Chapter 1: Overview

INTRODUCTION

The Early Permian Boggabri Volcanics (Hanlon, 1949b) crop out around Boggabri (160 km west of Armidale) in northern New South Wales (Fig. 1). The volcanic rocks are part of the surface expression of a major basement feature of the Gunnedah Basin known as the Boggabri Ridge (Brownlow, 1981b). This ridge trends north-north-westerly through Boggabri and is over 100 km long (largely in the subsurface).

The Boggabri Volcanics crop out over an area of about 18 km by 17 km (about 350 km^2) immediately north of Boggabri. These volcanic rocks form hills that rise up to about 200 m above the extensive alluvial plain of the Namoi River. The Namoi River cuts through the hills developed on the Boggabri Volcanics, even though they are some of the most resistant rocks in the district. In general, topography developed on overlying sedimentary rocks is more subdued except where those rocks are intruded by or capped by Tertiary igneous rocks.

REGIONAL GEOLOGICAL SETTING

The Gunnedah Basin is part of an extensive, northerly trending basin complex — the Permo-Triassic Sydney-Bowen Basin (Fig. 2). The Sydney-Bowen Basin (SBB) constitutes one of the most prominent features of eastern Australian geology (Mayne et al., 1974; Day et al., 1978; Scheibner, 1989; Tadros, 1993b). It is about 1700 km long, up to 250 km wide, and its fill is up to 10 km thick.

The SBB is divided into four segments, namely (from south to north): the northerly trending Sydney Basin which is about 400 km long and up to 200 km wide, the NNW trending Gunnedah Basin which is about 350 km long and up to 200 km wide, the northerly trending Taroom Trough which is about 600 km and 100 km wide, and the NNW trending Bowen Basin which is about 400 km and up to 250 km wide. The Meandarra Gravity Ridge (Murray et al., 1989; Tadros, 1993b) approximately marks the axis of the first three of these segments.

The Lachlan Fold Belt (LFB) in New South Wales and the Thomson Fold Belt (TFB) in Queensland underlies and extends westerly from the SBB. These two fold belts trend

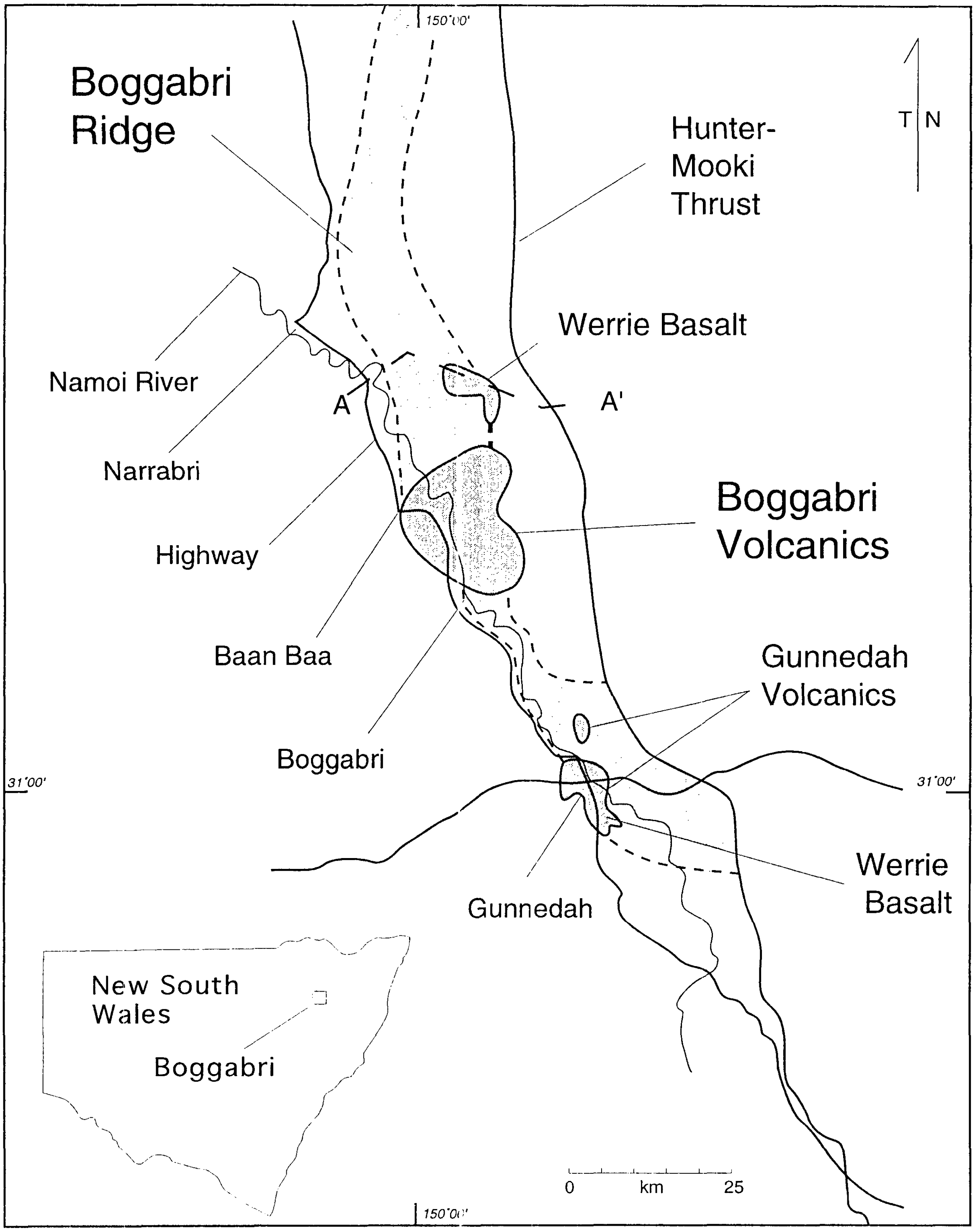


Fig. 1: Geographic setting of Boggabri and the Boggabri Ridge in the north-eastern Gunnedah Basin, including the subsurface ridge (pale stipple) and its surface expression as the Boggabri Volcanics, Gunnedah Volcanics, and Werrie Basalt (darker stipple) (modified from Hill, 1986). The study area corresponds to the outcrop area of the Boggabri Volcanics. See Fig. 4 for cross section along line AA.

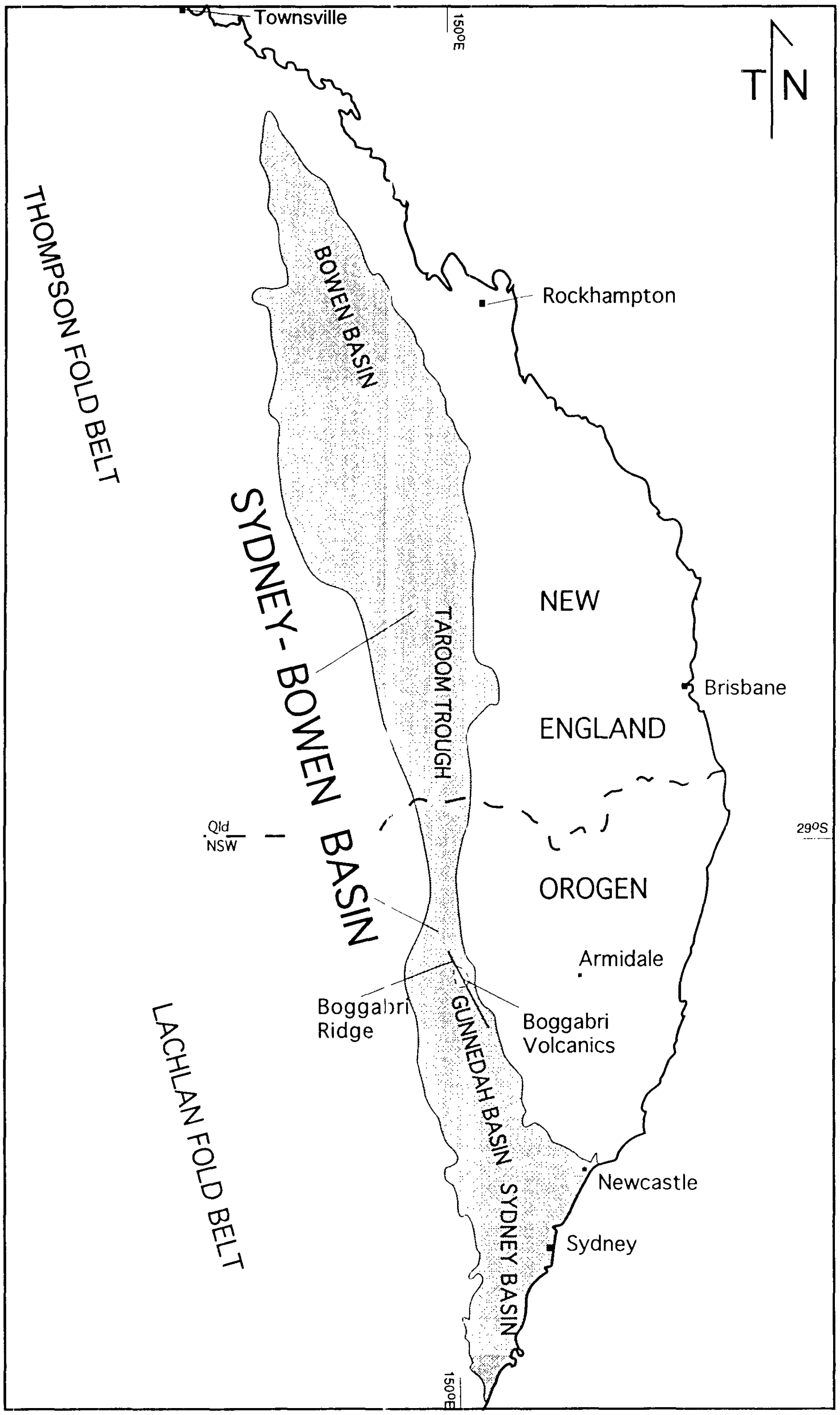


Fig. 2: Regional geological setting in relationship to the Sydney-Bowen Basin and its components, the LFB and TFB to the west, and the NEO to the east (after Tadros, 1993b).

northerly and comprise Palaeozoic metasediments and metavolcanics, intruded by granitoids ranging from Silurian to Carboniferous age (e.g., Scheibner, 1989). The Bathurst-type granitoids of mid? Carboniferous age are the youngest and most easterly of these suites and have commonly been considered to be related to the Late Carboniferous volcanic rocks of the Tamworth Belt in the western New England Orogen (e.g., Shaw and Flood, 1993). Felsic ignimbrites and lavas of the Early Permian Rylstone Volcanics (Shaw et al., 1989) locally overlie the LFB along its eastern margin.

The New England Orogen (NEO) or fold belt occurs immediately east of the SBB. It comprises a complex assemblage of pre-Permian arc fringe and fore-arc, accretionary complex, ophiolite and other terranes, and Permo-Carboniferous to Triassic granitoids, volcanic rocks and basins [see recent Geological Survey of NSW publications such as Gilligan and Brownlow, 1987; Brownlow *in* Gilligan et al., 1992; Brown et al., 1992; see also numerous papers *in* Flood and Aitchison (1993) for recent reviews; see also Appendix 5]. This is the easternmost zone of Palaeozoic rocks in eastern Australia and extends for about 1500 kilometres along the eastern Australian coastline from Newcastle in central New South Wales to Townsville in North Queensland. Devonian to Carboniferous accretionary complex rocks form much of the eastern part of the province, whereas arc-fringe and fore-arc rocks form much of the western part of this province (Tamworth and Yarrol Belts). Palaeogeographic reconstructions infer the presence of a series of Devonian to Carboniferous arcs west of the arc fringe and fore-arc rocks of the Tamworth and Yarrol Belts. These inferred arcs are apparently now buried beneath the SBB, or thrust easterly beneath the western margin of the Tamworth Belt. Minor Late Carboniferous volcanic rocks exposed in the Lochinvar Anticline in the northern Sydney Basin apparently represent a remnant of the youngest arc (e.g., Shaw and Flood, 1993). Several episodes of regional deformation, plutonism and volcanism affected the NEO during the latest Carboniferous to Late Triassic, and extensive basins developed in the region during Early Permian and Middle or Late Triassic volcanism (e.g., Brownlow, 1988b; Shaw and Flood, 1993; Veevers et al., 1993; see also Appendix 5).

GUNNEDAH BASIN — GENERAL GEOLOGY

The Gunnedah (structural) Basin (Fig. 3) is that part of the SBB lying between the Coricudgy Anticline and the Moree high (Bembrick et al., 1973; Tadros, 1993a,b). Tadros (1993a) and co-authors summarised known structural and stratigraphic relationships within this basin based on extensive drilling by the Department of Mineral Resources and various private exploration companies.

The Gunnedah Basin is only partly exposed, that part being along or adjacent to the Boggabri Ridge (Fig. 4). It is overlain in the north and west by the Surat Basin which

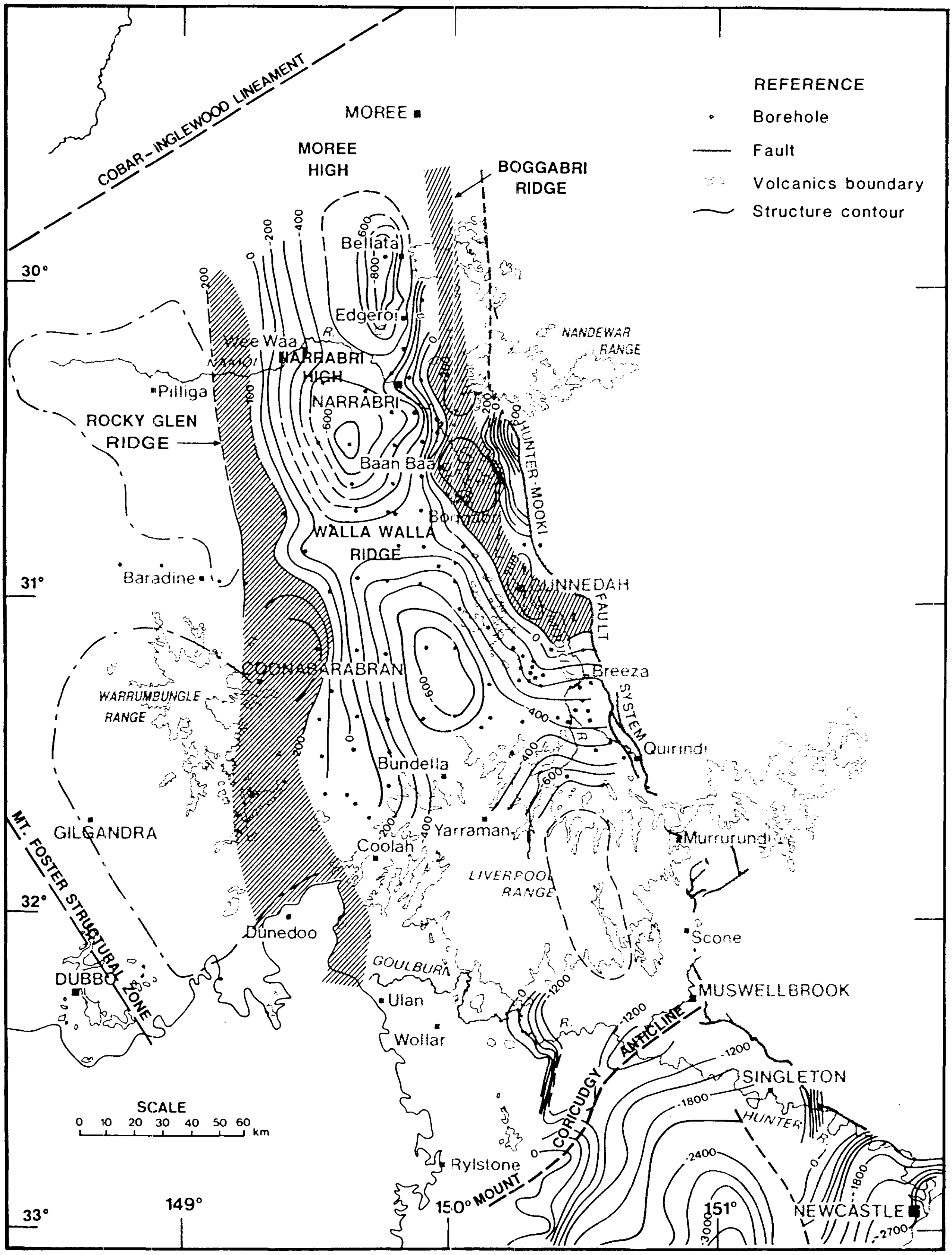


Fig. 3: Structure contours on top of the basal volcanic rocks of the Gunnedah Basin showing the basin structure of longitudinal sub-basins and prominent ridges and highs (after Tadros, 1993b).

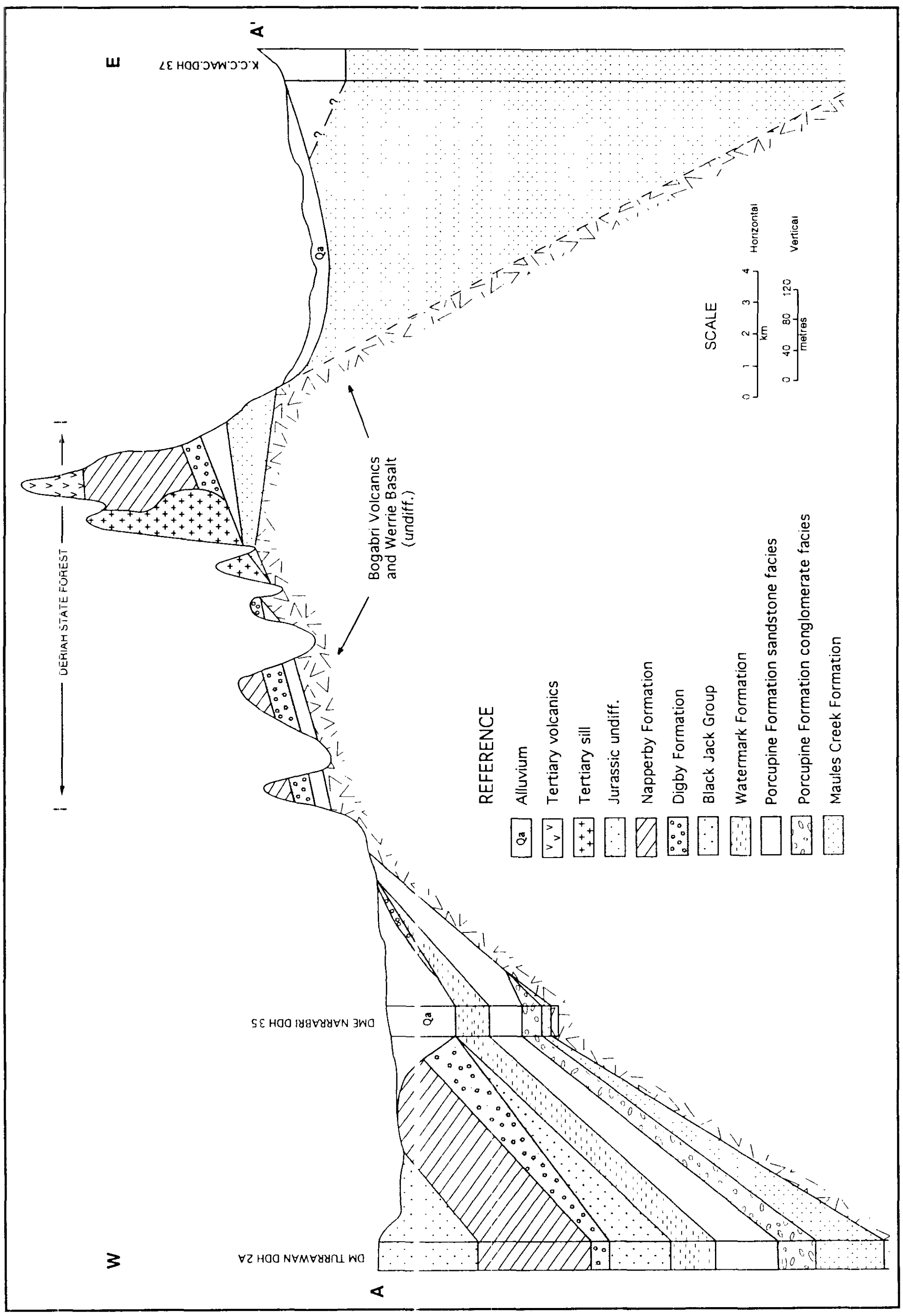


Fig. 4: Cross section across the Boggabri Ridge in the Deriah district about 50 km north-east of Boggabri (after Hill, 1986). This section corresponds to line AA′ on Fig. 1.

comprises Jurassic volcanic rocks (Garrawilla Volcanics) and Jurassic to Cretaceous sedimentary rocks. Tertiary volcanics of the Liverpool Range province overlie the southern extension of the Surat Basin in the Liverpool range area, and those of the Nandewar Province directly overlie the Gunnedah Basin in the Nandewar Range area.

Basin Structure

The Gunnedah Basin trends NNW (Fig. 3). It is bordered to the east by the Mooki Fault System (Carey, 1934) which separates it from the NEO. To the west it onlaps the LFB. The Coricudgy Anticline separates the Gunnedah Basin from the Sydney Basin to the south. The Moree High separates it from the Taroom Trough to the north.

Two flanking sub-basins and three transverse highs complicate an otherwise gentle basinal shape between two longitudinal ridges. The longitudinal ridges are the Rocky Glen Ridge in the western side of the basin, and the Boggabri Ridge in the east (Fig. 3). The main part of the basin (the Mullaley Sub-basin) occurs between these ridges, and contains up to 1200 m of sediments. The Gilgandra Sub-basin west of the Rocky Glen Ridge (Yoo, 1988) possibly contains > 2km? of sediment fill. The Maules Creek Sub-basin, east of the Boggabri Ridge contains up to 800 m of sediments and thickens eastward. The transverse structures in the Mullaley Sub-basin are (from north to south) the Narrabri High, the Walla Walla Ridge and the Bundella-Yarraman High. The outcrop area of Boggabri Volcanics at Boggabri approximately coincide with the intersection of the Boggabri and Walla Walla ridges. The Walla Walla Ridge is not obvious east of the Boggabri Ridge on Fig. 3. However, a basement high is evident in the Maules Creek Sub-basin, about 20 km further north around Timor Mountain where the Leard Formation has been mapped (Brownlow, 1981b) and in the nearby Deriah Creek area where the Werrie Basalt has been mapped (Hill, 1986).

This basin structure, as described above plus the eastern margin formed by the easterly dipping Mooki Fault System is confirmed by a recent east-west seismic profile (Korsch et al., 1993) across the Boggabri Volcanics just north of Boggabri.

Basal Volcanics

Felsic and mafic volcanic rocks crop out along the Boggabri Ridge close to the eastern margin of the Gunnedah Basin, and are widespread in the subsurface (Hanlon, 1949a,b; 1950; Manser, 1965a,b; Leitch et al., 1988; Leitch and Skilbeck, 1991; Leitch, 1993; Tadros, 1993c; McPhie, 1984b). Felsic volcanic dominate at Boggabri and have been named the Boggabri Volcanics (Hanlon, 1949b). Felsic volcanic rocks are less prominent around Gunnedah, where they have been known as the Gunnedah Lavas (Kenny, 1964), Gunnedah Volcanics (Manser, 1965a,b) and more recently the Boggabri Volcanics (Russell, 1981; Leitch, 1993). About 135 m of basalt (Werrie Basalt) overlies those felsic volcanic rocks at Gunnedah (Hanlon, 1949a; Manser, 1965a,b).

Similar volcanic rocks underlie much of the Gunnedah Basin sedimentary fill, and these have been extensively sampled in coal and petroleum drilling in the Gunnedah Basin (Tadros, 1993c; Letich et al., 1988; Leitch and Skilbeck, 1991; Leitch, 1993). Unwelded to densely welded ignimbrites, rare ash fall tuff and rare rhyolite lava occur in two restricted zones, one extending north-westerly from the exposed Boggabri Ridge, and the other along the eastern side of the Rocky Glen Ridge (Leitch and Skilbeck, 1991; Leitch, 1993). In addition, 70 m of 'rhyolite' underlies 600 m of andesite in MEO Pilliga No. 1 (Leitch, 1993). Current practice is to refer all of these felsic volcanic rocks to the Boggabri Volcanics (Russell, 1981; Leitch, 1993; Tadros, 1993c). Basalt, lesser andesite and dacite are widespread elsewhere at the base of the Gunnedah Basin (Leitch et al., 1988; Leitch and Skilbeck, 1991; Leitch, 1993). These rocks comprise lava flows from 1–32 m thick with highly amygdaloidal upper parts and more massive and coarser-grained lower parts along with minor autoclastic breccia, one intrusive dolerite, one basaltic ash fall, and scattered weathering intervals. These are all currently referred to the Werrie Basalt (Leitch and Skilbeck, 1991; Leitch, 1993), a practice questioned by McPhie (1984b). The stratigraphic relationship within the volcanic pile between the various volcanic rocks currently referred to the Boggabri Volcanics and between them and the apparently dominant Werrie Basalt is currently uncertain.

Direct dating of the Boggabri Volcanics and Werrie Basalt in the Gunnedah Basin is restricted to a few palynological samples. Evans (1967) recorded Stage 3a spores from the Werrie Basalt in Amoseas Bohena RDH 1 in the central Gunnedah Basin (see Fig. 6 and text for an explanation of these Stages). He also recorded Stage 2 or 3a spores from a lower horizon, and Stage 3a spores from sediments interbedded with ?Boggabri Volcanics in MEO Kelvin No. 1. The latter assignment is complicated because that hole probably intersected the Mooki Fault System, which separates the Gunnedah Basin from the NEO. Morgan (1978) recovered possible Stage 2 (PP1) spores from varved shales in the Boggabri Volcanics sampled during investigations by Brownlow (1981b). McMinn (1993) recorded a Stage 3a (PP2.1) age from 'Boggabri Volcanics' in DM Eulah DDH 1 which were drilled on the Boggabri Ridge north of Maules Creek, north-east of Boggabri. However, Hill (1986) had logged the sequence sampled as part of the Werrie Basalt. Thus the Werrie Basalt is probably Stage 3a in age, but the relative stratigraphic position and age of the Boggabri Volcanics is uncertain.

Basin Fill

A Permo-Triassic sedimentary sequence overlies the basal volcanic rocks (Fig. 5). This sequence is up to 1200 m thick in the Mullaley Sub-basin and mainly comprises Permian marine and coal measure sediments, and Early to Middle Triassic terrestrial sediments (see Tadros, 1993c and papers cited therein for extensive reviews).

Several of the lowermost Permian units are relevant to this study, because they either onlap the Boggabri Ridge and/or are supposedly derived from the Boggabri Volcanics forming the Ridge. These are the Goonbri, Leard, Maules Creek and Porcupine formations. Correlations with the classic Hunter Valley sequence (northern Sydney Basin) are indicated to illustrate their regional significance.

The Goonbri Formation comprises lacustrine siltstone, laminite, and sandstone. Palynological dating indicates a Stage 3b age (McMinn, 1981). These are apparently thin (probably a few tens of metres thick) and overlie the Boggabri Volcanics in the subsurface Maules Creek and Mullaley sub-Basins (Thomson, 1986). (The fine-grained nature of this unit is reminiscent of the Rutherford Formation of the Hunter Valley, except that the latter unit is marine.) The relationship of the Goonbri Formation with the Leard Formation is uncertain: Thomson (1986) and Thomson et al. (1993) suggested that the Goonbri Formation is younger, whereas palynological data suggests that the Goonbri Formation is older (cf Morgan, 1978, McMinn, 1981). Whether thin porcellaneous siltstones at the base of the Maules Creek Formation (Brownlow, 1981b) have been confused with the Goonbri Formation is unclear.

The Leard Formation is the lower of two coal measure units. It is a thin, 'flint clay' sequence comprising sediments with clasts of kaolinitic 'clayrock' or 'pelletoidal claystone' (Loughnan, 1975; Brownlow, 1981b; Tadros, 1993c; Whitehouse, 1993). Palynological dating indicates a Lower Stage 4 age (McMinn, 1993). This unit is < 1 m to a few metres thick in outcrop on the eastern side of the Boggabri Ridge, and thinner in outcrop on the western side of the ridge. It thickens irregularly to 12–18 m in the deeper parts of the Maules Creek and Mullaley sub-basins. The Leard Formation can be traced as far south as the Muswellbrook Anticline at the southern end of the Gunnedah Basin where the equivalent is the flint clay sequence forming the Skeletar Formation (Loughnan, 1975; Brownlow, 1981b; Tadros, 1993c). No lithological equivalent is known from the Sydney Basin. The Leard Formation was probably derived from intensely weathered volcanic rocks on the Boggabri Ridge, but whether these were felsic or mafic is controversial.

The Maules Creek Formation is the upper of the two coal measure units and is up to 800 m thick east of the Boggabri Ridge, and locally more than 125 m thick in the middle of the Gunnedah Basin. This unit comprises a thick, conglomeratic sequence composed of

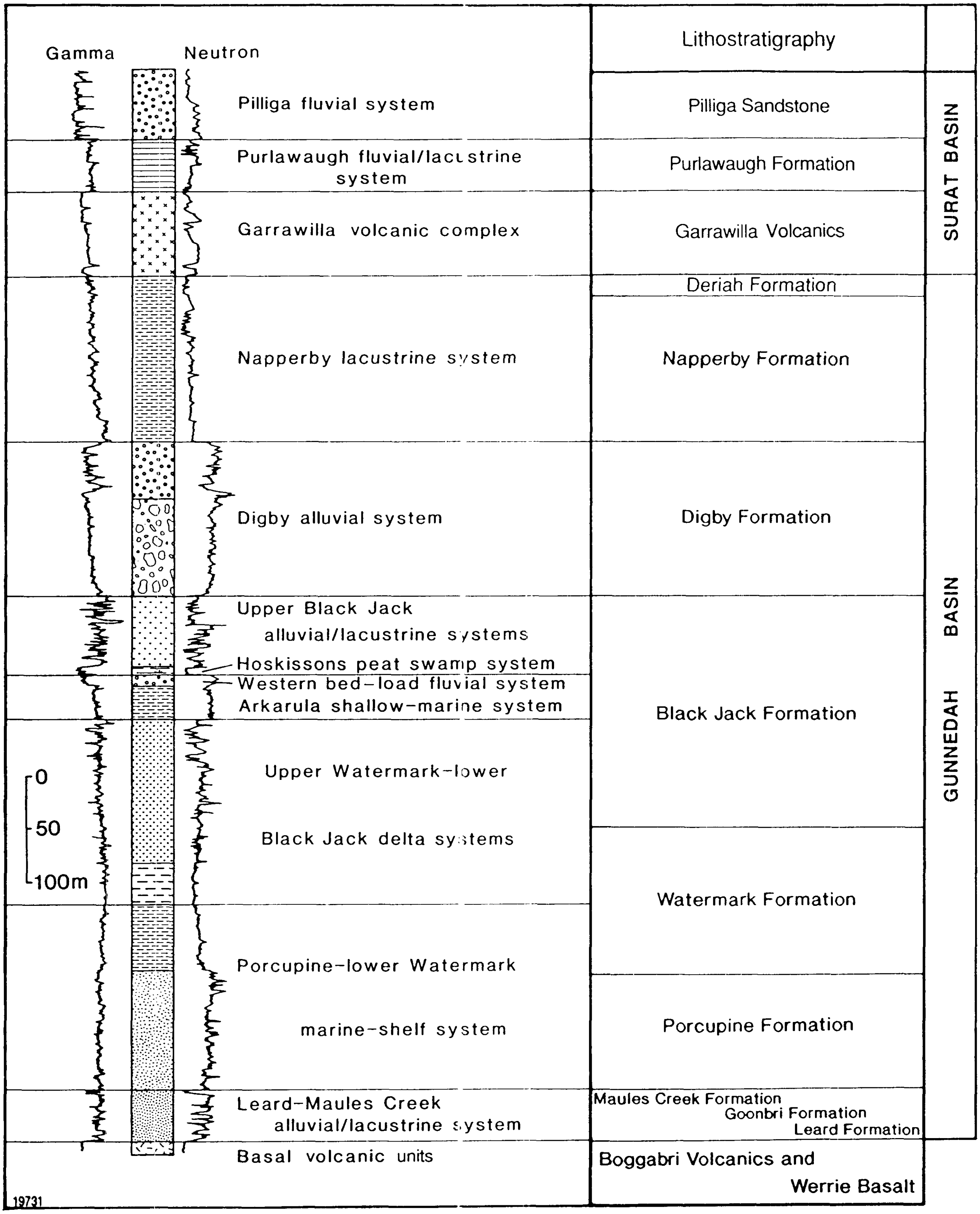


Fig. 5: Depositional systems and lithostratigraphy of the Permo-Triassic Gunnedah and Jurassic Surat Basin sequences (after Hamilton, 1993). Note that the Black Jack Formation is now the Black Jack Group (Tadros, 1993c).

slightly weathered clasts (contrasting with the intensely weathered clasts of the Leard Formation). Palynological dating indicates a Lower Stage 4 age to Upper Stage 4a age (McMinn, 1993). These sediments were mainly deposited in braided stream and lacustrine environments and supposedly derived mainly from uplifted parts of the Boggabri Ridge with a lesser quartzose component from the LFB to the west (Thomson, 1986; Thomson et al., 1993). The Maules Creek Formation is lithologically equivalent to the Rowan Formation at Muswellbrook in the upper Hunter Valley and probably to the Greta ('Lower') Coal Measures in the lower Hunter Valley. However, the time equivalents of the lower Maules Creek Formation could be the shallow marine Farley Formation beneath the Greta Coal Measures (Briggs, 1993). That would indicate that the onset of coal measure sedimentation in the Gunnedah Basin coincided approximately with a major regression in the Hunter Valley sequence (cf Herbert, 1980).

The Porcupine Formation comprises mainly pebbly to muddy sandstone. Palynological dating indicates a Lower Stage 5 age (McMinn, 1993). This formation and the lower part of the overlying, mudstone-dominated Watermark Formation were interpreted as products of retreating periglacial fan-deltas, retreating under the influence of marine transgression (Thomson et al., 1993). The coarser sediments were supposedly derived from the Boggabri Ridge. The Porcupine Formation can also be traced along strike into the Hunter Valley, where the Muree Conglomerates forms shoreline conglomerates similar to those locally developed on the eastern margin of the Gunnedah Basin.

The overlying Permian sequence comprises the remainder of the shallow marine Watermark Formation and the terrestrial coal measures and marginal marine sediments of the Black Jack Group (Tadros, 1993c; Hamilton 1993). These are overlain by terrestrial Triassic sediments of the Digby Conglomerate, Napperby Formation and Deriah Formation. The Deriah Formation is notable for containing minor basalt lava; as yet no chemical or petrological data are available for comparison with the Werrie Basalt or Boggabri Volcanics.

BOGGABRI AREA — PREVIOUS WORK

Jensen (1907) recorded 'rhyolites and rhyolitic tuffs' of uncertain age forming 'cones and necks' near Boggabri and showed that these were chemically and mineralogically distinct from the Tertiary volcanics of the Nandewar Range.

Carey (1935) suggested lithological correlation of basalts at Gunnedah and Boggabri with the Werrie Basalt which he defined in the Werrie Syncline, a fold in the Tamworth Belt of the western NEO.

Hanlon (1949b) named the Boggabri Volcanics for flat-lying 'acid lavas and tuffs' of presumed 'Lower Marine' (earliest Permian) age which crop out around Boggabri. He differentiated these (somewhat imprecisely) from: (a) an overlying Permo-Triassic sedimentary sequence; (b) minor basalts underlying the Boggabri Volcanics near the railway line north of Boggabri which he referred to the earliest Permian Werrie Basalt; and (c) a Tertiary alkaline suite composed of rhyolites (including rhyolite allegedly intruding Permian sediments), trachytes, trachyandesites, andesites which occur east of the Namoi River and related to the Nandewar province, north of Boggabri. Hanlon also recognised a structural high (now the Boggabri Ridge) and named several units in the overlying sedimentary sequence.

Manser (1960) described the Boggabri Volcanics and overlying sequence from reconnaissance mapping and petrological observations. He recognised the presence of ignimbrites.

Voisey (1964) summarised then available mapping of the Boggabri area.

Loughnan (1975) showed that the Early Permian sequence overlying the Boggabri Volcanics consists of a thin, basal 'flint clay' sequence (sediments with clasts of kaolinitic 'clayrock' or 'pelletoidal claystone') overlain by a thick 'lithic' sequence (with clasts of fresh to slightly weathered rock).

Brownlow (1981b) named these two sequences the Leard Formation and Maules Creek Formation respectively, discussed the differences between them in detail, mapped the eastern boundary of the volcanic rocks and distinguished a number of younger, probably Tertiary basaltic masses inferred to be intrusives. Brownlow (1981b) also named the Boggabri Ridge.

McPhie (1984b) described an unexpectedly steeply-dipping, ignimbrite-dominated, 600 m thick section through part of the Boggabri Volcanics north east of Boggabri, and within it recognised at least three separate felsic lavas separated by ignimbrites. The upper ignimbrite was about 300 m thick, composed of at least two cooling units, and comparable in profile to Layer 2b of modern ignimbrites (Sparkes et al., 1973). She also recorded several vitrophyre (densely welded, glassy) zones in ignimbrites, relict pyroxene in some dark lavas, and one thin epiclastic horizon containing tuffaceous mudstone, pebble sized glacially dropped stones and a locally lens of accretionary lapilli. She correlated this epiclastic horizon between one site at 'Daisymede' and two sites west of the Namoi River.

Thomson (1986) defined the Goonbri Formation. The need for an additional unit in the Boggabri sequence had arisen when Brownlow (1981, unpublished data) observed that steeply-dipping, fine-grained sedimentary rocks in MAC Maules Creek DDH 44 were lithologically distinct from the Leard and Maules Creek formations, and when McMinn (1981) showed that samples collected then were from palynological Stage 3b, and therefore older than the accepted age of the other two sedimentary formations.

Hill (1986) demonstrated the presence of the Werrie Basalt in the Nandewar Ranges east of Narrabri (and about 50 km north-east of Boggabri) and hence showed that outcrop of the Boggabri Ridge was more extensive than previously thought. The Werrie Basalt was intensely weathered in places and locally comprised two flows, with massive bases and amygdaloidal tops. He considered that they were readily distinguished from Tertiary dolerite by the fresher, harder, and finer-grained nature of the Tertiary rocks.

Schmidt (1988) recorded a minor Au-As(-Sb) soil anomaly and minor pyrite in an area of quartz-veining developed in Boggabri Volcanics north-east of 'Daisymede'.

Leitch et al. (1988), Leitch and Skilbeck (1991) and Leitch (1993) documented basal volcanic rocks in numerous basement cores from extensive Gunnedah Basin drilling carried out by the Department of Mineral Resources. They continued the practice of referring these to either the Boggabri Volcanics or the Werrie Basalt and dismissed objections by McPhie (1984b) who claimed that use of the term Werrie Basalt for these rocks was premature.

Tadros (1993b) postulated the presence of a thrust fault (his Boggabri Fault) cutting both the Boggabri Volcanics and the Boggabri Ridge along the Namoi River north of Boggabri. He inferred westward thrusting on this fault in order to explain the greater elevation of the Maules Creek Formation east to the ridge compared with that to the west of the ridge.

Numerous other authors, particularly those engaged in coal exploration have commented in passing on the Boggabri Volcanics at Boggabri (e.g., Kontos, 1983; Thomson, 1986; Tadros, 1993c and papers cited therein). The internal detail of the Maules Creek Formation is now comparatively well known through intense coal drilling (Thomson, 1986; Tadros, 1993c; Whitehouse, 1993; Thomson et al., 1993). However, the relationship of the Goonbri Formation to the Leard Formation is not well established, due partly to problems in recognising the Leard Formation. Rocks attributed to the Leard Formation at various times include rocks of the Goonbri Formation and a zone of intense alteration developed on rhyolitic lava of the Boggabri Volcanics. This is despite extensive documentation in the original definition of the Leard Formation (Brownlow, 1981b).

PRESENT INVESTIGATION OF THE BOGGABRI VOLCANICS

The Boggabri Volcanics have been selected for investigation because a comprehensive investigation would potentially provide critical information concerning several aspects of the Early Permian geological development of eastern Australia, including:

1. The internal rock relationships of the Boggabri Volcanics and implications for the

structure of the Boggabri Ridge, its development during Early Permian basin formation and modification during subsequent tectonism (especially during deposition of the Leard, Maules Creek and Porcupine formations).

2. The age and stratigraphic position of the Boggabri Volcanics relative to: (a) other supposedly earliest Permian volcanic rocks in the Gunnedah Basin and elsewhere in eastern Australia; (b) Stage 2 age glacigene sediments in the LFB and in the Koburra Trough of the Galilee Basin; and (c) scattered Permo-Carboniferous intrusives in the NEO.
3. The depositional environment of the Boggabri Volcanics, and implications for regional palaeogeography during Early Permian volcanism and basin formation.
4. The compositional range of the Boggabri Volcanics and the nature of causative processes.
5. The compositional affinity of the Boggabri Volcanics relative to global geochemical reservoirs and reference compositions, and relative to Permo-Carboniferous igneous activity in eastern Australia and implications for the nature of the magmatic source(s) for the Boggabri Volcanics and for other Early Permian igneous rocks in eastern Australia.
6. Their regional geological setting, and viability of any existing interpretative model for the genesis of the SBB and the origin of the Early Permian volcanic rocks.
7. The suitability of the Boggabri Volcanics as a source of conglomeratic sediments in the overlying Leard, Maules Creek and Porcupine formations, particularly concerning their compositional suitability and viability of possible uplift mechanisms.

The present study concentrates particularly on items 1 and 4, with briefer attention to other items.

Aims

The aims of field investigations have been to: (a) establish the range and distribution of lithologies and mappable rock units within the Boggabri Volcanics; (b) establish and the internal rock relationships within the Boggabri Volcanics and (c) to reassess the location and nature of the boundaries between the Boggabri Volcanics and other adjacent rock units; and hence to assess the correlation, petrogenesis, and facies development of the Boggabri Volcanics and the subsequent history of the Boggabri Ridge.

Methods

The Boggabri Volcanics and their immediate surrounds were mapped at 1:10,000 scale using enlargements of aerial photographs. Detailed mapping was undertaken wherever practical. However, this practice proved impractical in areas of thick forest cover. There, reconnaissance mapping was used instead, and greater reliance was placed on air photo interpretation. External time constraints, and a change in emphasis (to more extensive geochemical investigations) limited field work at a critical time. Mapping was then sufficiently complete to establish the broad framework of the volcanic rocks (see Map 1), but lacked intended refinements in problematic areas (particularly forested areas). More detailed geochemical sampling and investigations of stratigraphic correlations and physical volcanology were also impractical.

Lithological identification has involved recognition of both mineralogical composition and rock textures (cf Cas and Wright, 1987; McPhie et al., 1993). These identifications were initially carried out in the field using a hand lens, and subsequently refined using a binocular stereo-zoom microscope in concert with extensive Na-cobaltinitrite staining for K-feldspar. Selected samples were further investigated using standard petrographic, geochemical (XRF and INAA), X-ray diffraction and/or electron probe techniques.

CONVENTIONS AND DEFINITIONS

Compositional classification broadly follows the IUGS recommendations and is based primarily on the TAS diagram (LeMaitre et al., 1989), apart from the term "pitchstone" which is used to refer to felsic rocks containing 4-10% H_2O and comprising mainly glass with pitch-like lustre and sparse phenocrysts (Johannsen, 1932). Thin section textural classification follows McKenzie et al. (1982) and McPhie et al. (1993) and volcanic facies concepts follow Cas and Wright (1987) and McPhie et al. (1993). Petrological and geochemical acronyms are summarised in Table 1 (repeated as Table A2.1).

The basic data model used for describing the field occurrence of volcanic rocks is similar to that advocated by McPhie et al. (1993). It involves (a) objective recognition of lithologies at hand specimen scale based on identification of both composition and texture; (b) the objective recognition of lithofacies (rock masses) at outcrop or broader scale; and (c) the inference of depositional facies (genetic) based on use of facies models ('an eruptive unit or part thereof, having distinct spatial and geometric relations and internal characteristics (e.g., 'grainsize and depositional structures...' — Cas and Wright, 1987; McPhie et al., 1993). However, one difference from McPhie et al. (1993) is that the outcrop scale emphasis herein is on 'mappable rock units' rather than on lithofacies.

A mappable rock unit for this purpose is: 'a body of rock that: (a) comprises one rock type or a group of compatible rock types possibly arranged in a regular order; (b) extends over sufficient area to be satisfactorily represented at the mapping scale; (c) can be distinguished in the field from adjacent rock units based on differences in content or

Table 1: Acronyms

ACC	Average Continental Crust
ArcF	Fuji Volcano, Fuji Arc Japan
ArcR	Rindjani Volcano, Lombok, Indonesian Arc
BAB	Back Arc Basalt
BV	Boggabri Volcanics
CAB	Calc-Alkaline Basalt
CFB	Continental Flood Basalts
CRZ	Continental Rift Zone
eM	E-MORB
IAT	Island Arc Tholeiite
IAV	Island Arc Volcanic
LKT	Low-K Tholeiite
mg	Mole Granite
MORB	Mid Ocean Ridge Basalt
NM	Hawaiian Nephelinite Melilitite
OFB	Ocean Floor Basalt
OIA	Ocean Island Alkaline
OIP	Ocean Intraplate
OIT	Ocean Island Tholeiite
pM	Primitive MORB
pyr	Pyrolite
syn-COLG	Syn-Collision
UV	Unassigned volcanic rocks from Boggabri
VAB	Volcanic Arc Basalt
VAG	Volcanic Arc Granite
WP	Within Plate
WPB	Within Plate Basalt
IA & CM	Island Arc and Continental Margin
SCI	Spreading Centre Island
PM	Plate Margin
ACM	Active Continental Margin

internal distribution of lithologies, structures or organic relicts (e.g., body fossils); (d) when considered in context, is worth showing separately from adjacent rock units; and (e) excludes incompatible internal boundaries, such as intrusive boundaries or unconformities in bedded rock bodies...' (from Brownlow in prep., modified after Stevens and Willis, 1983 and the International Stratigraphic Guide, 1983). Apart from emphasising the practicalities of mapping, this concept is broadly compatible with that of a facies which is 'a body or interval of rock or sediment which has a unique definable character (based on composition, texture, sedimentary structures fossils etc) that distinguishes it from other facies or intervals of rock or sediments (e.g., Cas and Wright, 1987; McPhie et al., 1993). There are however, minor but significant differences between facies and mappable rock units: separate facies might be unresolvable and have to be mapped together at a broad scale, whereas detailed mapping might differentiate components of facies (e.g., vitrophyre zones in ignimbrites, multiple flow units in a lava or ignimbrite, cooling units in an ignimbrite).

Time Conventions

This study is principally concerned with 'earliest Permian' times. That interval is defined herein as approximately the time range of palynological Stage 2 (PP1.1) to 3b (PP2.2) inclusive, or of the *Lyonia* to *strzlecki* macrofaunal zones inclusive and apparently corresponds to the late Asselian, Sakmarian and earliest Artinskian epochs (Briggs, 1993 — see Fig. 6). Limited SHRIMP dating of zircons suggests a range of about 298 Ma to possibly 280 Ma for this interval (Roberts et al., 1995; Claoue-Long et al., 1995). Note that palynological Stage 2 has sometimes been considered to be very latest Carboniferous in age (e.g., Evans and Roberts, 1980), and hence the Boggabri Volcanics would probably also have been latest Carboniferous (Brownlow, 1981b, 1982b). Briggs' (1993) Early Permian assignment of both is followed herein.

The 'latest Carboniferous' as used herein is defined as the interval between the end of Late Carboniferous deposition in the Tamworth Belt sequence of northern NSW (about 306 Ma — Claoue-Long et al., 1995) and the beginning of Permian time. Thus the 'latest Carboniferous' would have lasted about 8 Ma, as the base of the Permian is estimated to be about 298 Ma (Roberts et al., 1995). The latest Carboniferous and earliest Permian are also referred to as 'Permo-Carboniferous' when discussing the geological development of the region.

The 'mid Permian' as used herein is defined as the interval spanning the range of the *curtosa* to within the *discinia* macrofaunal zones or the range of Stage 4 (APP3.1 to APP3.3) palynological zones (Briggs, 1993). This interval spans most of the Artinskian and part of the Kungurian epochs (Briggs, 1993), and includes volcanic rocks in the range 274 to 278 Ma (Roberts et al., 1995).

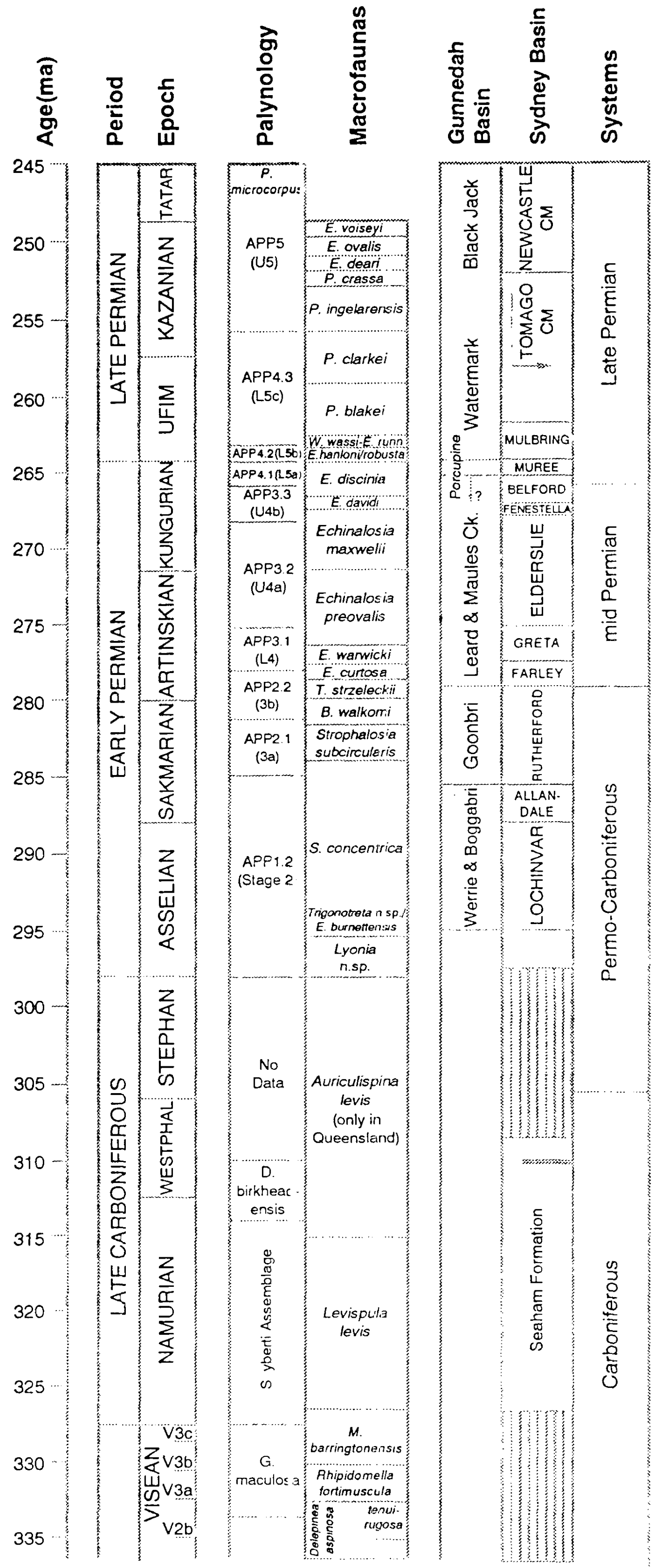


Fig. 6: Time scale for the Permian and Late Carboniferous. Note that there are small but important discrepancies between biostratigraphic correlations of Roberts et al. (1995) which is the source of the radiometric dates, and of Briggs (1993) which is the source of the macrofaunal scale.

Chapter 2: Field Geology of the Boggabri Volcanics

INTRODUCTION

Investigations to date of the Boggabri Volcanics have been essentially reconnaissance in nature and/or limited in extent, and have yielded conflicting information. Jensen (1907) recorded 'rhyolites and rhyolitic tuffs' of forming 'cones and necks'. Hanlon (1949b, 1950) defined the Boggabri Volcanics and recognised a predominance of felsic lavas. In contrast, Manser (1960) claimed a preponderance of felsic ignimbrites. Both implied a mainly flat-lying sequence, probably not much thicker that the 210 m of relief of the exposed volcanic rocks, whereas McPhie (1984b) recorded a 600 m thick, moderately-dipping sequence in the Daisymede area She recognised mainly felsic ignimbrites there, but mainly felsic lavas elsewhere in the Boggabri Volcanics. Hanlon (1950) recorded minor basalt low in the volcanic sequence near the railway line north-west of Boggabri and referred it to the Early Permian Werrie Basalt. His distinction between the Boggabri Volcanics, the Werrie Basalt and the Tertiary volcanics of the Nandewar Province was not consistently clear. Hanlon (1949b) also recorded Tertiary rhyolite intruding the Permian sediments overlying the Boggabri Volcanics in the Leard State Forest. Tadros (1993b) postulated faulting of the Boggabri Volcanics along the Namoi River (the Boggabri Fault).

Specific features of the Boggabri Volcanics recorded to date include: (a) a 300 m thick ignimbrite near the top of the Daisymede section composed of at least two cooling units which resemble Layer 2b of modern ignimbrites (McPhie, 1984b); (b) a thin epiclastic horizon at several localities, containing tuffaceous mudstone, pebble-sized glacial dropped stones and a lens of accretionary lapilli (McPhie, 1984b); (c) a pitchstone at the base of Robertsons Mountain passing laterally into rhyolite (Hanlon, 1950); (d) a pitchstone dyke intruding a more basic flow near 'The Rock' (Hanlon, 1950); (e) olivine-bearing pitchstone at Gins Leap (Manser, 1960); (f) quartz veining and minor pyrite in altered trachyte north-east of 'Daisymede' (Schmidt, 1988); (g) laterally extensive pitchstone beneath rhyolites in the Robertson Mountain/Gins Leap area and associated with distinctive soil and clay (Schmidt, 1988); (h) several deposits of bentonitic clay (Brownlow *in* Brown et al., 1992); scattered occurrences of 'thunder eggs' (agate filled geodes) in the Boggabri-Baan Baa-Therribri district apparently associated with the Boggabri Volcanics (McNevin and Holmes, 1980).

OVERVIEW

The present investigation of the Boggabri Volcanics has revealed:

1. A compositional spectrum ranging from olivine basalt to leucocratic rhyolite, comprising five compositional groups: basalt, andesite, dacite, pyroxene rhyolite, and biotite rhyolite.
2. Expression of this compositional spectrum mainly as lavas, less commonly as ignimbrites, and rarely as volcanic breccias or minor intrusives (Figs 7–9; see also Petrology chapter). Rare volcanogenic sedimentary rocks also crop out.
3. At least 80 mappable rock units recognisable at 1:85,000 scale (approximate scale of Map 1) as lavas and volcaniclastics of the olivine basalt-rhyolite spectrum or as volcanic-derived epiclastic sediments (Fig. 7, Map 1). Most are characterised by single composition and one or more lithofacies. A few composite mappable rock units have not been subdivided owing to the limitations of exposure or mapping scale.
4. Eight discrete domains within the Boggabri Volcanics (Fig. 9), encompassing various of these 80+ mappable rock units (Fig. 9). These domains are designated: the Baan Baa (*B*), Railway (*R*), Heathcliffe (*H*), Therribri (*T*), Daisymede (*D*), Northern Forest (*N*), Southern Forest (*S*), and Barbers Pinnacle (*P*) domains. Each domain has its own stratigraphic sequence (Fig. 10). There are also a few scattered outliers not easily related to any of these domains.
5. Several minor mafic rock units of uncertain affinity. One minor mass near 'Daisymede' (Fig. 7, Map 1) overlies thin, unconsolidated, jasperoidal gravels (probably derived from the Woolomin Formation of the Central Block of the NEO), and is most probably Tertiary in age and related to the Nandewar volcanics (Stolz, 1983). Several other masses adjacent to the western edge of the Leard and Maules Creek Formations in the Leard State Forest (Fig. 7, Map 1) were originally distinguished from the Boggabri Volcanics partly because one appeared to be discordant to, and possibly intrude, the Boggabri Volcanics, and partly because none appeared to be affected by Early Permian weathering (Brownlow, 1981b). However, contact metamorphism is not evident in the field, suggesting a pre-Leard Formation age. These volcanic rocks are geochemically and petrologically distinct form both the Tertiary Nandewar volcanics (Stolz, 1983) and the Boggabri

Volcanics, but resemble the latter.

6. Several deposits of unconsolidated (Cainozoic), bouldery, poorly sorted sedimentary breccia derived from the Boggabri Volcanics and occurring high up along the sides of gullies draining these volcanic rocks.
7. Extensive, finer-grained aprons of scree (Cainozoic) that form the lower slopes bordering the outcrop areas of the Boggabri Volcanics, and separating them from alluvial deposits developed in the floodplains of active streams.

Mapping has also confirmed the absence of any older rock units such as Carboniferous basement analogous to that known to underlie the Early Permian Lochinvar Formation in the Lochinvar Anticline of the northern Sydney Basin (Mayne et al., 1974).

Nomenclature

The 80+ mappable rock units in the Boggabri Volcanics are labelled herein using a combination of three letters (in order):

- a first letter in capitals representing the domain (*B, D, H, N, P, R, S,* or *T*, as defined above) ;
- a second letter representing the rock composition (*b* = basalt, *a* = andesite or basaltic andesite, *d* = dacite, *r* = pyroxene rhyolite, *i* = biotite rhyolite, *v* = volcanic sediment); and
- a third letter representing the lithofacies (*l* = lava, *i* = ignimbrite, *x* = breccia, *p* = plug, *d* = dyke, *s* = sedimentary rock).

Duplicate letter symbols within a domain are further distinguished by a trailing, sequential number (e.g., *Brl1* and *Brl2)*, starting from the top of the sequence.

These labels are in italics to distinguish them from labels for other units in ordinary type (e.g., Tv = Tertiary volcanics, Qa = Quaternary colluvium and alluvium, and Plm = Permian Leard and Maules Creek Formations).

LITHOLOGIES OF MAPPABLE ROCK UNITS

The 80+ mappable rock units recognised at 1:85,000 scale among the Boggabri Volcanics comprise mainly coherent lavas (64 covering an estimated 90% of the outcrop area) and ignimbrites and breccias (14 covering 10% of the outcrop area). Small intrusives and epiclastics are additional minor mappable rock units in the Boggabri Volcanics. Additional rock units that are too small to map separately at 1:85,000 scale (but can be mapped at the 1:10,000 field scale) include several small ignimbrites (mainly underlying compositionally similar lavas), sparse minor intrusives and rare air-fall tuff and scoria.

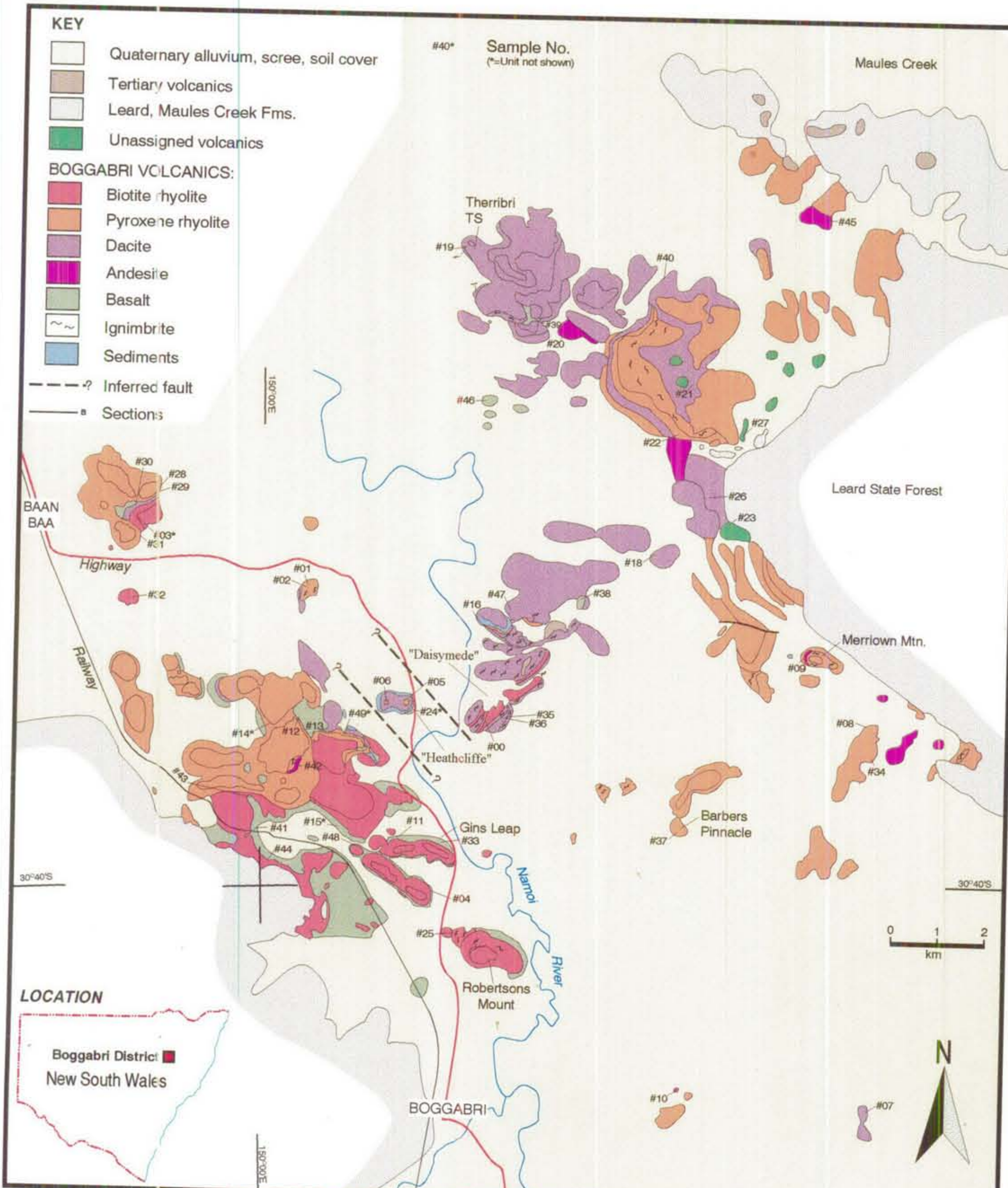


Fig. 7: Distribution of common lithologies in the Boggabri Volcanics — see text for explanation.

Fig. 8a: Gins Leap showing 40 m high cliff of white biotite rhyolite lava with poorly-welded biotite rhyolite ignimbrite, fine-grained basalt and amygdaloidal, coarse-grained basalt forming the rising foreground.

Fig. 8b: Coarse, polyvolcanic breccia in a densely welded groundmass immediately underlying thin, black vitrophyre (#13). The breccia is interpreted as a co-ignimbrite lag deposit.

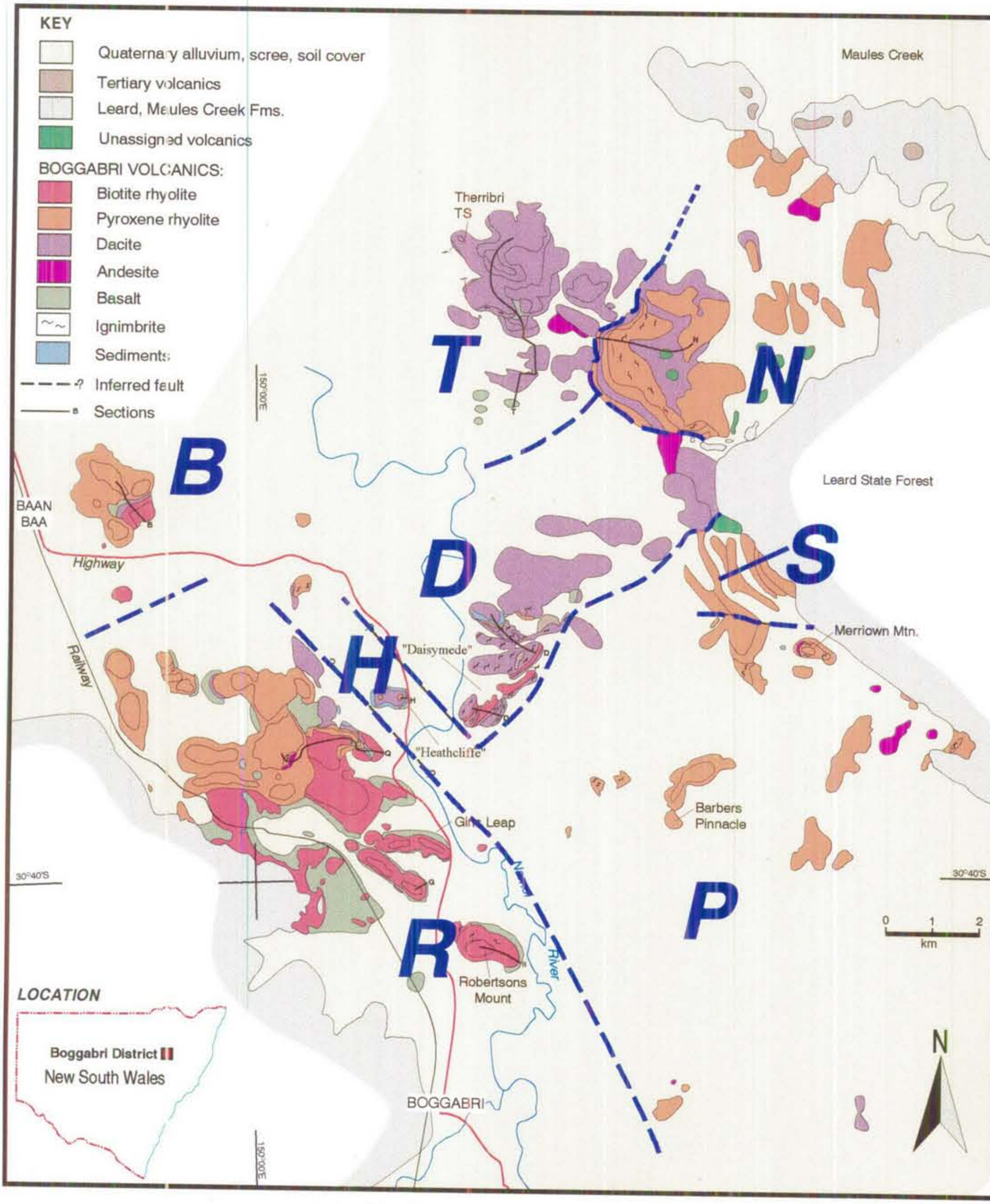
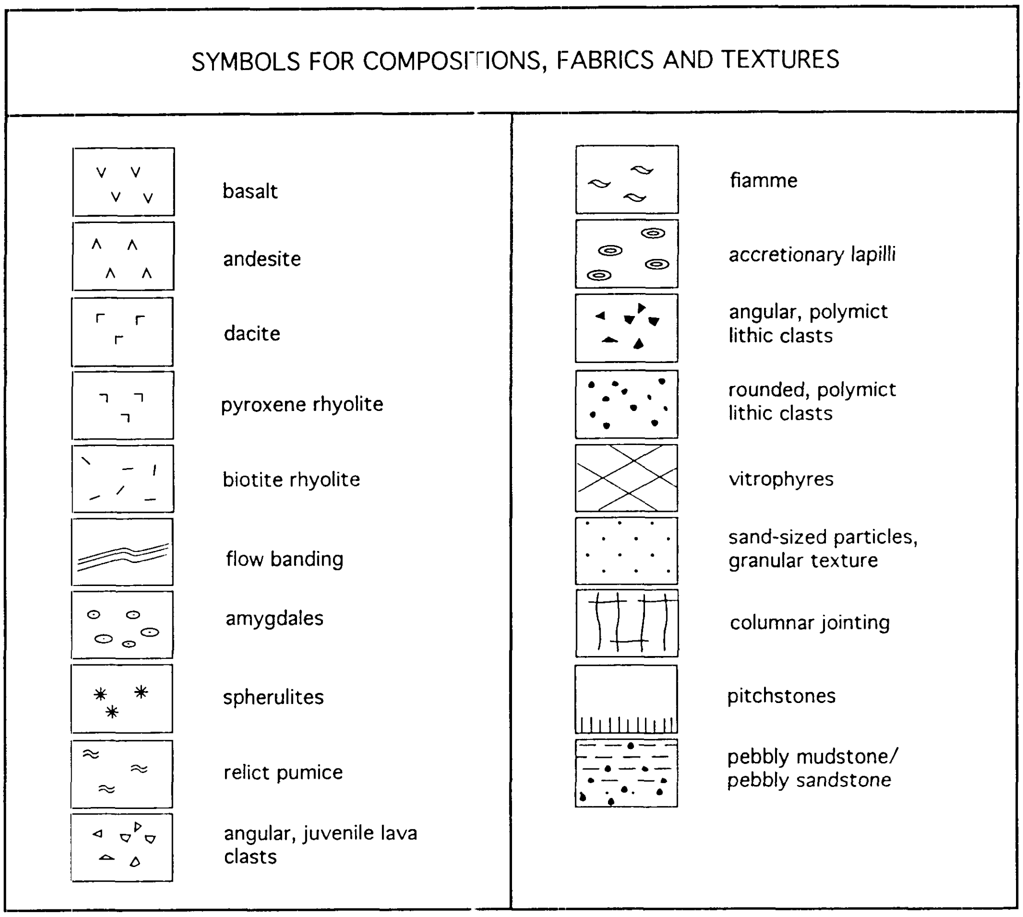
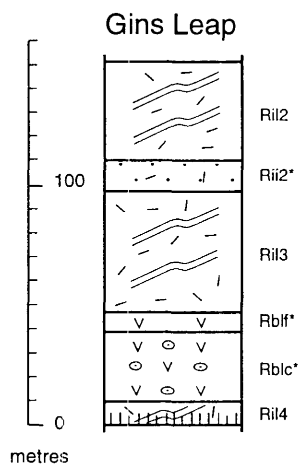


Fig. 9: Domains in the Boggabri Volcanics: Baan Baa (*B*), Railway (*R*), Heathcliffe (*H*), Therribri (*T*), Daisymede (*D*), Northern Forest (*N*), Southern Forest (*S*), and Barbers Pinnacle (*P*) domains — see text for explanation.

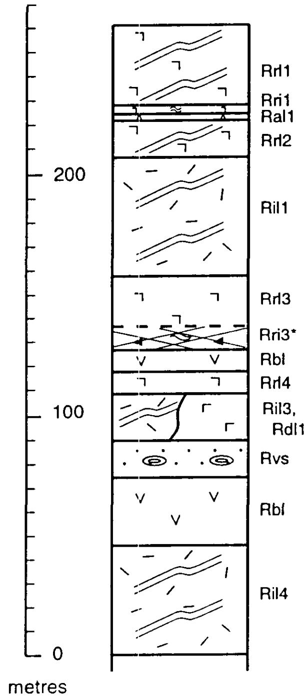




Ril2	BIOTITE RHYOLITE LAVA , off-white, sparsely porphyritic, plagioclase-biotite-phyric, flow-banded; forming 40 m high cliff (Gins Leap); thin, slightly welded crystal-vitric (plagioclase-biotite-phyric) BIOTITE RHYOLITE IGNIMBRITE at base.
Rii2*	BIOTITE RHYOLITE IGNIMBRITE, pale buff, crystal (plagioclase-biotite)-vitric, slightly welded.
Ril3	BIOTITE RHYOLITE LAVA, off-white, plagioclase-biotite-phyric, flow-banded.
Rblf*	BASALT LAVA, dark greenish grey, weakly porphyritic, plagioclase-olivine-phyric, fine-grained.
Rblc*	BASALT LAVA, dark, greenish brown, amygdaloidal, moderately porphyritic, plagioclase-olivine-phyric, medium-grained; strongly amygdaloidal in upper section.
Ril4	BIOTITE RHYOLITE LAVA (PITCHSTONE), dark green, sparsely porphyritic, plagioclase-biotite-phyric, medium-grained.

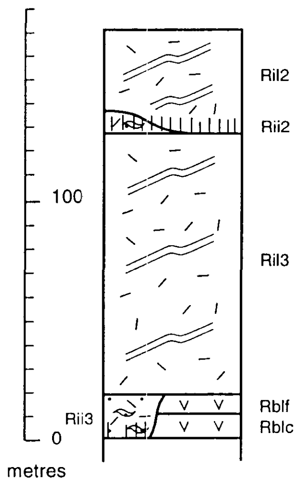
Fig. 10: Indicative stratigraphic sections through the Boggabri Volcanics (estimated from field mapping and topography), and their designation on Map 1: (a) Symbols; (b) Gins Leap (G). See text for explanation.

The Quarry



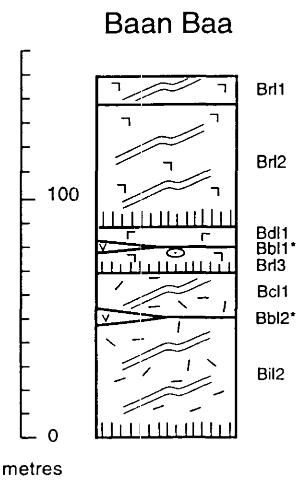
Rrl1	LEUCOCRATIC PYROXENE? RHYOLITE LAVA, off-white, sparsely porphyritic, plagioclase-phyric, medium-grained, flow-banded.
Rri1	LEUCOCRATIC PYROXENE? RHYOLITE IGNIMBRITE, grey, densely welded, plagioclase-phyric.
Ral1	ANDESITE LAVA, grey, very sparsely porphyritic, plagioclase-pyroxene-oxide-phyric, fine-grained.
Rrl2	LEUCOCRATIC PYROXENE? RHYOLITE LAVA, off-white, sparsely porphyritic, plagioclase-phyric, medium-grained, flow-banded.
Ril1	BIOTITE RHYOLITE LAVA, off-white, sparsely porphyritic, plagioclase-biotite-phyric, flow-banded.
Rrl3	LEUCOCRATIC PYROXENE? RHYOLITE LAVA, grey, strongly porphyritic, plagioclase-phyric, coarse-grained.
Rri3*	LEUCOCRATIC PYROXENE? RHYOLITE IGNIMBRITE, grey, strongly porphyritic, plagioclase-phyric, coarse-grained, densely welded and locally vitrophyric; local lithic concentration zones with clasts to 600 mm.
Rbl	BASALT LAVA, dark greenish grey, moderately porphyritic, plagioclase-olivine-phyric, medium-grained.
Rrl4	LEUCOCRATIC PYROXENE? RHYOLITE LAVA, grey, strongly porphyritic, plagioclase-phyric, medium-grained; pink altered plagioclase.
Rdl1	DACITE LAVA, pinkish buff (or green and altered), moderately porphyritic plagioclase-pyroxene-phyric.
Ril3	BIOTITE RHYOLITE LAVA, flow-banded, moderately porphyritic, plagioclase-biotite-phyric, fine to medium-grained.
Rvs	Fine pebbly CONGLOMERATE, pebbly SANDSTONE, pebbly BRECCIA, and varved MUDSTONE, green to grey, polyvolcanic; thin tuff bed with accretionary lapilli.
Rbl	BASALT LAVA, dark greenish-grey, sparsely porphyritic; poor outcrop.
Ril4	BIOTITE RHYOLITE LAVA(S), white, plagioclase-biotite-phyric, flow-banded; compound flow or composite unit.

Robertsons Mountain

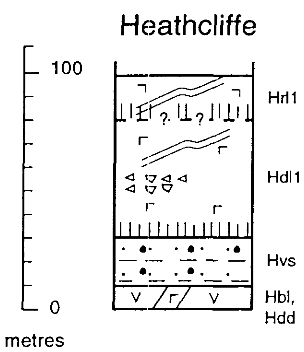


Ril2	BIOTITE RHYOLITE LAVA, off-white, sparsely porphyritic, plagioclase-biotite-phyric, flow-banded; locally thin plagioclase-biotite-phyric BIOTITE RHYOLITE IGNIMBRITE at base; basal LAVA and ?IGNIMBRITE locally altered to dark green pitchstone.
Ril3	BIOTITE RHYOLITE LAVA, white, sparsely porphyritic, plagioclase-biotite-phyric, flow-banded; altered to dark green PITCHSTONE at base.
Rii3	BIOTITE RHYOLITE IGNIMBRITE, grey, porphyritic, plagioclase-biotite-phyric, eutaxitic; spherulitic in part; altered to dark green PITCHSTONE in part.
Rblf	BASALT, dark, greenish grey, sparsely porphyritic, fine-grained.
Rblc	BASALT, dark greenish brown, moderately porphyritic, medium-grained; strongly amygdaloidal in upper section.

Fig. 10: (cont.) Indicative stratigraphic sections through the Boggabri Volcanics: (c) The Quarry (Q); (d) Robertsons Mountain (R). See Fig. 10 (a) for key, and text for explanation.

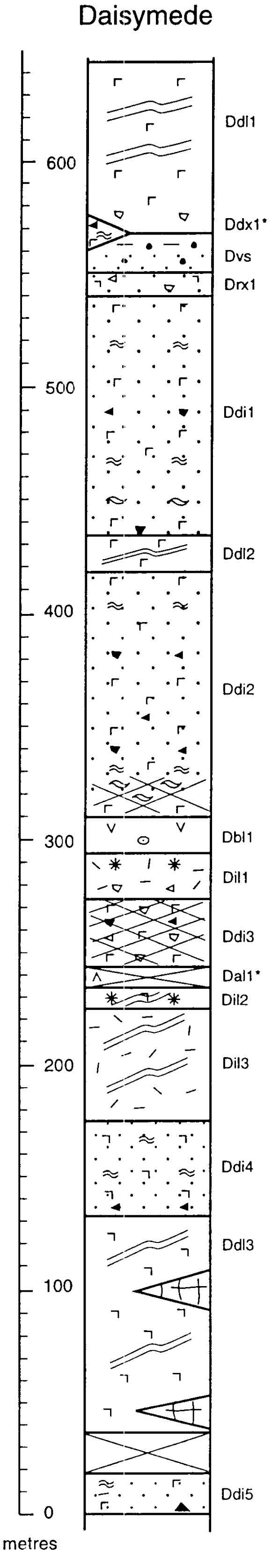


Brl1	LEUCOCRATIC PYROXENE? RHYOLITE LAVA, off white, sparsely porphyritic, plagioclase-phyric, medium-grained, flow-banded; forms prominent cliff in eastern-most outcrops.
Brl2	LEUCOCRATIC PYROXENE RHYOLITE LAVA, off-white, platy, sparsely porphyritic, plagioclase-phyric, fine to medium-grained, flow-banded; poorly outcropping, dark green rhyolite pitchstone at base.
Bdl1	DACITE LAVA grey/purple, moderately to strongly porphyritic, plagioclase-pyroxene-phyric, medium to fine-grained; base commonly altered (green); widespread orangy brown soils.
Bbl1*	BASALT LAVA, dark grey.
Brl3	LEUCOCRATIC PYROXENE? RHYOLITE LAVA, off white to yellowish, plagioclase-phyric; in part spherulitic, remainder largely altered to poorly outcropping dark green, rhyolitic pitchstone (mainly grey, cracking soils).
Bil1	BIOTITE RHYOLITE LAVA, off-white, plagioclase-biotite-phyric, flow-banded.
Bbl2*	BASALT LAVA?, dark grey, carbonate-altered, sparsely porphyritic, plagioclase-olivine-phyric, medium to fine-grained.
Bil2	BIOTITE RHYOLITE LAVA, off white, sparsely porphyritic, plagioclase-biotite-phyric, fine to medium-grained, flow-banded; altered to dark green pitchstone zone at base.



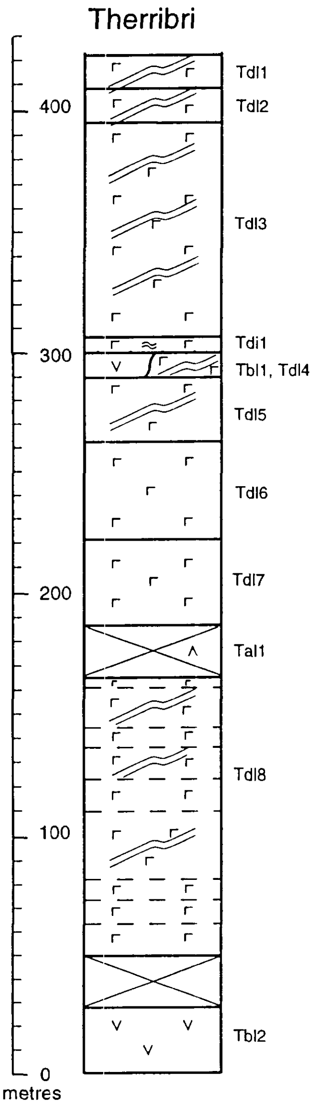
Hrl1	MELANOCRATIC PYROXENE RHYOLITE LAVA, IGNIMBRITE?, PITCHSTONE AND BRECCIA, purple to green, weakly to moderately porphyritic, plagioclase-pyroxene-oxide-phyric, medium to fine-grained.
Hdl1	DACITE LAVA and LAVA BRECCIA, purple, buff or green, moderately-sparsely porphyritic, plagioclase-pyroxene-oxide-phyric, fine to medium-grained; basal buff pitchstone; several flows/ flow units.
Hvs	CONGLOMERATE, fine pebbly, pebbly SANDSTONE, pebbly BRECCIA, and varved MUDSTONE, green to grey, polyvolcanic.
Hdd	DACITE VITROPHYRE DYKE, black, strongly porphyritic, medium to fine-grained, plagioclase-2 pyroxene-oxide-phyric; subhorizontal columnar-jointing.
Hbl	BASALT (Hbl), weathered; locally intruded by dyke. (Hdd)

Fig. 10: (cont.) Indicative stratigraphic sections through the Boggabri Volcanics: (e) Baan Baa (B); (f) Heathcliffe (H). See Fig. 10 (a) for key, and text for explanation.



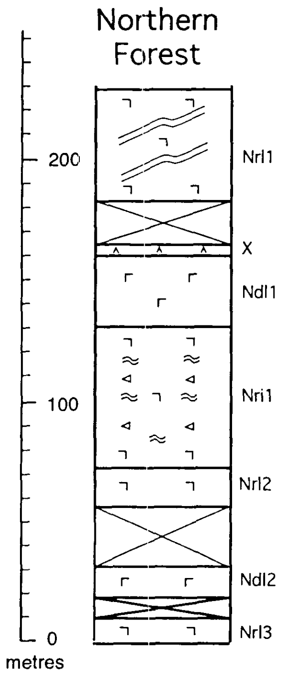
Ddl1	DACITE LAVA, brown, sparsely porphyritic, plagioclase-2 pyroxene-oxide-phyric, fine-grained, devitrified; basal autobreccia; locally, rare black vitrophyre relicts.
Ddx1*	DACITIC? BRECCIA, reddish white; off-white, subangular clasts to 25 mm in a welded?, reddish ignimbrite matrix; clasts mainly welded.
Dvs	Fine pebbly CONGLOMERATE, pebbly SANDSTONE, pebbly BRECCIA, and varved MUDSTONE green to grey, polyvolcanic; thin tuff bed with accretionary lapilli.
Drx1	LEUCOCRATIC PYROXENE? RHYOLITIC BRECCIA, grey; off-white, angular clasts to 50 mm in a poorly welded shard-rich matrix; clasts diverse but mainly altered RHYOLITE LAVA with distinctive small spherulites?; yields distinctive sandy soil.
Ddi1	DACITE? IGNIMBRITE, pale buff, lithic-pumice-pumice, plagioclase-pyroxene-oxide-phyric, sparsely welded; 10 to 15 mm diam. flattened pumice;composite; crude columnar-jointing and dense welding in basal 5-10 m.
Ddl2	DACITE LAVA, buff to green, altered, moderately to strongly porphyritic, plagioclase-2 pyroxene-oxide-phyric, medium-grained, glomeroporphyritic; slightly discordant to overlying and underlying units.
Ddi2	DACITE IGNIMBRITE, purple, moderately welded, lithic-pumice-crystal-rich, plagioclase-pyroxene-oxide-phyric ; multiple gently dipping ledges (thin flow units?); basal VITROPHYRE and densely welded IGNIMBRITE.
Dbl1	BASALT?, purple with green amygdales.
Dil1	BIOTITE RHYOLITE LAVA, off white, plagioclase-biotite-quartz; spherulitic in part; green LAVA breccia in part.
Ddi3	DACITE IGNIMBRITE VITROPHYRE, buff, densely welded and black vitrified pumice-crystal-lithic plagioclase-pyroxene-oxide.
Dal1*	ANDESITE LAVA and BRECCIA, grey.
Dil2	BIOTITE RHYOLITE LAVA, off-white, plagioclase-oxide-biotite-quartz, spherulitic in part; basal PITCHSTONE in part; lateral equivalent is green, altered, tuffaceous rhyolitic breccia with diverse welded ignimbritic clasts.
Dil3	BIOTITE RHYOLITE LAVA, off-white (locally purple), plagioclase-oxide-biotite, flow-banded.
Ddi4	DACITE IGNIMBRITE, buff, poorly welded, crystal-vitric plagioclase-oxide-pyroxene-phyric; yields sandy soil.
Ddl3	DACITE LAVAS, green and purple, strongly to sparsely porphyritic, plagioclase-2 pyroxene-oxide-phyric, medium to fine-grained; columnar jointed in part.
Ddi5	DACITE IGNIMBRITE, green, porphyritic, plagioclase-pyroxene-oxide-phyric, densely welded.

Fig. 10: (cont.) Indicative stratigraphic sections through the Boggabri Volcanics: (g) Daisymede (D). See Fig. 10 (a) for key and text for explanation.



Tdl1	DACITE LAVA, purplish brown, porphyritic, plagioclase-pyroxene-oxide-phyric, flow-banded; forms thin capping.
Tdl2	DACITE LAVA, purple, porphyritic, plagioclase-pyroxene-oxide-phyric, flow banded.
Tdl3	DACITE LAVA, grey, porphyritic, plagioclase-pyroxene-oxide-phyric; forming prominent 20 m + high cliff.
Tdi1	DACITE IGNIMBRITE, grey, moderately porphyritic, plagioclase-oxide-amphibole?-phyric, medium to fine-grained, welded; poor outcrops.
Tbl1	BASALT LAVA, dark, porphyritic, plagioclase-pyroxene-olivine-phyric, fine-grained; forming minor outcrops in dark brown soil.
Tdl4	DACITE LAVA, purple, moderately porphyritic, plagioclase-oxide-pyroxene-phyric, medium-grained.
Tdl5	DACITE LAVA, purplish buff, strongly porphyritic, plagioclase-pyroxene-oxide-phyric, coarse-grained; forming prominent cliffs to 10 m.
Tdl6	DACITE LAVA, purplish brown, sparsely porphyritic, plagioclase-pyroxene-oxide, fine-grained.
Tdl7	DACITE LAVA, pale green, strongly porphyritic, plagioclase-pyroxene-oxide, coarse-grained.
Tal1	ANDESITE LAVA, sparsely porphyritic, plagioclase-pyroxene-oxide-phyric, medium to coarse-grained.
Tdl8	DACITE LAVA, purple, strongly porphyritic, plagioclase-pyroxene-oxide, medium-grained; forms numerous benches and small shelves (compound flow?).
Tbl2	BASALT LAVA, dark, red speckled, strongly porphyritic, plagioclase-olivine-phyric, medium to fine-grained; forms low rocky rises and 20 m high cuestas; crude 600 mm diameter, m high columnar joints in part.

Fig. 10: (cont.) Indicative stratigraphic sections through the Boggabri Volcanics: (h) Therribri (T). See Fig. 10 (a) for key, and text for explanation.



Nrl1	LEUCOCRATIC PYROXENE? RHYOLITE LAVA, purple or pale (bleached), sparsely porphyritic, plagioclase-phyric, flow-banded.
X	BENMOREITE; greenish grey, altered, sparsely porphyritic, plagioclase-pyroxene-phyric, fine to med-grained.
Ndl1	DACITE LAVA, red-purple, moderately porphyritic, plagioclase-pyroxene-oxide-phyric, medium-fine-grained, flow-banded.
Nri1	LEUCOCRATIC PYROXENE? RHYOLITE IGNIMBRITE, lithic-crystal (plagioclase)-pumice, densely welded in part; vitrophyre in float; lithic-rich (10 to 20 mm rhyolitic clasts) in part; associated with yellow, coarse, sandy soils.
Nrl2	LEUCOCRATIC PYROXENE? RHYOLITE LAVA, grey plagioclase-phyric; possible composite unit - purplish-red IGNIMBRITE along strike.
Ndl2	DACITE LAVA, purple, porphyritic, plagioclase-pyroxene-oxide-phyric.
Nrl3	LEUCOCRATIC PYROXENE? RHYOLITE LAVA, grey, sparsely porphyritic, plagioclase-phyric; possible composite unit; float includes ANDESITE and RHYOLITIC IGNIMBRITE.

Fig. 10: (cont.) Indicative stratigraphic sections through the Boggabri Volcanics: (i) Northern Forest (N). See Fig. 10 (a) for key, and text for explanation.

The compositions of the mappable rock units recognised are as follows: (a) 26 pyroxene rhyolites (22 lavas, 3 pyroclastic flows, 1 breccia); (b) 14 biotite-rhyolites (12 lavas, 2 ignimbrites); (c) 23 dacites (16 lavas and 6 ignimbrites, 1 breccia); (d) 6 andesites and basaltic andesites (5 lavas and 1 scoria and breccia); (e) 9 basalts; and (f) 4 volcanic sediments. The individual mappable rock unit are not necessarily internally uniform. Ignimbrites especially are variable due to up sequence changes in the degree of welding, and pumice and lithic contents. Lateral textural variations are also evident in some mappable rock units (e.g., a thick dacite, *Ddl1* in the Daisymede Domain) that would be consistent with coeval eruption from multiple magma chambers or from multiple tappings of a large magma chamber.

Pyroxene Rhyolites

This group mainly occurs as lava flows and domes, less commonly as pyroclastic flows (ignimbrites and one possible block and ash flow), and rarely as possible plugs (Barbers Pinnacle — see Fig. 7, Map 1). Collectively, pyroxene rhyolites form about 40% of the outcrop area of the Boggabri Volcanics, and occur throughout the outcrop area except in the Therribri Domain (Figs 7, 9, Map 1). They form the uppermost or youngest units of several domains, and apparently occur throughout the Northern and Southern Forest domains (Figs 7, 9, Map 1).

The lavas are mostly extensive (mappable at 1:85,000 scale), compositionally uniform, tabular or dome-like masses of coherent rock locally associated with minor masses of breccia or pitchstone. In hand specimen, lavas range from aphyric to porphyritic with up to 20% plagioclase phenocrysts that are up to 3 mm in diameter, set in a fine-grained, texturally coherent groundmass.

Pyroxene rhyolites are most commonly leucocratic. Least-altered leucocratic lavas are generally off-white or pale yellowish and weakly ironstained, and are non-vitreous (devitrified and/or weakly altered). A small proportion of the leucocratic lavas are more lustrous, greyish and hard, probably reflecting pervasive silicification. In outcrop, the leucocratic lavas are commonly intensely flow banded. Minor pale-coloured breccias are associated with these lavas (possible flow breccias). Exposures of the leucocratic lavas are typified by extensive bare rock on flatter ground and bold outcrops on steeper slopes (e.g., *Rrl1, Rrl2*). Soils developed on these lavas are commonly thin (< 300 mm), grey, and rocky or sandy and contain pale-coloured rock fragments (except where strongly ferruginised). The basal sections of some leucocratic lava flows are dark green, resinous, pitchstones (e.g., *Brl2* at sample #29, *Prl2* at #08 — Map 1). These zones are thin (generally < 10 m thick) but extensive (mappable at field scale of 1:10,000) and are expressed either as poorly outcropping, friable, hackly fractured, masses or as distinctive, dark grey, cracking soil. Agate and chalcedony geodes ('thunder eggs') locally litter the surface of pyroxene rhyolite lavas, especially that of 'white' rhyolite lavas with pitchstone bases (e.g., *Prl2* near #08 and #34). Some altered lavas are pale to mid green, and are locally associated with green breccias (possible hyaloclastites), such as on the western side of Merriown Mountain (*Prl2* on Map 1).

One pyroxene rhyolite mappable rock unit is melanocratic (Hrl). It overlies dacite at the top of the 'Heathcliffe' section (Hrl at #06) and comprises lava and/or rheomorphic ignimbrite that has partly altered to pitchstone. The rhyolite is very similar petrologically to the underlying dacites and require geochemical analysis for correct identification. Additional melanocratic pyroxene rhyolite could occur among the more leucocratic of the rocks mapped as dacites.

Leucocratic pyroxene rhyolite lava flows are individually from many metres to a few tens of metres thick, and can be traced for as much as 3 km. Several large, pan-cake-like leucocratic rhyolitic lava masses with barish tops and steep sides developed west of the Namoi River are probably domes (e.g., *Rrl1, Rrl2*). These masses are up to 100 m thick and up to 1 km in diameter. Barbers Pinnacle in the Barbers Pinnacle Domain (Figs 7, 9, Map 1, unit *Prp*), rises 120 m above the adjacent plain and could be the feeder for two leucocratic lava flows that extend for about 2 kilometres to the north.

Ignimbrites are a minor expression of the pyroxene rhyolites. Individual ignimbrites are from many metres to a few tens of metres thick. Thick ignimbrites can be traced for as much as 3 km (e.g., *Nri1*). Thin ignimbrites are locally developed beneath lavas of the same composition (e.g., at the base of *Rrl3 at* #13). Ignimbrites are lithologically diverse, with wide variations in the proportion of crystals, lithics, pumice, colour and the degree of welding, and consequently in their hand specimen and field occurrence. The most common types are pale-coloured, weakly to moderately welded, lithic-poor (< 5% lithics), sparsely pumiceous, matrix-supported breccias that resemble lavas in outcrop pattern and in alteration style. Parts of some ignimbrites are densely welded, and these tend to crop out as prominent low ledges, in contrast to the more recessive occurrence of less strongly welded ignimbrite. In places, intense welding has produced thin (≈ 1 m) zones of black vitrophyre (e.g., #13). Dark green, resinous pitchstones (strongly resembling those developed in pyroxene rhyolite lavas) are locally developed in vitrified or densely welded ignimbrite zones, especially in the Railway Domain (e.g., locally at the base of *Prl3* near Barbers Pinnacle). Pale green alteration is also developed in some less densely weathered, lithic-rich ignimbrites, such as those forming scattered, unmapped outcrops on the lower slopes of Merriown Mountain. In a few localities occur poorly sorted, polymictic volcanic breccias up to a metre thick, that comprise gravel-sized and less commonly boulder-sized clasts of diverse volcanic lithologies in tuffaceous (commonly partly welded) matrices (e.g., underlying *Rrl3* at #13 — Fig. 8b). These are interpreted as lithic concentration zones within ignimbrite deposits. When weathered, these breccias resemble the sparsely developed thin epiclastic horizons.

A single monomict, clast-supported, pale-coloured breccia comprising angular, pebble sized clasts in a tuffaceous matrix (possibly a block and ash flow) is developed beneath an epiclastic horizon near the top of the Daisymede section (*Drx1*).

Various additional styles of alteration are developed in these rocks. Locally developed alteration includes pale pink colour (probably oxidation), sulfide-filled 'crackle breccia' and quartz veining and/or silica flooding and carbonate flooding. Earthy (kaolinitic?) alteration is extensively developed especially in the Northern and Southern Forest domains (e.g., *Nrd*, a possible ring dyke) close to the base of the Leard Formation. Limonitic staining is locally strong, possibly due to oxidation of sulfides. Extreme hydrothermal? alteration has locally produced zones that are pink (hematitic) and very hard (silicified).

Biotite Rhyolites

This group is manifest by a virtually identical range of rock units, lithologies and field expressions as the pyroxene rhyolites: only their ferromagnesian mineralogy, and apparent lack of biotite-bearing analogues of the melanocratic pyroxene rhyolites, differentiates them in the field. Collectively, biotite rhyolites form about 15% of the Boggabri Volcanics. As with the leucocratic pyroxene rhyolites, the principal mode of occurrence is as lava flows and domes, and less commonly as ignimbrites. Several possible small plugs (e.g., *Rip* at the western end of Robertsons Mountain at the south-eastern of the Railway Domain) are also tentatively recognised although each could be an erosional remnant of a lava flow or dome. Collectively, the biotite rhyolites form about 15% of outcrops of the Boggabri Volcanics. They are largely restricted to the Railway Domain, apart for minor occurrences in the Daisymede Domain (Figs 7–9, Map 1). Yellow bentonitic clay deposits have locally developed from alteration of pitchstones in the Railway Domain and bentonite has been mined from several such deposits close to the Railway line north-west of Boggabri (*Ril3* immediately overlying basalt at #41 — Brownlow *in* Brown et al., 1992). There are also minor developments of such clays in pitchstones on the south-western side of Robertsons Mountain (base of *Ril3*).

Dacites

This group mainly occurs as dacitic lava flows, ignimbrites, and rare dykes (too small to map at 1:85,000 scale). Collectively these rocks form about 35% of the outcrops of the

Boggabri Volcanics. They dominate the Therribri Domain and Daisymede domains, are prominent in the Northern Forest Domain, but form only a minor component in each of the other domains (Figs 7, 9, Map 1).

The dacitic volcanic rocks form prominent outcrops that are reminiscent of the rhyolitic lava flows and ignimbrites. However, commonly darker rock colour (dark to mid brown, greenish grey, purple) and generally darker soil colour (mainly dark brown on lavas, lighter on ignimbrites) distinguish most dacites from the paler rhyolites (bleached dacites and black rhyolitic vitrophyres excepted). A greater abundance of dark phenocrysts (pyroxenes and opaques) relative to plagioclase in hand specimen also distinguishes dacites from leucocratic rhyolites, but melanocratic rhyolite is very similar to enstatite dacite. Distinguishing dacites from andesites is difficult both in the field and petrologically, and generally requires geochemical analysis. Therefore some rocks tentatively identified herein as dacite could in fact be andesite or melanocratic pyroxene rhyolite. However, the colour of rock and soil developed on a melanocratic rhyolite can be a guide, with fresh or weathered dacite and dacitic soil tending to be lighter-coloured than their andesitic equivalents.

Dacitic lavas are generally from a few metres to perhaps few tens of metres thick. A few thicker flows over 100 m thick are recorded, but are probably either compound flows (Walker, 1971), or unrecognised composite units. Typical field occurrence of the lavas is as bare or partly covered ledges and rises, and less commonly as flat bare rock. The lavas are distinctly coloured, commonly purplish or brown or grey. In hand specimen, dacitic lavas are uniform, sparsely to strongly porphyritic and devitrified. Relict black glass occurs in one partly devitrified dacite lava at the top of the Daisymede section (*Ddl1* at #47). Lava breccia is associated with a few dacitic lavas. Columnar jointing is developed at a few localities especially in dacitic lavas of the Daisymede Domain (units *Ddl1* and *Ddl3*, near the top and base respectively). In addition, buff-coloured vitrophyre with perlitic fabric occurs at the base of dacite lavas of the Heathcliffe section. Especially thick dacitic lavas cap the Daisymede section (*Ddl1*). These crop out discontinuously over about 6 kilometres as discrete masses. Textural variations among the lavas of the different masses and the presence on aerial photographs of traceable ledges in the western-most mass suggest the presence of multiple flows.

An augite dacite vitrophyre dyke with sub-horizontal columnar jointing (#24, Fig. 7, Map 1 — recorded as pitchstone by Hanlon, 1950) intrudes altered basalt at the base of the 'Heathcliffe' section. This vitrophyre is brown, glassy and strongly porphyritic.

Dacitic ignimbrites are prominent in the Daisymede section (Figs 9–10, Map 1), where they are up to about 100 m thick, and can be traced laterally for up to 3 km (*Ddi2*). Outcrop character tends to reflect the degree of welding and densely welded zones tend to form the boldest outcrops. However, black vitrophyre occurs as thin (≈ 1 m) zones which tend to crop out as friable, low rocky patches of bare ground or as low rises. Outcrop of the remainder of the ignimbrites is variable, possibly due to subtle variations in welding, and abundance of lithics. For example, the lowermost thick ignimbrite on Daisymede (*Ddi2*) forms numerous low ledges that can be traced laterally over hundreds of metres on aerial photographs and on the ground: this pattern is typical of the effects of differential welding in multiple flow units within a composite flow (Smith, 1960).

Andesites

Andesite (including basaltic andesite) is uncommon among the Boggabri Volcanics (≈ 3% of the outcrop area) and mainly occurs as lava. One lava with a glassy brown groundmass forms prominent outcrops on the western side of Merriown Mountain (*Pal1* at #09). Others crop out less prominently in the Railway, Daisymede, and Therribri domains (Figs 7, 9, Map 1). One mass of andesitic breccia and scoria occurs in the eastern corner of the Daisymede Domain (*Dax*). Its relationships and domain assignment are uncertain.

Some andesites form prominent outcrops that resemble dacitic and rhyolitic lava flows and ignimbrites, whereas others crop out more poorly and resemble basalts. Distinguishing andesites is difficult in the field. However, the andesites are commonly darker in rock or soil colour (dark to mid brown, greenish grey, purple) than dacites, and tend to crop out more prominently than the basalts. In addition, andesites tend to have more dark phenocrysts (pyroxenes and opaques) than the dacites, and can sometimes be differentiated from basalts by common presence of opaque microphenocrysts and absence of olivine phenocrysts (except in sparse hybrid andesites — see Petrology chapter).

Basalts

This group also mainly occurs as lava flows. Collectively these rocks form ≈ 6% of outcrops of the Boggabri Volcanics. They are most prominent in the Railway Domain especially in the lower parts of the section, and at the base of the Therribri Domain, but also occur sparsely in other domains. Other manifestations of this group include one small dyke and some minor occurrences of scoria that are too small to be mapped at 1:85,000 scale.

Field occurrence of the basalts is characterised by generally poor, dark-coloured outcrops and dark-coloured soils. Commonly, only the upper parts of the lavas are exposed, in contrast to other compositions where the lower parts of lavas are commonly also exposed. The only extensively exposed flows is fine-grained and underlying coarser-grained lava in the Railway Domain of which a few metres of exposure can be traced for several kilometres around the northern side of Robertsons Mountain and Gins Leap (upper and lower parts of *Rbl* — Fig. 10 and Map 1). Extensive development of dark soils, for example, in low-lying areas immediately north of Boggabri in the Railway Domain, implies extensive development of basalts there.

In hand specimen, basalts are commonly dark greenish grey or reddish, uniform in texture and weakly porphyritic in plagioclase and/or olivine. The common presence of olivine and general absence of opaque microphenocrysts distinguishes them from andesites (not always evident in the field).

Sedimentary Rocks

Sedimentary beds crop out as thin units at six localities. Three are in one horizon near the base of the Quarry section in the Railway Domain. The others occur near the base of the Heathcliffe section, near the top of the Daisymede section and in Merrygowen Creek, west of Merriown Mountain (Figs 9–10, Map 1). McPhie (1984b) implied correlation of the outcrops in the Railway, Healthcliffe and Daisymede domains. These sedimentary rocks include varved siltstone with sparse dropped cobbles and boulders, coarse angular sandstone and coarse matrix-supported breccia with rounded, diverse (volcanic) boulders up to 600 mm. The matrix of many of these rocks is green, due to alteration. There is a single occurrence of accretionary lapilli tuff interbedded with the epiclastics of the Quarry section (McPhie, 1984b).

DOMAINS AND MAPPABLE ROCK UNITS

The eight domains recognised within the Boggabri Volcanics (the Baan Baa, Railway, Heathcliffe, Therribri, Daisymede, Northern Forest, Southern Forest, and Barbers Pinnacle domains (Fig. 9) are each identified by a combination of dominant lithologies, a gross mappable sequence (except for the scattered outcrops of the Barbers Pinnacle Domain), and gross attitude of their bedded volcanic rocks. Some domains abut others, but poor outcrop obscures boundary relationships.

The eight defined domains are identified herein for convenience and brevity of description and do not necessarily have any palaeovolcanological significance.

Railway Domain

The Railway Domain is characterised by a laterally extensive stratigraphy and by an abundance of both biotite and leucocratic pyroxene rhyolite lava flows, domes? and ignimbrites. This domain extends northwesterly from Robertsons Mountain to Leytonstone, a distance of 11 km, and is up to 4 km wide. Maximum relief is about 150 m. A gentle north-westerly dip (averages 2 to 3 degrees) suggests that the exposed sequence is somewhat thicker than the 150 m of relief.

The most complete section is at the Quarry (section Q on Figs 9–10, Map 1). There, basal biotite rhyolite lavas (*Ril4*) are overlain by basalt (*Rbl*) and thin epiclastic sediments (Rvs). To the north of the section line occurs a thick dacitic lava (*Rdl1*), whereas to the south occur thick biotite rhyolite units (*Ril2, Ril3* — Fig. 8a) that can be mapped southeasterly to Robertsons Mountain and west past the railway line. These are followed in the section by thin leucocratic pyroxene rhyolite lavas (*Ril3, Ril4*), minor basalt and a further biotite rhyolite lava dome? (*Ril1*) Two thick leucocratic rhyolitic lava domes? (*Rrl1, Rrl2*) crop out prominently on high ground to the west, forming the top of the section. Andesite lava (*Ral1*) and overlying rhyolitic ignimbrite (*Rri1*) occur between these two rhyolite lavas.

The Robertsons Mountain and Gins Leap sections (R and G on Figs 9–10, Map 1) are typical of the southern part of the domain, and can be traced laterally for over 5 km. The Robertsons Mountain section comprises comprises coarse- then fine-grained basaltic lavas (Rblc, Rblf on Fig. 10), then two thick biotite rhyolitic lavas *Ril2, Ril3*), each with basal ignimbrites (*Rii2, Rii3* respectively). Pitchstone zones are locally developed in the rhyolite lavas and ignimbrites, and the pitchstone has altered to a small patch of yellow clay on the south-west side of Robertsons Mountain (*Ril3*). Biotite rhyolite, possibly a plug, occurs at the western end of Robertsons Mountain (*Rip*), and in a nearby outcrop, steeply-dipping ignimbrite is partly converted to pitchstone (Fig. 10). This is probably the transition from pitchstone to 'lava' cited by Hanlon (1950).

Baan Baa Domain

The Baan Baa Domain is similar in character to the Railway Domain, and could be an upfaulted northern extension of it. This domain measures about 1 km x 1 km, and occurs immediately east of Baan Baa.

The section here (B on Figs 9–10, Map 1) comprises biotite rhyolite lavas (*Bil1, Bil2*) overlain by leucocratic pyroxene rhyolite lavas (*Brl1, Brl2, Brl3*) with intervening dacite lava (*Bdl1*) and minor basalt (*Bbl1, Bbl2*).

Heathcliffe Domain

The Heathcliffe Domain is characterised by a flat-lying sequence dominated by dacites. This domain forms a single hill covering an area of about 1.5 x 1 km, immediately west of the Namoi River. It lies between the Daisymede and Railway domains, from which it is separated by inferred faults and areas on no outcrop.

The Heathcliffe section (H on Figs 9–10, Map 1) comprises basal basalt (Hbl) overlain by epiclastics (Hvs), followed by thick dacite lavas (Hdl1) and a thin capping of melanocratic pyroxene rhyolite pitchstone (Hrl). This rhyolite resembles the associated dacites far more in hand specimen and field occurrence than the voluminous leucocratic pyroxene rhyolites. Distinctive basal buff-coloured perlites are developed at the base of the dacite lavas. A columnar-jointed vitrophyre dyke (*Hdd* at #24) intrudes the basal basalt.

Daisymede Domain

The Daisymede Domain is characterised by a north-westerly dipping sequence, by locally moderate dips, and by a dominance of dacite lavas and ignimbrites. This domain occupies an area of about 8 x 3 km and extends south-westerly from the southern limit of the Northern Forest Domain to the Namoi River.

The section (D on Figs 9–10, Map 1) is about 600 m thick (modified from McPhie, 1984b). Dips are up to to 35° near the base, shallowing to about 15° at the top of the section. Basal dacitic ignimbrite (*Ddi5*) and overlying lava flows (*Ddl3*) are followed by dacite ignimbrite (*Ddi4*) and biotite rhyolite lava (*Dil3*). This lower interval is followed by two thin, poorly outcropping intervals of quartz-biotite rhyolite (*Dil2, Dil1*) that are separated by dacite ignimbrite vitrophyre (*Ddi3*). The lower rhyolite unit mainly comprises spherulitic lava and pitchstone and locally, green altered green ignimbritic(?) breccia, and is associated with minor andesite lava and breccia. The upper rhyolite interval is associated with minor amygdaloidal basalt? These are followed by two thick dacite ignimbrites (*Ddi2, Ddi1*) that are separated by a discordant dacite lava flow? or dyke (*Ddl2*). A thin interval of leucocratic rhyolite breccia (possible block and ash flow — *Drx1*) and overlying epiclastics (*Dvs*) is followed by thick dacite lava(s) (*Ddl1*) which cap the sequence. Textural variations among the lavas of the different masses of *Ddl1* and the presence on aerial photographs of traceable ledges in the western-most mass suggest the presence of multiple flows. Some of the hills displays extensive alteration and quartz stockworking (around #18 and the hill to the west — Fig. 7, Map 1) and there Schmidt (1988) recorded minor pyrite and a Au-As-Sb anomaly in soil samples.

This domain is atypical of the Boggabri Volcanics due to the dominance of dacites, the abundance of dacitic ignimbrite, and the steep dip (up to 35°) of the lower units, and the occurrence of quartz in biotite rhyolite.

Apparently discordant masses of hawaiite (unit X at #23) and andesite? (Dax) border the eastern margin of this domain. The hawaiite mass is texturally coherent, and it could be a plug. It is geochemically distinct from the Boggabri Volcanics and is included in the unassigned volcanics. The andesite mass comprises scoria and breccia. It has not been analysed, and its affinity is uncertain.

Minor Tertiary? basalt locally unconformably overlies the Boggabri Volcanics of the Daisymede Domain (Fig. 9, Map 1), and scattered water-worn jasperoidal pebbles litter the depositional surface where the basalt has been eroded.

Therribri Domain

The Therribri Domain is characterised by a northerly dipping, apparently conformable, sequence dominated by thick dacitic lavas. This domain occurs in the north of the mapped area and is over about 5 km in diameter.

The Therribri section (T on Figs 9–10, Map 1) is up to 500 m thick. Scattered cuestas of olivine basalt (*Tbl2*) in the flat, cleared farmland in the south form the more steeply-dipping, basal units of the domain. Overlying this are discontinuous outcrops of dacite lava (*Tdl4–8*), basalt lava (*Tbl1*) and andesite lava (*Tal1*). Thick dacitic lavas (some possibly flattened domes) cropping out on a forested ridge in the north, form the more gently-dipping upper units of the sequence (*Tdl1–3*). Dacite ignimbrite (*Tdi1*) underlies the lowermost of these upper dacite lavas.

This section is significant in containing no identified rhyolite, only a single identified ignimbrite and the most convincing example of probable relict amphibole phenocrysts (in dacite at #19) recorded from the Boggabri Volcanics.

Northern Forest Domain

The Northern Forest Domain is characterised by an easterly dipping sequence dominated by leucocratic pyroxene rhyolite and dacite. This domain occupies an area of 7 x 4 km in the north-east. The timbered slopes and ridges of hills of the Leard State Forest on the western side of the domain exhibit about 150 m of relief and poor outcrop. In contrast, the largely cleared farmlands in north-east of the domain exhibit only about 50 m of relief, and better outcrop due to less soil cover. The overlying Leard and Maules Creek Formations mark the eastern limits of this domain.

The Northern Forest section (N on Figs 9–10, Map 1) dips easterly, gently at the base and more shallowly at the top. The sequence is at least 150 m thick (local relief). Basal rhyolitic and dacitic lavas (*Nrl2, Nrl3, Ndl2*) and a single, thick rhyolitic ignimbrite (*Nri1*) in the middle of the sequence appear to be transgressed by overlying dacitic and rhyolitic lavas (*Ndl1, Nrl1*) along the north-western margin of the domain. The sequence appears to be faulted along the southern margin, where a kaolinised rhyolite dyke? (Nrd) is developed. The rhyolite lava at the top of the sequence appears to form a dome that transgresses the south-eastern boundary of the structure. Scattered benmoreite and mugearite (unassigned volcanics at #21, #27 respectively) also occur near the top of this domain, and could be an integral part of it.

This domain is notable for having the shape of a caldera with a down-sagged margin to the west and a down faulted margin of the south. A dominance of rhyolite and dacite lavas is also notable. Stratigraphic correlation with other domain has not been established.

Southern Forest Domain

The Southern Forest Domain appears to be dominated by a sequence of leucocratic pyroxene? rhyolitic lavas that dip moderately to the east. This domain occupies a small area of about 3 km in diameter along the eastern margin of the Boggabri Volcanics. However, investigations to date have only been brief, and understanding is inhibited by poor outcrop and extensive forest cover.

A sequence cannot yet be reliably defined for this domain, nor are correlations established with any other domain. The dominance of leucocratic pyroxene rhyolite resemble the upper part of the Northern Forest Domain or the Barbers Pinnacle Domain.

Barbers Pinnacle Domain

Barbers Pinnacle Domain is characterised mainly by scattered, generally flat lying, leucocratic pyroxene rhyolite lavas and lesser ignimbrites. This domain extends over an area of about 8 km in diameter in the south and south-east of the mapped area. Possible faults separate it from the Daisymede Domain to the west, and from the Southern Forest Domain to the north. The northerly dipping sequence on Merriown Mountain is tentatively included in this domain, but the attitude of its upper units is more typical of the Southern Forest Domain.

A coherent stratigraphy is difficult to discern due to the scattered outcrops. The most complete section is on the western side of Merriown Mountain. Basal polyvolcanic diamictite (in Merrygowen Creek) and an andesitic lava (*Pal1*) high in the sequence are interbedded with leucocratic pyroxene rhyolite lavas and lesser ignimbrites (*Prl1, Prl2*).

Many of the lavas and associated ignimbrites in the lower half (*Prl2*) have been converted to pitchstones and locally to green breccia (hyaloclastites? in part).

Elsewhere, outcrop is dominated by low rises of nearly flat-lying white leucocratic rhyolite lava. Rhyolitic ignimbrite locally underlies some lavas (e.g., north of Barbers Pinnacle — *Prl2*). Basal dark green pitchstones are developed at the base this unit and some white rhyolite lavas. Possible correlation of lavas and ignimbrites is inferred on Map 1. Minor outcrops of andesite (*Pal*) south-east of Merriown Mountain could represent a lower horizon.

Several outcrops are anomalous. Firstly Barbers Pinnacle (Figs 7, 9, Map 1) is a rounded mass of white leucocratic rhyolite with steep flow banding that rises 120 m above the adjacent plain. It could be the feeder for rhyolite lava flows and a thin ignimbrite of similar composition (underlying the upper lava) that form a ridge extending for about 2 kilometres to the north. Also anomalous is a mass of southerly dipping rhyolite lava and ignimbrite west of Merriown Mountain (*Prl2, Prl3, Pri2*). This mass is included in this domain because of its compositional affinity, and despite its anomalous attitude. Also included in this domain is an apparently flat-lying mass of dacite lava that lies adjacent to more steeply-dipping dacite lavas of the Daisymede Domain. Here, the contrast in attitude could reflect faulting and the inferred fault is tentatively taken as the domain boundary. The relationship of the dacite to the remainder of the Barbers Pinnacle Domain is unclear, but it could represent the lowermost exposure, in which case it is probably represents the same level as an isolated outcrop of porphyritic dacite in the extreme south-east of the area (about 7 km from Barbers Pinnacle).

SUMMARY

1. Eight separate domains, each with a separate stratigraphy, are recognised in the outcrop area of the Boggabri Volcanics.
2. Over 80 mappable rock units are recognised in the Boggabri Volcanics at 1:85,000 scale (Map 1).
3. Lava flows and fewer domes form about 80% of the mappable rock units and probably close to 20% of the outcrop area of the volcanic rocks, whereas ignimbrites form about 20% of the mappable rock units and probably about 10% of the outcrop area.
4. Epiclastics are sparse, and crop out at only six localities.
5. The Boggabri Volcanics span the compositional range from olivine basalt to leucocratic pyroxene or biotite rhyolite.
6. Pyroxene rhyolites comprise 26 mappable rock units (22 lavas, 3 pyroclastic flows, 1 breccia) and are the most second voluminous compositional group.

7. Biotite rhyolites comprises 14 mappable rock units (12 lavas, 2 ignimbrites), and are the third most voluminous compositional group.
8. Dacites comprise 23 mappable rock units (16 lavas and 6 ignimbrites, 1 breccia), and are the most voluminous compositional group.
9. Andesites comprise 6 mappable rock units (5 lavas and 1 scoria and breccia), and are the least voluminous compositional group.
10. Basalts comprise 9 mappable rock units (all lavas). These constitute the second least voluminous compositional group.
11. Leucocratic pyroxene rhyolite lavas are widespread. They form the uppermost units of the Baan Baa, Railway, Heathcliffe Northern Forest, and Barbers Pinnacle domains, and form the only recognised units in the Southern Forest Domain. Many of the units in the Railway Domain are probably lava domes.
12. The only major leucocratic pyroxene rhyolite ignimbrite occurs in the Northern Forest Domain, but minor ignimbrites (most too small to map separately at 1:85,000 scale) are recognised in the Railway and Barbers Pinnacle domains.
13. Biotite rhyolites occur in the Railway, Baan Baa and Daisymede domains. The latter are notable as the only quartz-biotite-bearing mappable rock units recognised.
14. Dacites and lesser andesites are dominant in the Therribri Domain (as lavas) and in the Daisymede Domain (as major ignimbrites and lavas).
15. Basalts occur scattered throughout the Railway Domain, and in other domains.
16. Pitchstones are widely developed at the base of many rhyolite lavas and some rhyolite ignimbrites, including pyroxene and biotite rhyolites as well as the one melanocratic pyroxene rhyolite.
17. Bentonitic clay is locally developed from alteration of pitchstone.
18. Agate and chalcedony are sporadically developed in the area, most commonly littering the surface of white rhyolite lavas that have pitchstone bases.
19. Green breccias (hyaloclastites?) only outcrop sporadically.
20. Alteration is common. Earthy (kaolinitic?) alteration appears to be more strongly developed in the east, close to the base of the overlying Leard Formation.
21. The Baan Baa Domain resembles the Railway Domain and could be an upfaulted northern extension of it.
22. The only other (tentatively) identified correlation between domains is that implied by McPhie (1984b) between an epiclastic horizon near the top of the Daisymede section, that near the base of the Heathcliffe section and that near the base of the Quarry section of the Railway Domain.
23. The boundaries of the above mappable rock units generally are masked by soil and rubble and do not crop out. Most boundaries are probably depositional (except for minor intrusives). However, the possible presence of cryptic, bedding-parallel

thrusts, especially at the base of the flat lying leucocratic pyroxene lavas of the Railway Domain, cannot be disproven without further investigation.

24. A number of possible lava domes and plugs have been identified, but require detailed examination for confirmation.
25. There is a crude symmetry across the Boggabri Ridge, with leucocratic pyroxene rhyolite lavas most prominent on either margin, and dacites most prominent in the middle; only the ?downfaulted Barbers Pinnacle Domain with is conspicuously exceptional, due to the occurrence of leucocratic pyroxene rhyolites in its centre.

Overall, the present investigation has broadly confirmed previous reports about the nature of the Boggabri Volcanics, but has added significant detail even to the Daisymede section of McPhie (1984b). The presence of basalt is confirmed, but it is an integral part of the Boggabri Volcanics, and referring it to the Werrie Basalt (Hanlon, 1949b) is impractical. Manser (1960) first documented the presence of ignimbrites in the Boggabri Volcanics, but was misguided in claiming them to be dominant. The Tertiary 'rhyolite' intruding Permian sediments along the eastern margin of the Boggabri Volcanics (Hanlon, 1949b) was shown to be a porcellanite (fine-grained siliceous sediment) by F.C. Loughnan (pers. comm, 1976). It occurs widely as a thin horizon observable both in outcrop and in coal bores at the base of the Maules Creek Formation and immediately overlying the thin (<1–10 m thick) flint clays that comprise the Leard Formation (Brownlow, 1981b).

Field relationships of the 'unassigned volcanics' (hawaiite-mugearite-benmoreite) in the north-eastern corner of the area) are equivocal, and these rocks are just as likely to belong to the upper part of the Boggabri Volcanics as to the Tertiary volcanics of the district. Jasperoidal pebbles underlying one mass of Tertiary basalt is currently the only unequivocal field criterion for distinguishing Tertiary basalts that overlie the Boggabri Volcanics. Some basalts in the Boggabri Volcanics are fairly fresh, in contrast to ubiquitous alteration in the Werrie Basalt in the Werrie Basin (Carey, 1935), or in the Deriah Forest area (Hill, 1986).