9	6	13	8	9	9	7	13	11	9	10	4	3	6	4
Nd	42	32	38	46	46	44	24	28	38	38	42	32	46	26	54	48	30	16	38	28	34	20	16	32	18
Ni	3	5	-1	3	3	3	10	12	-1	-1	-1	-1	-1	12	-1	-1	6	-1	-1	-1	-1	33	83	-1	8
Pb	6	4	10	6	8	8	6	8	10	8	10	12	28	4	12	12	4	16	8	14	16	8	4	12	4
Pr																									
Rb	84	77	89	97	120	110	82	73	110	110	160	160	200	71	130	120	47	100	130	140	140	27	26	170	46
Sc	8	10	6	8	6	6	8	10	10	10	4	4	6	10	2	6	22	-2	-2	2	6	32	30	4	32
Sm	12	8	8	10	10	10	6	8																	
Sn	-5	-5	-5	-5	-5	5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Sr	190	360	180	130	86	73	280	280	260	270	61	120	9	280	87	110	400	8	7	59	55	480	200	53	200
Ta																									
Tb																									
Th	11	10	9	12	13	12	7	9	12	12	15	14	22	9	13	11	7	16	13	14	15	4	3	17	4
Ti																									
Tm																									
U	3	2	2	4	4	4	2	3	2	3	3	3	5	2	5	3	1	3	3	4	4	-1	1	5	-1
V	22	70	20	16	14	12	68	74	58	58	8	14	-2	70	8	10	220	-2	4	4	6	220	220	14	210
W																									
Y	52	41	48	57	56	54	30	35	39	39	52	37	90	34	56	61	36	40	45	35	42	30	31	46	28
Yb	7	6	8	8	8	10	5	5	6	6	7	5	12	5	6	9	4	7	7	5	7	2	3	8	2
Zn	73	60	51	59	53	55	55	49	63	45	55	62	44	40	54	42	95	49	24	25	150	91	73	19	57
Zr	310	220	250	310	280	270	220	260	260	250	160	200	97	270	200	270	200	200	200	150	41	62	130	320	110