DEPARTMENT OF
MINERALS AND ENERGY

# BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS



Record 1974/176

# GEOLOGY OF THE TANTANGARA 1:100 000 SHEET AREA, AUSTRALIAN CAPITAL TERRITORY AND NEW SOUTH WALES

by

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## SUMMARY

The Tantangara Sheet area lies within the southern part of the Lachlan Fold Belt, and includes strongly folded Ordovician and Early Silurian chert, flysch sediments, and tholeiitic volcanics unconformably overlain by gently folded clastic and carbonate shelf sediments of Middle to Late Silurian age. Middle and Late Silurian acid calc-alkaline volcanics are widespread, and high-potassium latites and rhyolites were extruded in the Early Devonian. Granitic intrusives of Late Silurian and Early Devonian age crop out over much of the area, and basic rocks were intruded in the Middle Devonian. The dissected remnants of once widespread Tertiary fluviatile sediments and basalts are present in the southeast and western parts of the area; those in the southeast are of late Eocene age and those in the west are early Miocene. Late Quaternary colluvial deposits are extensive, and alluvial sedimentation is continuing along many streams at the present day. Economic mineral deposits are limited to now-exhausted alluvial gold near Kiandra.

The oldest rocks in the area are quartz arenite, siltstone, and shale forming the ?Darriwillian Bolton Beds. They represent a distal flysch deposit, and pass up into the bedded chert and minor tuff of the Temperance Chert. Tuffaceous beds become increasingly common upwards until they dominate the sequence at the level that interbedded tholeiitic lava appears. These volcanics (Nine Mile Volcanics) are chemically related to tholeiitic island-arc volcanics, and are dated as Gisbornian by graptolites found in intercalated shale near Tumut Ponds Dam, southwest of the Sheet area. After volcanicity ceased, probably in the late Gisbornian, flysch sedimentation resumed in the region during the Eastonian and early Bolindian. Flysch of both proximal (Adaminaby Beds) and distal (Nungar Beds) aspects was developed. Faunal evidence suggests that these may be partly lateral equivalents, though part of the Adaminaby Beds may be younger than the Nungar Beds. Deformation at the close of the Ordovician was probably relatively minor in the Tangangara area, and was soon followed by a renewal of flysch sedimentation in the lower Llandoverian (Tantangara Beds). Flysch deposition ceased in the area in mid-Llandoverian time when the region was subjected to a major period of isoclinal folding (equivalent to the Panuara phase of folding of Packham, 1969).

Marine conditions returned to the region soon afterwards, with the deposition of the transgressive Peppercorn Beds which consist of a basal conglomerate, derived from underlying units, which passes up into first sandstone and then siltstone. Carbonate sediments appear in the upper part of the sequence and are dated by conodonts as latest Llandoverian. Although

direct field evidence is lacking, the Peppercorn Beds are considered to pass conformably upwards into the shelf sediments forming the Cooleman Plains sequence comprising the Pocket Beds (similar to the upper Peppercorn Beds), the Cooleman Limestone, and the Blue Waterhole Beds. Complex facies relations exist between these units. Marine sedimentation ceased within the area during the Late Silurian, probably in the early Pridolian, and was followed by a phase of gentle folding on approximately east-west axes.

While the Cooleman Plains sequence was being deposited, a thick pile of calcalkaline subaerial volcanics, Goobarragandra Beds, was being formed farther west. The rhyodacite to dacite ignimbrite flows and agglomerates have been dated as 438+16 m.y. old. Similar but younger volcanics (Kellys Plains Volcanics) were extruded after the Pridolian folding which affected the Cooleman Plains sequence, and were subsequently eroded, though not folded, before the final volcanic episode in the region (Mountain Creek Volcanics), during which extrusion of the Rolling Grounds Latite preceded the accumulation of thick high-potassium rhyolites and tuffs.

Concurrent with the extrusion of the Kellys Plain Volcanics huge granite plutons were intruded, the main bodies being the Murrumbidgee Batholith in the east, the Gingera Granite in the central part of the area, the McLaughlins Flat Granodiorite in the south, and the Happy Jacks Granite to the southwest. All of these intrusives are chemically related to the Silurian dacitic volcanics and are apparently derived from partial melting of meta-sedimentary rocks. The rock types present are dominantly foliated biotite granodiorite rich in sedimentary xenoliths, biotite adamellite, and biotite muscovite leucogranite. This first phase of granite intrusion was followe in the Early Devonian, probably not more than 5 to 10 million years later, by a second phase of granitic intrusion chemically related to the Mountain Creek Volcanics. The main intrusives forming the second phase are the Boggy Plain Granite, Pigeon Square Gabbro, Cooleman Igneous Complex, and Jackson Granite. They are characterized by being unfoliated, commonly rich in hornblende, augite, and hypersthene, as well as biotite, and have low initial Sr ratios. This phase of intrusion forms the final recorded Palaeozoic event in the area and it is not until the Tertiary that there is evidence of the subsequent history of the area. Near Shannons Flat, lacustrine and fluviatile sediments are preserved beneath basalts dated as 35 to 45 m.y. old (late Eocene) and there are similar deposits near Kiandra underneath basalts dated at 20-22 m.y. old (early Miocene). Extensive colluvial deposits formed in the Quaternary and alluviation continues at present.

Alluvial gold within the Miocene sediments near Kiandra formed the only economic mineral deposits within the area, but are now worked out. Subeconomic deposits of lead and zinc in limestone at Blue Waterhole, and magnetite associated with the Jackson Granite are the only other noteworthy mineral occurrences.

# 1. INTRODUCTION

(M.O.)*

Detailed mapping of the Tantangara 1:100 000 Sheet area begain in October 1971, as a stage in the revision of the Canberra 1:250 000 geological map. Fieldwork was carried out from October 1971 to April 1972 and October 1972 to March 1973. A regional stream-sediment geochemistry survey of the Sheet area took place during the 1972-3 season (Shackleton in prep.).

Personnel involved were M. Owen (whole period); D.E. Gardner (1971-2 season and February-March 1973); A.L. Jaques (January-March 1972); P.A. Langworthy (February-April 1972); D. Wyborn (March-April 1972, November 1972, and January-March 1973); J. Saltet (October 1972 to March 1973) and P. Jell (November 1972).

The Tantangara 1:100 000 Sheet area is southwest of Canberra, about one-third within the A.C.T. and two-thirds in New South Wales (Fig. 1). Much of the area within New South Wales is part of the Kosciusko National Park, from which a permit for geological work is needed from the State National Parks and Wildlife Service.

No major towns lie within the area, though Adaminaby is situated on the southern border and Kiandra is about 1 km west of the area. Much of the area is uninhabited, except in the southeast where numerous grazing properties are centred on Adaminaby, Shannons Flat, and Yaouk.

## Access (Fig. 2)

Access through much of the area is good owing to numerous four-wheel-drive fire trails, though vehicular access is generally poor away from the fire trails. Primary access in the south is by the Snowy Mountains Highway which enters the area at Adaminaby and runs west-north-west to Kiandra and then north to Rules Point before turning northwest out of the area. From Rules Point a two-wheel-drive gravel road runs north along Long Plain, and provides dry-weather access via Brindabella to Canberra. Several fire trails from the Long Plain Road give limited access to the Fiery Range and fairly good access eastwards.

Midway between Adaminaby and Kiandra, a two-wheel-drive gravel road from the Snowy Mountains Highway provides access to Tantangara Dam and continues north, part Tantangara Dam, for about 15 km before dividing into three fire trails, two of which cross the Bimberi Range into the Cotter

* Authorship of the various sections is indicated by initials after the heading.

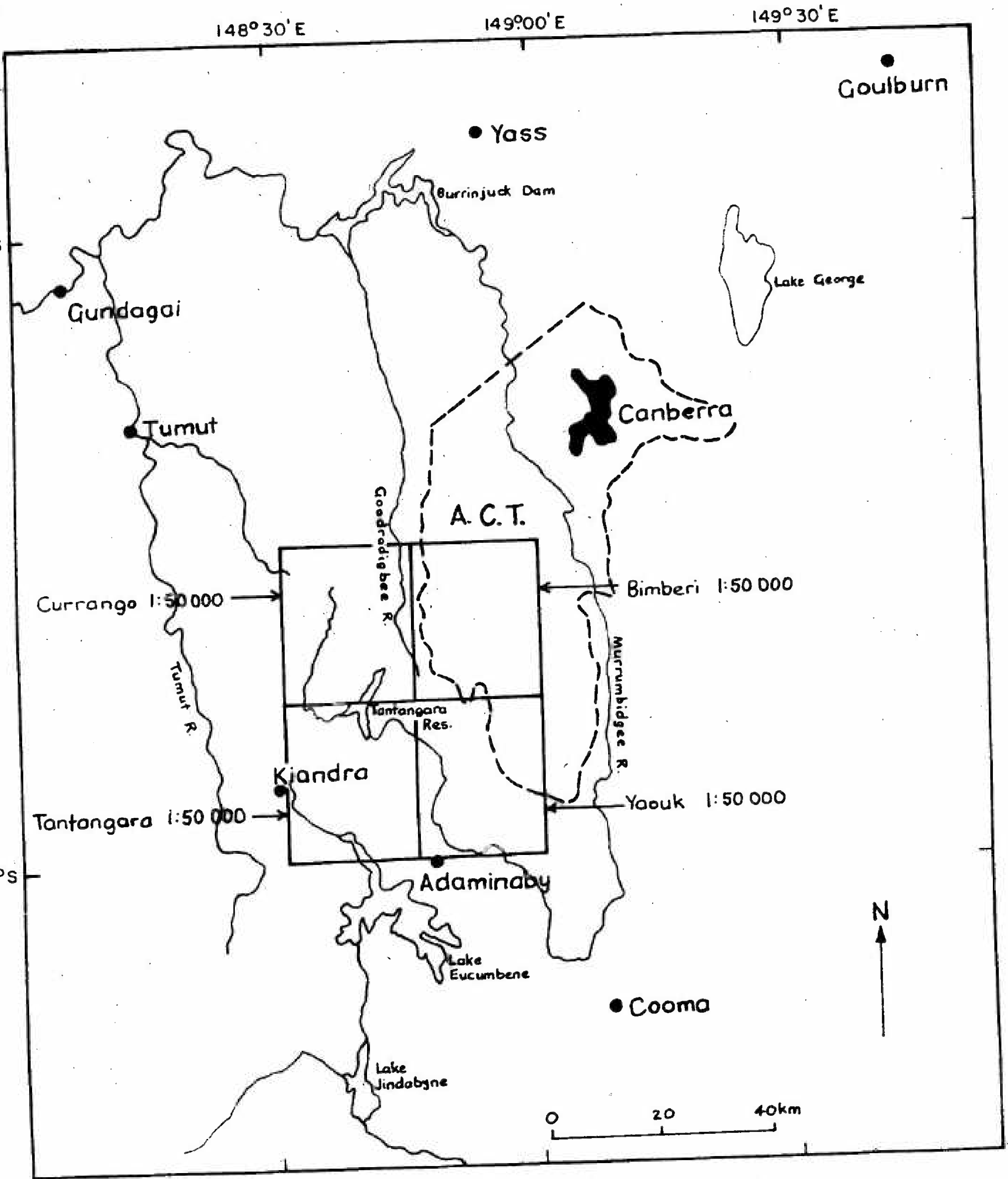


Fig. 1. Location map.

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Valley and the third heads northwest through the Cooleman Plains and Cave Creek areas, to join the Long Plain Road at the northern end of Long Plain.

From Adaminaby two-wheel-drive roads head east to Jones Plain and Shannons Flat and north to Yaouk, with a connexion between Yaouk and Shannons Flat. A fire trail also connects Yaouk with the Cotter Valley. Access to the northeastern part of the Sheet area is by the road from Canberra, via Tharwa, to the Orroral Valley Tracking Station. This continues as a fire trail into the Cotter Valley, to connect with the trails from Yaouk and Tantangara Dam. Before the Orroral Valley Road crosses the Orroral River a two-wheel-drive gravel road continues south, east of the Sheet area past Gudgenby to Shannons Flat, allowing access to the eastern edge of the Sheet area.

## Climate and vegetation

The climate reflects the high altitude of much of the area, which ranges from less than 780 m in the extreme northeast to 1912 m on Bimberi Peak. Rainfall and temperature markedly reflect the effects of altitude, and this is reflected in the vegetation. Full climatic figures are only available for Kiandra, but they are probably typical of much of the western part of the Sheet area. The mean annual rainfall for Kiandra is 1600 mm, with a winter and spring maximum and a summer minimum; June, July, and August average a total rainfall of 480 mm, and January, February, and March total 224 mm. Eastwards, a marked rain-shadow effect is noticeable at lower altitudes, and at Adaminaby, 29 km to the east-southeast, the mean annual rainfall is only 695 mm. A winter rainfall maximum also occurs at Adaminaby, but is much less obvious, and autumn rather than summer is the driest time of year. Other places for which rainfall data are available are Gudgenby with an annual rainfall of 773 mm, and Cotter House (now named Cotter Hut) with a rainfall of 876 mm.

The mean temperatures over much of the area largely reflects altitude, though local frost hollows may cause minimum night temperatures, particularly in winter, to be much lower than average. Kiandra's average minimum temperature in July is -4.4°C and the average maximum +4.2°C, and temperatures below -20°C have been recorded. Frost occurs on average 159 days a year. Summer temperatures are mild, with February having an average maximum of 20.8°C and a minimum of 6.3°C.

Snowfalls may occur in any part of the area during winter, and above 1000 m may be frequent and heavy. Snow commonly lies on the ground continuously for several months during winter above 1500 m.

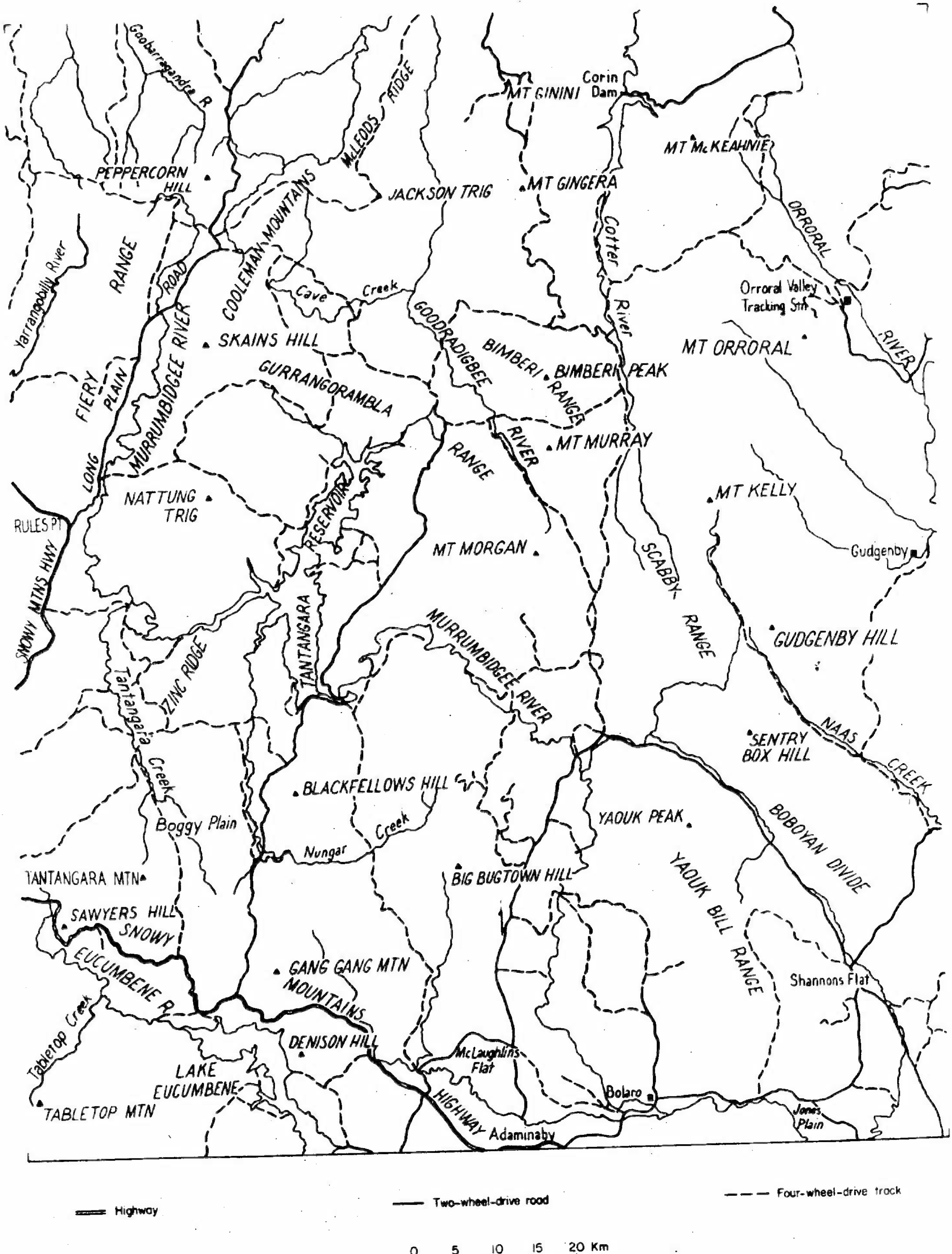


Fig. 2 . Main topographic features and roads in the Tantangara. 1:100 000 sheet area .

The wide variation in climate and altitude within the Sheet area has led to a diverse range of vegetation communities. Costin (1954) divided the Monaro region, of which the Tantangara Sheet area is part, into four regional tracts on an altitudinal basis. Each is present on the map sheet. The montane (about 1000 to 1500 m) and the subalpine (about 1500 to 1800 m) tracts are widespread. The alpine tract (above about 1800 m, approximating the treeline) is found only around the highest peaks whilst the tableland environment (below 1000 m) is restricted to narrow areas along the lower valleys. This altitudinal zonation is disrupted over significant areas where topographic configurations which trap cold air drainage have depressed the subalpine into the montane tract. These frost hollows often produce an inversion of the normal altitudinal sequence of vegetation (Moore, 1958).

The alpine environment is not well developed in the area, being represented on the highest peaks by small patches of woodland Eucalyptus pauciflora (snow gum) broken by open grassed areas dominated by Poa spp., with many seasonally colourful perennial herbs.

The subalpine tract is dominated by woodland forest areas of E. pauciflora (previously E. niphophila). In places the woodland is open and floored with various small shrubs, grasses, and herbs; this community is very fire-sensitive and in the past considerable areas have been greatly modified. The subalpine grasslands, most common at higher altitudes within the tract and more particularly in frost hollows, carry a sod tussock cummunity, dominated by a Poa caespitosa-Danthonia nudiflora-Themeda australis alliance. Vegetation above the frost hollows in the subalpine tract is often a montane wet sclerophyll alliance of E. dalrympleana-E. delegatensis (mountain gum-alpine ash), though usually this last alliance is found beneath the subalpine tract.

The extensive areas of wet sclerophyll forest which occupy the steep mountain slopes are made up of two alliances (Burbidge & Gray, 1970). The alpine ash-mountain gum alliance is comparatively widespread on the upper slopes, merging at times into the snow gums of the subalpine tract. A shrubby understorey of Acacia and other legumes is usual, and a diverse ground flora is common where shrubs are not dense. Below this alliance is the E. fastigata-E. viminalis (brown barrel-ribbon gum) alliance, with the ribbon (or manna) gum tending to occupy lower wetter sites. Several strata may be found below the closed canopy, discontinuous Acacia melanoxylon (to 20 m) above a 10-15 m layer of tall shrubs is common, whilst in wetter gullies a tree fern community of Dicksonia antarctia may be found.

In the relatively drier southern portion of the A.C.T. and the area near Adaminaby is a savanna woodland alliance of E. pauciflora-E. stellulata (snow gum-black sallee). In warmer areas the woodland is a more open E. melliodora - E. blacklevi (yellow box-red gum) alliance. Both these alliances are rather open; shrubs are few and the understory is dominated by grasses such as Stipa falcata and Danthonia spp.

(The above account of the vegetation of the area was condensed by M. Owen from notes provided by A. Spate, CSIRO Woodlands Ecology Unit).

## Mapping methods

When the project started in 1971 the only base maps available were 1:50 000 scale maps produced by the Royal Australian Survey Corps. The four maps covering the Tantangara 1:100 000 Sheet area are Currango, Bimberi, Tantangara and Yaouk (Fig. 1). These maps were enlarged to 1:20 000 for the compilation of field data. New South Wales Lands Department aerial photography taken in 1961 and 1963, at an average scale of about 1:40 000, was enlarged to 1:20 000 for field use. The National Mapping 1:100 000 Tantangara Sheet became available after completion of mapping and field information was transferred to it for production of the final map.

Field mapping generally consisted of closely spaced traverses, but in critical areas an attempt was made to examine all outcrops. The rugged nature of the country necessitated numerous walking traverses.

## Geological setting

The Tantangara Sheet area is in the southern part of the Lachlan Fold Belt. Using the terminology of Scheibner (1973) for the structural units forming the Fold Belt, most of the area falls within the Molong/South Coast Anticlinorial Zone. The area east of the Tantangara and Goodradigbee Faults is included within this zone and is termed the Molong/South Coast East Anticlinorial Zone and the belt of Ordovician and Early Silurian units extending north along the upper Eucumbene River and Long Plain, as far as Peppercorn Plain, is termed the Molong/South Coast West Anticlinorial Zone. The area between two belts of the Molong/South Coast Anticlinorial Zone is considered to be a southern extension of the Cowra-Yass Synclinorial Zone, represented within the Tantangara area by the Upper Silurian sediments and volcanics of the Cooleman Plains/Tantangara Reservoir region.

The area west of the Long Plain Fault appears also to be part of the same synclinorial zone, and is here termed the Cowra/Yass West Synclinorial

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Zone, as distinct from the Cooleman area which is termed part of the Cowra/Yass East Synclinorial Zone.

The anticlinorial or synclinorial nomenclature of Scheibner may be correlated with the horst and graben nomenclature previously used in this area, and shown in Figure 3 of Struasz (1971). The Cotter Horst is equivalent to the Molong-South Coast East Anticlinorial Zone; the Goodradigbee Graben is part of the Cowra-Yass East Synclinorial Zone, and the Cowra Trough of Strusz (1971) corresponds to the Cowra/Yass West Synclinorial Zone. The area considered to belong to the Molong/South Coast West Synclinorial Zone was shown by Strusz as part of the Cotter Horst, although it is probably better considered as the northern end of the Kosciusko Block.

## 2. PHYSIOGRAPHY AND GEOMORPHOLOGY
(D.E.G.)

Physiographic Units (Fig. 3)

Virtually all the Tantangara 1:100 000 Sheet area is above 900 m and more than two-thirds is above 1200 m. The western part consists of the moderately to deeply dissected Kiandra Tableland (Sussmilch, 1909) which occupies more than half the Sheet area; it extends a few kilometres west of the Sheet area to the edge of the Tumut valley. The country east of the Kiandra Tableland consists of two upland areas, and a small area of tableland at a lower elevation; all are bounded by major faults.

One upland area, for which the name Bimberi-Brindabella Upland is proposed, includes the Bimberi and Brindabella Ranges. It occupies a small wedge-shaped area in the northern half of the Sheet area. The larger upland area for which the name Mount Kelly Upland is proposed inclues Scabby and Yaouk Bill Ranges and the southern part of Tidbinbilla Range; it extends east of the Sheet area past Billy, Booth, and Clear Ranges to the Murrumbidgee River. The small triangular area of tableland in the south-eastern part of the Sheet area which extends north to Yaouk village lies between the Kiandra Tableland and the southern part of the Mount Kelly Upland. It is the northern part of the Adaminaby Tableland of Sussmilch (1909).

The Bimberi-Brindabella Upland and the northeastern part of the Kiandra Tableland, are separated by the Goodradigbee Fault along the upper part of the Goodradigbee valley. The Mount Kelly Upland is separated from the Bimberi-Brindabella Upland by the Cotter Fault. Not far south of

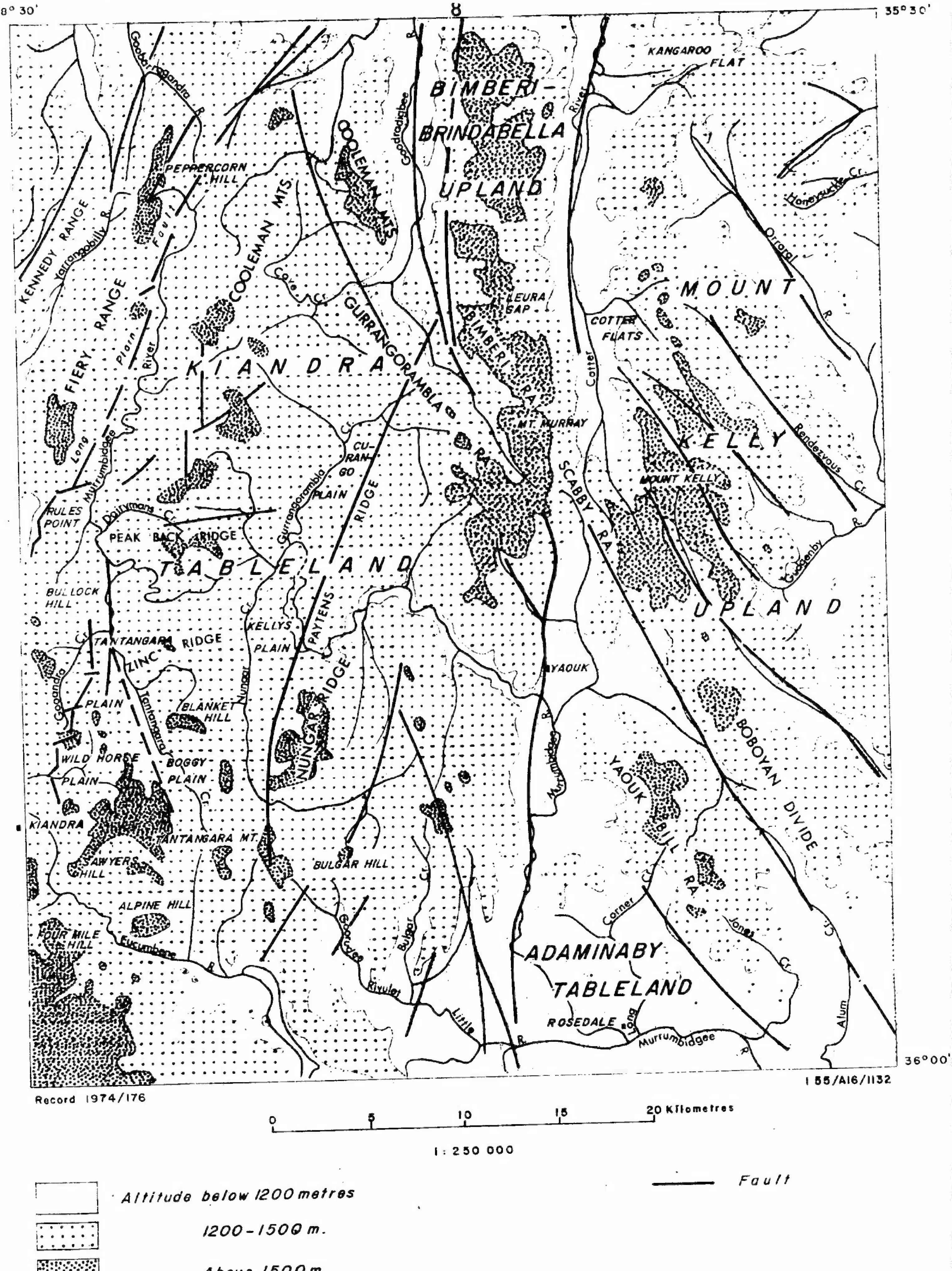


Fig. 3. Physiographic units in the Tantangara 1:100 000 Sheet area.

the source of Long Corner Creek, a northwesterly striking fault separates it from the Adaminaby Tableland; this fault presumably continues northwest or north-northwest to the Cotter Fault, but it has not been recognized north of the source of Long Corner Creek.

Drainage

Nearly all the area is rained by the Murrumbidgee River system; a small part in the southwest is drained by the Eucumbene River. The Murrumbidgee River rises in the northwest, flows south-southwest along the line of Long Plain Fault, then deviously southwards and eastwards at the southeast corner of the Sheet area; after 5 km it turns and flows northwards at about 10 km east of the Sheet area; about 60 km north of the Sheet area it turns westwards and flows several hundred kilometres west to join the Murray northwest of Swan Hill. In the north the streams flow northwards; the Goodradigbee and the Cotter join the Murrumbidgee; the Goobarragandra River joins the Tumut River, which flows north towards the Murrumbidgee a short distance west of the Sheet area. In the northwest and west, the streams flow southwest to join the Tumut. Along the eastern edge of the Sheet area, the streams drain southeast to join the Gudgenby River, a northward-flowing tributary of the Murrumbidgee.

In their upper reaches, the streams meander in broad valleys over mildly or moderately dissected terrain. Farther downstream, where they have been rejuvenated by uplift or stream-capture, their valleys are youthful.

Valley-in-valley landforms are common. This could be due, in the main, to uplift, but in some locations is due to rejuvenation following stream capture and in others to the establishment of a temporary base level through the damming of the drainage by basalt flows.

Remnants of terraces are widespread in the valley floors; they rise about 5 m above the general flood-plain level in the Eucumbene valley west of Sawyers Hill, up to 75 m above the Murrumbidgee River near Yaouk village, and 3 to 4 m in the Tantangara valley near Blanket Hill. Many terraces are due to cyclic aggradation and erosion during the Pleistocene, aggradation during the cold stages and erosion in the warmer intervals; some terraces are probably older than Pleistocene. Thick colluvium on the lower parts of slopes had a similar origin; the process of mass movement of soil and rock detritus down slopes, through gelation and solifluction made a major contribution to the Pleistocene alluviation.

The Murrumbidgee River rises on the western side of Peppercorn Hill and flows 18 km south-southwest, in a valley that follows a system of faults along Long Plain to a locality near Rules Point where, through a gap eroded in basalt that filled an ancient valley, the river turns eastwards, southwards, and eastwards, flowing in deeply incised meanders as far as Kellys Plain; here it enters a wide, mature, but deep valley in dacitic volcanic rocks. It leaves the southern end of Kellys Plain through a gorge in the resistant sedimentary rocks of Paytens Ridge, in the northern part of Nungar Ridge. In a kilometre or so, it enters a wide mature valley in which it is entrenched by about 40 m; it flows northeast and east across the valley, and enters a gorge to flow southeast towards Yaouk village. There it enters a wide alluviated valley at an elevation of about 1080 m and flowing south, becomes again entrenched after a few kilometres. It then leaves the valley and enters a narrow gorge, from which it emerges into a wide, mature valley that runs east through Rosedale.

The alternating of mature valley and gorge suggests past changes in the ancestral route of the river. The upper part, in Long Plain, might at one time have formed the headwaters of the Goodradigbee River, flowing northward from a source in a divide near the present-day Bullock Hill. It is possible that the valley became blocked by basalt, remnants of which cap Peppercorn Hill, Bullock Hill, and low hills near Rules Point. The dammed river overflowed to the south and east, a short distance east of the present-day basalt residuals, into Tantangara Creek, which entered a meandering stream that flowed eastward to Gurrangorambla Creek and the Goodradigbee River. At that time the gaps in Paytens and Nungar Ridges, through which the Murrumbidgee River and Nungar Creek now flow, had not been eroded.

Nungar Creek possibly had its source on the eastern side of Nungar Ridge, not far east of the present-day gap. Contours around its catchment show a wide outlet to the southeast at an elevation of about 1370 m; it is improbable that the gap had been eroded then as the bottom of the gorge has, even now, an elevation of 1325 m. Instead, the creek probably flowed eastward and southward around the eastern side of Bulgar Hill across a low divide at an elevation slightly above 1340 m into Bulgar Creek. The Murrumbidgee River at that time possibly had its source east of the gap in Paytens Ridge, and meandered in a mature valley northward and eastward to a less mature valley at the location of the present gorge leading down towards Yaouk village. Contours around the catchment suggest that this was the only outlet below 1400 m, assuming that the gap had not been eroded in Paytens Rigde. Headward erosion of the source to form the gap resulted in the capture

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of the extensive stream system west of Nungar Ridge. The flow in Gurrangorambla Creek, which was then the headwaters of the Goodradigbee, was reversed. Rejuvenation and deep erosion started in the meandering stream that flowed into it from the west, to initiate the present-day deeply incised meanders in this part of the valley. Rejuvenation in the stream flowing north on the western side of Nungar Ridge resulted in the capture of the present-day upper Nungar Creek which was then probably the upper Bulgar Creek.

The headwaters of the Eucumbene River flow south in a slightly incised channel in a mature valley north of Kiandra, a short distance east of the boundary of Early Tertiary basalt. West of Sawyers Hill, the river flows through a deep gorge for nearly 2 km to moderately dissected country south of the hill, where it is incised a little deeper than 30 m. Near Alpine Hill, the river enters a second deep gorge, from which it emerges into a wide, mature valley. Contour maps and geological maps (Moye et al., 1963; suggest that, at the time the basalt was extruded, a divide followed roughly the ridges of Tantangara Mountain, Sawyers Hill, and Four Mile Hill, and that the drainage of the Kiandra area was to the north and slightly east of north, close to the present valley of Gooandra Creek. The basalt blocked the channel near Gooandra Creek and caused the drainage to overflow the divide in the south, where the edge of the basalt met Sawyers Hill; the overflow was into a tributary of the Eucumbene near its source at that time. Probably the upper Eucumbene had already formed a maturely dissected area or small plain, with an elevation above 1350 m at the site of Rocky Plain, east of Sawyers Hill, and flowed from it through a narrow valley to Providence Flat; this presumably had an elevation of at least 1200 m, which is that of some residual benches around its margin. Accelerated erosion owing to the drainage from the Kiandra area resulted in the formation of the gorges, and the incising of the river channel on the western side of Rocky Plain.

## Kiandra Tableland

The Kiandra Tableland is above 1200 m in elevation; its higher parts, perhaps five percent of its area, rise above 1500 m. Around the margins of the map area, the tableland is dissected by the upper parts of some of the larger rivers and their tributaries - in the north by the Goodradigbee and Goobarragandra, in the northwest by the Yarrangobilly-Tumut system, in the south by the Eucumbene, and in the southeast by the Murrumbidgee.

In the southwest, near Kiandra, the tableland grades into the Kosciusko Plateau, which extends outside the map area more than 70 km to the south-

southwest. This plateau is elongated and gently tilted towards the north-northeast, and has the appearance of an asymmetrical dome or swell (Moye et al., 1963). It is bounded on the west by a series of northeast-trending major scarps arranged en echelon, and is deeply dissected by large streams and their tributaries. The deep erosion extends to the western side of the Kiandra Tableland, a short distance west of the Sheet area, in the steep valleys and gorges of the Tumut and Yarrangobilly Rivers and tributaries.

The rocks beneath the tableland are cut by several large and numerous minor faults, many of which mark the positions of scarps and valleys. The Long Plain Fault, a major normal fault with downthrow to the west, strikes north-northeast from Rules Point past Peppercorn Hill; it consists of a number of parallel faults and wedge-shaped slices, in a zone 1 to 2 km wide. The fault is represented topographically by a fault-line scarp of Silurian acidic volcanic rocks on the downthrow side; the scarp stands 100 to 200 m above the Ordovician sediments on the upthrow side. A valley has been eroded below the general level of the surface on the Ordovician sediments - about 60 m below it near Rules Point.

The presence of residual hills and ridges of basalt along the valley shows that the valley and the scarp had already been formed early in the Tertiary when the basalt was extruded. The pre-basalt relief, as shown by the difference in elevation between the crest of Fiery Range and the base of the basalt, must have been at least 275 m, disregarding post-basalt erosion of the range. The presence of streams flanking both sides of the basalt suggests that the lava-flow was confined to the old valley.

A major fault that trends north-northeast, parallel to the Long Plain Fault, follows the western edge of Nungar Range; resistant sedimentary rocks form the range, and Devonian volcanics form the lower country of Kellys and Currango Plains. Faults parallel to the Long Plain Fault are followed by valleys between the ridges of the Fiery and Kennedy Ranges. Inferred faults in the same direction, in an area northeast of Kiandra, between Wild Horse Plain and Tantangara Plain, are based on the distribution of the rock types in the area, in relation to stream valleys, and lineaments on aerial photographs.

Major faults that trend north-northwest to northwest are terminated by faults of the Long Plain system, and presumably are older. Topographically, they are not prominently marked; in some places gullies follow them, and locally they form indefinite scarps or changes of slope. An exception is a probable reverse fault that is followed by Tantangara Creek, on the western side of Boggy Plain; it is marked by a scarp where resistant Ordovician rocks stand above more easily weathered granite, and by a valley where there are resistant rocks on either side.

The Murrumbidgee and Eucumbene Rivers, and the possible history of their development, are described under Drainage. Many of the tributary streams, in the upper parts of their courses, flow in intricate meanders in flat-bottomed valleys. Extreme cases are the headwaters of Nungar, Gurrangorambla, and Cave Creeks; these rise in low divides which probably originated through capture and reversal of the flow in the upper part of the stream. At the other extreme are Hell Hole Creek on the southern side of Peak Back Ridge, and the lower reaches of Tantangara and Dairymans Creeks, which are rejuvenated and deeply incised.

The lithology of the bedrock is commonly reflected in the topography. Resistant rocks are the dominantly arenitic Late Ordovician and Early Silurian sedimentary rocks of Zinc, Peak Back, and Nungar Ridges; the hornfelsed beds, principally Ordovician, in contact with the Happy Jacks Granite in Sawyers Hill, Tantangara Mountain and Blanket Hill; the Silurian volcanic rocks of Fiery and Kennedy Ranges and the Devonian volcanics of Gurrangorambla Range and Cooleman Mountains. The least resistant rocks are the Late Silurian sediments along the middle and lower parts of Nungar Creek, in the mildly dissected plain drained by Cave Creek, and probably in Currango Plain. At these localities overlying resistant Devonian volcanic rocks have probably been undercut through erosion of the underlying sediments.

## Bimberi-Brindabella Upland

The Bimberi-Brindabella upland drops steeply at its western and eastern edges to the valleys of the Goodradigbee and Cotter Rivers, which follow major northerly-trending faults. A ridge which forms a divide between the two rivers runs northwest through Mount Murray and Bimberi Peak in the Bimberi Range, passes over Leura Gap and continues generally northwards in the Brindabella Range; short lateral ridges slope abruptly into the river valleys.

About four fifths of the Bimberi-Brindabella Upland rises above 1200 m in elevation, and about half of this is higher than 1500 m; some of the peaks in the divide rise above 1800 m.

The Goodradigbee valley is incised to a depth of 60 m within a distance of 2 km from its source, which is in steep country in the Gurrangorambla Range. At the northern end of the map area, 20 km direct from the source, the valley is cut down deeply to an elevation of 800 m; the Kiandra Tableland on its western side rises steeply to more than 1200 m, and the Bimberi-Brindabella Upland on its eastern side to more than 1500 m. The Cotter River rises in steep country at an elevation above 1500 m; after flowing slightly west of north for 3 km, it enters a deep but wide mature stretch of valley, flanked by the Bimberi-Brindabella Upland on the west, and the Mount Kelly Upland on the east. In a distance of 5 km, the valley narrows and deepens; at the northern end of the map area it is down to an elevation of 850 m, and uplands on either side rise to more than 1200 m.

Mount Kelly Upland

The Mount Kelly Upland is more widely eroded than the Bimberi-Brindabella Upland. In the northeast and east, deep valleys have been cut by four southeasterly flowing tributaries of the Gudgenby-Naas river system. In the south, a wide area has been eroded and reduced in elevation by Alum Creek and Jones Creek, tributaries of the Murrumbidgee River. Within the limits of the Sheet area, a little less than half the area of the Upland is above 1200 m; of this, about one-eighth rises above 1500 m.

The divide between westward and eastward drainage runs northeast and north from the southern end of Yaouk Bill Range to Boboyan Divide and Mount Kelly, then generally northwards, at a distance of 3 to 5 km east of the Cotter River.

The Mount Kelly Upland within the map area shows three topographically distinct areas, the Honeysuckle Creek and Cotter valley areas in the northeast and northwest, and the large Rendezvous Creek Area. The Honeysuckle Creek area is characterized by ridges and intervening valleys that strike about northeast. One fault that has this strike has been mapped. The divide enters the Honeysuckle Creek area around the top of the Orroral River, swings around from north to follow a ridge northeast for 5 km, and turns sharply northwest for 4 km past the headwaters of northeasterly draining creeks, before turning north past the edge of the Sheet area to follow the crest of Tidbinbilla Range.

The Rendezvous Creek area consists of a series of long narrow southeasterly trending ridges, most of which rise well above 1500 m. They

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are separated by faults along which streams have eroded deep valleys southeast to the Gudgenby and Murrumbidgee Rivers and northwest to the headwaters of the Cotter River. The divide passes northwards through the Rendezvous Creek area by a zig-zag route, following successive ridges northwestwards, and crossing the intervening valleys by turning northeast at the saddle between northwesterly and the southeasterly drainage.

The Cotter Valley area forms a narrow strip in the north on the western side of the divide. The area is dissected by the Cotter River and tributaries, and no clear pattern is visible in the trends of the ridges and valleys, except near Cotter Flats in the south and Kangaroo Flat in the north, respectively, where ridges of the Rendezvous Creek and the Honeysuckle Creek Areas extend into it.

## Adaminaby Tableland

The Adaminaby Tableland is separated by faulting from the higher country in the Kiandra Tableland in the west and, in part at least, from the high Yaouk Bill Range in the northeast.

About two-thirds of the area is below 1150 m in elevation, and the highest parts are between 1200 and 1300 m. Benches with summit levels at about 1170 m suggest a probable former surface, over almost all the area. Benching above the flat country immediately north and south of Yaouk village suggests that two younger surfaces were established. One at about 1120 m extended through the area as mature valleys and small plains eroded into the 1170-m surface. A younger surface of small extent was apparently established south of Yaouk village at an elevation of about 1070 m; it is being dissected by present-day erosion.

The lower surface elevation of the Adaminaby Tableland is due in part to erosion by the Murrumbidgee River. However, the suggested 1170-m surface is co-extensive with the Adaminaby Tableland, most of which is underlain by resistant Ordovician sedimentary rocks, and it hardly encroaches at all on the high country of the Yaouk Bill Range and the Kiandra Tableland, which in the general area is underlain mainly by granite; for this reason it appears likely that the lower elevation is due principally to differential uplift.

It is suggested that the 1170-m surface was established before the Murrumbidgee River had captured the drainage west of Nungar Ridge; the river probably flowed in a mature valley that followed a fault line at the edge of the Kiandra Tableland. The stream capture resulted initially in deep alluviation of the earlier valley along the fault and eastward diversion of the river into a meandering course in a new valley in approximately the same position as the present valley. Continued erosion resulted in the formation of the 1120-m surface. The absence of erosion surfaces at these elevations on the western side of the fault suggests possible uplift of the Kiandra Tableland at about this time. The contours on the western side give no strong positive evidence but they do suggest possible remnants of erosion surfaces at elevations of about 1300 m and 1250 m; these, if correlated with the 1170-m and 1120-m surfaces would indicate an uplift of 120 m.

Assuming that it did take place, the uplift of the Kiandra tableland sharpened the scarp, which is not yet greatly modified, and accentuated the topographic lack of symmetry that exists between the western and eastern margins of the Adaminaby Tableland. The uplift was followed by alluviation below the scarp; subsequent erosion formed the 1070-m surface, and the meandering river settled approximately into its present incised channel.

## 3. ORDOVICIAN SEDIMENTARY AND VOLCANIC ROCKS

### BOLTON BEDS

(D.E.G.)

#### NOMENCLATURE

Fairbridge et al. (1951) gave the name 'Boltons Greywacke' to 'a very fine-grained clastic rock with lighter and darker constituents' which outcrops over a wide area around Bolton Hill (formerly Boltons Hill), in the Wagga Wagga and Tallangatta 1:250 000 Sheet areas, about 2.8 km east-northeast of the junction of the Happy Jacks and Tumut Rivers. 'Minor bands or lenses in the greywacke consist of thin-bedded cherts; impure quartzites ........, silicified sandstones ..........., and dark slates and shales'. Moye (1953), as a result of more detailed mapping, found that the sequence is essentially quartzite, tuffaceous quartzite, greywacke, and slate; he called it the 'Boltons Beds'.

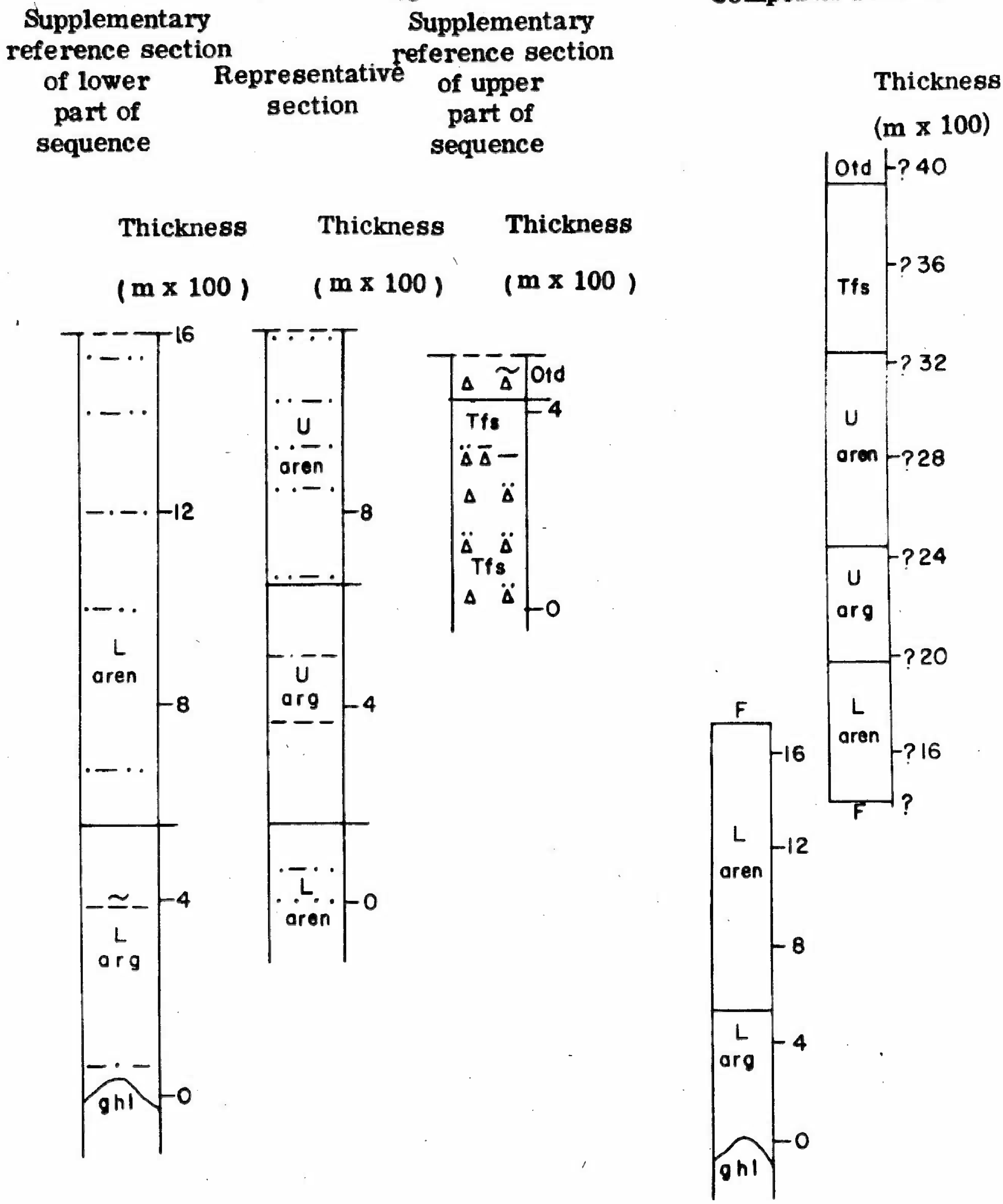
In the present mapping which covered the Tantangara Sheet area as well as the area around Bolton Hill, five lithological units were distinguished. Two are fine-grained to very fine-grained altered quartz arenite and interbedded argillite, and three argillitic beds with interbedded arenite. One of the latter units, at the top of the sequence, is slightly tuffaceous. The quartz arenite has an argillitic matrix, commonly recrystallized to sericite, with chlorite and minor epidote; it is apparently the same as Fairbridge's 'Greywacke'. Lithic fragments are scarce or absent, and the tern arenite is used rather than greywacke. As a name for the sequence as a whole, Bolton Beds has been adopted.

DERIVATION OF NAME

The name is derived from Bolton Hill around longitude 148°28' and latitude 36°, where the beds are well exposed.

REPRESENTATIVE SECTIONS

Fairbridge et al. (1951) described the distribution of the Bolton Beds between Temperance Creek and Happy Jacks River (Pl. 1), but did not name a type section. A continuous section of the complete succession of the beds has not been found; the sequence is faulted at several localities along Temperance Creek, Temperance Spur, and Happy Jacks Road. The M-Bend and Bolton Hill Faults were inferred (Pl. 1) to explain these breaks in the succession; they follow lineaments that can be seen on aerial photographs of the area. A representative section is described on page 20 in the type area of Fairbridge et al. (op. cit.) between Bolton Creek and Bolton Hill; it includes upper argillitic and arenitic units. A supplementary reference section of lower argillitic and arenitic units is described on page 20 along Temperance Spur, and one (p. 21) for the slightly tuffaceous unit, at the top of the sequence, along Happy Jacks Road. The locations of the sections are shown in Fig. 5; the sections are shown diagrammatically in Fig. 4 and summary descriptions of outcrops are given in Table 1. The upper boundary of the Bolton Beds passes through a locality along Happy Jacks Road where chert enters the sequence of interbedded tuffaceous arenite, tuffaceous argillite, and tuff. It is probably a little higher stratigraphically, perhaps 100 to 200 m, than the boundary used by Fairbridge et al.




ghl Happy Jacks Granite
Otd Temperance Chert
U Upper
aren Arenitic unit
arg Argillitic unit
Tfs Tuffaceous unit

·· Arenite
– Argillite
Δ Tuff
~ Chert

Tuffaceous arenite
Tuffaceous argillite
Tuffaceous chert
≃ Silty chert

Fig. 4. Reference sections of the Bolton Beds.

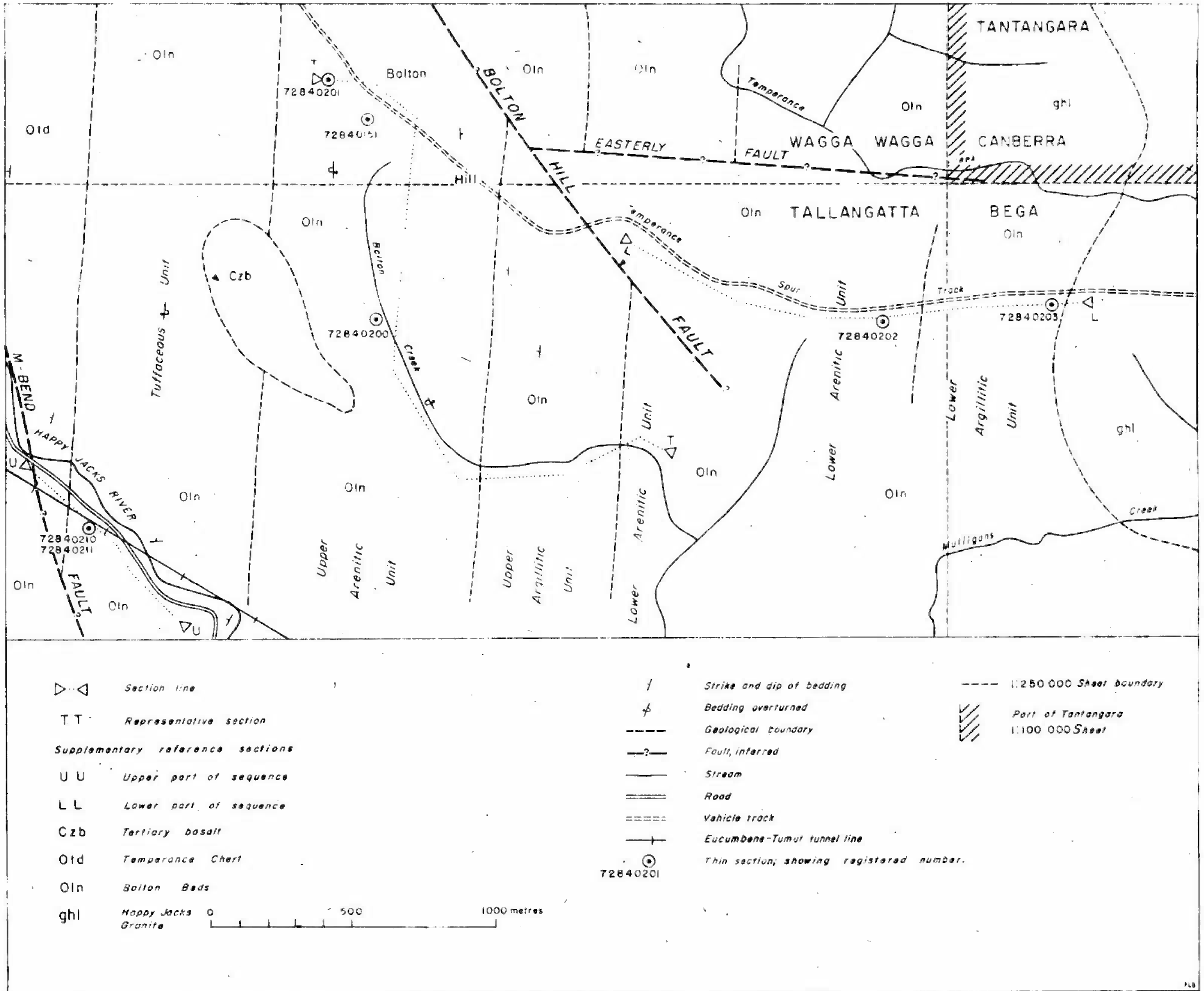



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**Fig. 5. Location of reference sections of the Bolton Beds.**

Wagga Wagga, Tallangatta, and Bega 1:250 000 Sheet area

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TABLE 1. REFERENCE SECTIONS OF THE BOLTON BEDS

Location: Bega, Tallangatta, and Wagga Wagga 1:250 000 Sheet areas (Fig. 5)

| Approx. distance (m) | Geographic description | Geological description. Thin section described in Table 2 |
|---|---|---|
| | **Type Section** | |
| 0 | Start of section: Bolton Creek, 350 m NNW of junction of tributary creek that flows from NNE. Section line runs 280° | Lower arenitic unit: thick-bedded fine-grained altered quartz arenite |
| 80 | Section line turns to 240° | Altered fine-grained quartz arenite or sandstone and interbeds of silty mudstone |
| 150 | | Boundary of lower arenitic unit; section passes up into upper argillitic unit. Outcrop is scarce: fragments in soil are of thin-bedded siltstone and laminated shale |
| 300 | | Altered siltstone, shale, fine-grained quartz sandstone |
| 380 | Section line turns to 267° | Thin-bedded siltstone and shale |
| 520 | | Siltstone, shale, fine-grained altered quartz-sandstone |
| 670 | | Boundary of upper argillitic unit; section passes into upper arenitic unit |
| 720 | Section line turns to 330° | Altered fine-grained quartz sandstone (probably tuffaceous), siltstone, and shale |
| 1170 | Section line tuns to 005° | Fine-grained argillitic arenite, siltstone, and interbeds of slate |
| 2010 | Section line crosses track on crest of Bolton Hill | |
| 2060 | Section line turns to 306° | Fine-grained argillitic arenite, siltstone, and argillite interbeds |
| 2260 | Section line turns to 270° | Very fine-grained argillitic arenite or siltstone, very fine-grained quartz-arenite or quartz-siltstone, thin beds of argillite (TS 72840151) |
| 2380 | End of section | Fine-grained slightly argillitic quartz arenite or impure quartzite (TS 72840201) |
| | **Supplementary reference section of lower part of sequence** | |
| 0 | Start of section: On southern side of Temperance Spur track near head of Mulligans Creek. Section line runs 268° | In outcrop area of Happy Jacks Granite |

| Approx distance (m) | Geographic description | Geological description. Thin section described in Table 2 |
|---|---|---|
| 30 | | Boundary of granite; section enters lower argillitic unit |
| 60 | | Finely banded argillitic arenite and argillite (TS 72840203) |
| 390 | Section line turns to 260° | Siltstone, silty chert, silty mudstone; in part hornfelsed |
| 530 | | Boundary of lower argillitic unit; section passes up into lower arenitic unit |
| 570 | | |
| 650 | | Fine-grained argillitic arenite or quartz-greywacke (TS 72840202) |
| 670 | Section line turns to 270° | |
| 900 | Section line turns to 283° | |
| 980 | | Very fine-grained argillitic arenite or greywacke and argillitic siltstone |
| 1180 | Section line turns to 297° | Argillitic siltstone or very fine-grained greywacke |
| 1380 | | Argillitic arenite or greywacke; hornfelsed |
| 1520 | | Fine-grained argillitic arenite or greywacke, and argillitic siltstone |
| 1580 | End of section | |
| | Supplementary reference section of upper part of sequence | |
| 0 | Start of section: on southern side of Happy Jacks Road 1900 m SE of bridge over Happy Jacks River. Section line runs 315° | |
| 50 | | Tuff, tuffaceous quartz arenite |
| 220 | Section line turns to 330° | Tuffaceous quartz arenite |
| 350 | Section line turns to 308° | Tuff, tuffaceous quartz arenite; shows intricate slump-folding |
| 470 | | Tuff, tuffaceous siltstone and tuffaceous argillite (slump-folding), and quartz siltstone (TS 72840210, 72840211) |
| 580 | | Upper boundary of Bolton Beds; section enters Temperance Chert |
| 670 | | Tuff; tuffaceous chert or cherty tuff |
| 730 | End of section | |

## TABLE 2. THIN SECTIONS FROM THE BOLTON BEDS

(Localities are shown in Fig. 5)

TS 72840151. An altered argillitic quartz-siltstone

Consists of detrital quartz (40-60%) and an altered argillitic matrix. The quartz is angular, and the modal grainsize close to 0.02 mm. The matrix consists of sericite, muscovite, rare biotite, epidote, actinolite, and minute quartz. Epidote ranges from about 3 to 7%. Actinolite amounts to about 2 to 10% in bands or thin laminae 0.1 to 0.4 mm thick. A few detrital grains of tourmaline are present.

TS 72840201. Slightly argillitic quartz-arenite or impure quartzite

Consists of detrital quartz (90%) and an altered argillitic matrix. The quartz grains are angular, poorly sorted, and show extensive interpenetration; the modal grainsize is about 0.2 mm. The matrix consists of quartz in grains smaller than 0.01 mm, sericite, chlorite, probable epidote, and rare carbonate. Possible lithic fragments have the same detrital constituents as the matrix, and were regarded as matrix.

TS 72840202. An argillitic arenite or quartz-greywacke

Consists of about 40% detrital quartz in a matrix of minute granular quartz and altered argillaceous sediment. The quartz is present in two poorly defined size-grades: One of angular embayed and round grains has a mode of about 0.5 mm; the other, of angular grains, has a mode of 0.1 mm. A few plates of clear muscovite are up to 0.5 mm long. The matrix consists of fibres of sericite to 0.1 mm (70%) and very small detrital quartz (30%).

TS 72840203. Alternating bands or thin beds of argillitic arenite or quartz-argillite (20 mm thick) and argillite (2 mm thick); the rock is spotted

Consists of detrital quartz (about 30%) in two size-grades (modal diameters 0.3 and 0.1 mm), and a matrix (about 70%) of well-formed muscovite and biotite. The argillitic bands consist of muscovite (60%), biotite (15%), very small detrital quartz (15%), and opaques, probably pseudomorphs after sulphide (4%). The reason for the spotting is not clear; clusters of sericite in the argillitic band possibly represent altered cordierite.

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Table 2 continued.

(Localities are shown in Fig. 5)

TS 72840210. Banded tuffaceous silty argillite and tuffaceous argillitic siltstone

Consists of wavy bands 1 mm thick, very fine-grained, and predominantly argillite; some very thin bands contain almost 80 percent of minute granular quartz.

The argillitic bands consist predominantly of sericite, minor pale brown biotite, chlorite, carbonate, minute fibres or actinolite, and about 5% of opaques. The chlorite, actinolite, and carbonate suggest the presence of tuffaceous sediment or, more likely, of sediment derived from weathered basic to intermediate volcanic rocks.

TS 72840211. Slightly argillaceous quartz-siltstone, almost quartzite

Consists of about 95% quartz and 5% of altered argillitic material. More than 80% of the quartz consists of angular interpenetrating grains, with serrated margins, about 0.1 mm in size. Less than 15% consists of grains about 0.02 mm in size.

The proportion of altered argillitic matrix throughout the slide ranges from about 2 to 5%, except in some wisp-like bands where it amounts to about 20%. The argillaceous material is altered to sericite and minor epidote and chlorite.

DISTRIBUTION

In the area mapped, the outcrop of the Bolton Beds extends north and northeast, west of the Happy Jacks Granite, from Happy Jacks Road in the Tallangatta and Wagga Wagga 1:250 000 Sheet areas, past Sawyers Hill and Tantangara Mountain to the edge of Boggy Plain in the Tantangara 1:100 000 Sheet area. From Happy Jacks Road northwards past Sawyers Hill, the outcrop area is more than 3000 m wide; about 800 m south of the Eucumbene River, the boundary of the granite swings around to the west, and the outcrop width of the Bolton Beds is reduced to less than 1000 m. A small area of Bolton Beds 8 km north of Tantangara Mountain is surrounded by Temperance Chert, which appears to be conformable; the area is here called the Gooandra Inlier, after Gooandra homestead 2 km to the west. In the same general area, Bolton Beds occupy a small area 1 km to the southeast at the edge of Blanket Plain. Most of Blanket

Hill, 5 km north of Tantangara Mountain, consists of Bolton Beds. This is apparently a displaced part of the outcrop area near Tantangara Mountain: it was probably displaced by movement along a ?transcurrent reverse fault, the Boggy Plain Fault. There is a narrow area of Bolton Beds at the edge of the granite on the eastern side of Boggy Plain.

## LITHOLOGY

### Lithological Subdivision

The five lithological units that were distinguished by the author are summarized in Table 3.

Between the northern area at Sawyers Hill, near Kiandra, and the southern area around Happy Jacks Road and Temperance Spur, some reconnaissance mapping was done, but not enough information was obtained to permit a subdivision of the beds into lithological units. An approximate boundary for the top of the Bolton Beds in this area is shown on the sketch-map of Plate 1; at Happy Jacks Road and near Sawyers Hill the boundary is at about the position given by Moye (1953). Of the lithological units shown in Table 3,

TABLE 3. LITHOLOGICAL UNITS OF THE BOLTON BEDS

| Unit | Dominant Lithology | |
|---|---|---|
| | Tantangara 1:100 000 (in Canberra 1:250 000) Sheet area | Wagga Wagga, Tallangatta, and Bega 1:250 000 Sheet areas |
| | East and northeast of Kiandra | Bolton Hill, Temperance Creek, and Happy Jacks Road. See Plate 1 |
| Tuffaceous | Quartz arenite and argillite; minor tuff | Quartz arenite and argillite; |
| Upper arenitic | Quartzite | Quartz arenite |
| Upper argillitic | Not present | Argillite and quartz arenite |
| Lower arenitic | Quartzite and quartz arenite | Quartz arenite |
| Lower argillitic | Quartz arenite, quartzite, and argillite | Argillitic quartz arenite and argillite |

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only the upper one, the tuffaceous unit, and probably part of the upper arenitic unit, can be followed north of the Eucumbene River into the Tantangara Sheet area; the others terminate south of the river, against the Happy Jacks Granite.

In the southern area, mapping was done along the Happy Jacks Road, Bolton Creek, Bolton Hill, Temperance Spur, and Temperance Creek. Differences in the lithological sequences within the area are attributed to faults coincident with lineaments that can be seen on aerial photographs. One of the inferred faults, here named the M-Bend Fault, is very steep or vertical and strikes north-northwest through an M-bend in the Happy Jacks River. A second, named here the Bolton Hill Fault, strikes northwest through the northeastern side of Bolton Hill. A third fault, here termed the Eastern Fault, follows a westerly-flowing upper part of Temperance Creek. The beds dip generally at 80° or steeper, and, disregarding any repetition by folding, their thickness is almost equal to the width across the strike.

## Lower argillitic unit

### Bega 1:250 000 Sheet area

The oldest of the exposed Bolton Beds consist of interbedded argillite and arenite in the eastern part of Temperance Spur. Beds that can possibly be correlated with them crop out on Four Mile Hill, Tabletop Creek, and on the western and eastern parts of Blanket Hill, northeast of Kiandra.

Temperance Spur. Predominantly argillitic beds that crop out at the eastern end of Temperance Spur occupy a width of 500 m, across the strike, at the edge of the Happy Jacks Granite near the southwestern corner of the Tantangara Sheet area. They consist of very fine-grained arenite with an abundant argillitic matrix, finely banded silty argillite, and argillite.

A spotted rock near the granite at the eastern end of Temperance Spur consists of alternating bands of argillitic arenite or quartz argillite (20 mm wide) and argillite (2 mm). A thin section of the rock (TS 72840203) is briefly described in Table 2.

### Tantangara 1:100 000 Sheet area

Four Mile Hill. A finely banded rock which is probably part of the lower argillitic unit crops out on the northeastern side of Four Mile Hill where the track descends to the Eucumbene River, 500 m northwest of the junction of Tabletop Creek with the river. Thin bands, 0.5 to 5 mm thick, consist of altered argillite and silty argillite. The argillitic bands are altered to muscovite, sericite, and biotite; they are calcareous, and spotted with incipient ?cordierite porphyroblasts. The silty bands contain up to 40% detrital quartz, as grains 0.01 to 0.04 mm across. In the field, the spotted argillite appears to have the texture of a fine-grained arenite.

Tabletop Creek. Along Tabletop Creek, argillitic beds are dominant in a section that is exposed over a distance of 400 m upstream from the junction of Waterhole Creek. The beds consist of micaceous shale and slaty mudstone (in part silty), siltstone, and fine to medium-grained quartz arenite. The siltstone and micaceous silty shale and mudstone are finely banded and dark to black. The shale is black, finely laminated, and lustrous from sericite on bedding planes; it occurs in beds a few millimetres to several metres thick. This sequence of beds is possibly near the top of the lower argillitic unit; it passes upwards into arenitic beds which crop out 400 m farther upstream where a small creek joins from the south. The arenite beds are fine to medium-grained, grey in outcrop, and a few centimetres to several metres thick. A thin section of a tuffaceous-looking band consists of detrital quartz (50%) in an altered argillitic matrix. The quartz occurs in two modes, one angular and semi-rounded 0.2 to 0.3 mm in size (4%), and the other angular and 0.05 to 0.01 mm (40%). The matrix is of colourless and yellowish sericite and muscovite (40%), pale brown biotite (5%), yellow-brown epidote (5%) and detrital quartz less than 0.05 mm in size (5%). The rock is an argillitic arenite or a quartz argillite. It is not tuffaceous; however, the epidote suggests a possible small proportion of tuff or fine volcanic dust in the original sediment.

Blanket Hill. The two outcrop areas on Blanket Hill that can possibly be correlated with the lower argillitic unit are thought to be separated by minor faults. On the eastern side, the northern boundary of the argillitic beds is situated 180 m north of the peak of the hill; it strikes north of east and dips steeply northwards beneath quartzite. From this boundary, a sequence of argillite and quartzite has a width, southwards across the strike, of 1200 m through the hill to a southern boundary with the Boggy Plain Granite. This boundary runs slightly north of east, about the same as the predominant strike of the bedding.

The area occupied by the argillite-quartzite sequence on the western side of Blanket Hill is covered by, or faulted against, Silurian sediment in the north (see Fig. 52) and rests conformably on quartzite in the west. The boundaries in the east and southeast have not been accurately located; in the east there is probably a minor fault, and in the southeast probably a conformable boundary with arenitic beds.

The quartzite is predominantly fine-grained; some interbeds are medium-grained; it is interbedded with quartz-siltstone that generally has an argillitic matrix. It is dark or black, weathering grey. Much of it is thick-bedded, and some of it at least is tightly folded and slightly overturned; at G.R. 444370 where the folding is isoclinal, bedding and axial planes dip 75° in the direction 350°. The quartzite commonly contains minor argillite. In places, particularly in the argillitic and tuffaceous sequences, the proportion of non-siliceous interstitial material increases to give arenite rather than quartzite, such as an argillitic quartz arenite at G.R. 441338.

The finer grained beds - very fine-grained quartzite, siltstone, and argillitic arenite - are finely banded (1-4 mm at G.R. 440338). Many outcrops display intricate slump-folding. Some of the convolutely folded argillite contains boudins of quartzite from disrupted sand beds - small ones of a few centimetres dimension come from thin beds (G.R. 438339) and larger ones (1.5 x 1 m at G.R. 439340) from thick beds. The effects of tight tectonic folding are imposed on sedimentary structures in the area as at G.R. 445334 where sedimentary breccia or boundinage structure has been compressed and elongated.

An argillitic bed on the crest of the Blanket Hill ridge 250 m from the granite (G.R. 445335) is a very fine-grained turbidite that contains curved shreds of a disrupted bed of fine-grained quartzite or quartz arenite. The altered argillitic material consists of minute fibres of sericite (the dominant constituent), flakes of biotite, and incipient porphyroblasts of cordierite in a matrix of minute grains of chlorite, epidote, and quartz. Tuffaceous argillitic greywacke at G.R. 443340, 400 m north-northwest of the last locality, consists of laths of actinolite, primary and secondary plagioclase, muscovite, chlorite, some epidote, scattered silt-size grains of quartz, and small patches of secondary mafic minerals, actinolite, and brown-green hornblende - which seem to be alteration products of earlier grains of pyroxene or amphibole.

The argillitic arenite on the western side of Blanket Hill provides little outcrop; it is recognized mainly from detrital fragments. The member consists predominantly of fine-grained quartzite, quartz arenite, siltstone, banded argillite, and banded tuffaceous argillite. The quartzite is apparently thick-bedded; at G.R. 509334 boulders of fine to medium-grained quartzite are 80 cm across, and the fine-grained quartzite forms bands or thin beds 1 to 8 mm wide. Metamorphosed slightly silty argillite at G.R. 424350 consists of biotite, sericite, epidote, chlorite, and incipient porphyroblasts of cordierite. Silt-size grains of quartz are scattered throughout. The quartzite below the argillitic sequence is bounded on its western side by the Boggy Plain Fault;

elsewhere at this locality the position is approximate, being based on information obtained largely from detrital rock fragments in the soil, during traverses east along the northern boundary and the southwest corner of the area. The quartzite, which appears to be the dominant or sole lithological component, is bounded in the north by Silurian sediments and in the south by granite. In the northeast it is assumed to dip beneath interbedded argillite and arenite; this assumption is based on the general attitude of the bedding in Ordovician sediments farther to the east and to the west. Within the outcrop area of the quartzite, the attitude of the bedding is obscured by tight folding and jointing.

## Lower arenitic unit

The argillitic beds just described pass upwards, along Temperance Spur, into the lower arenitic unit that extends westwards 1400 m to the Bolton Hill Fault. On the western side of the fault, the top of the unit is exposed in Bolton Creek, where it passes upwards into the upper argillitic unit. The thickness of the unit is estimated to be about 1500 m, assuming no repetition by folding; an unknown but probably small thickness has been faulted out. A small area of quartzite that is possibly part of the same unit crops out along the northeastern side of Blanket Hill.

### Wagga Wagga and Tallangatta 1:250 000 Sheet Areas

Temperance Spur. The lower arenitic unit at Temperance Spur consists of quartz arenite and quartz siltstone, both with an argillitic matrix. A thin section (TS 72840202) cut from an outcrop near the eastern end of the spur is briefly described in Table 2. In Bolton Creek thick beds of dark grey, medium to fine-grained arenite pass upwards through slump-folded, fine-grained arenite, siltstone, silty shale, and silty mudstone or very fine-grained quartz-greywacke into the upper argillitic unit.

### Tantangara 1:100 000 Sheet Area

Four Mile Hill. Arenitic beds on the ridge south of Four Mile Hill possibly are near the top of the lower arenitic unit. A thin section from an outcrop near grid northing 213 consists of quartz in two size-grades: one which has a modal diameter of 0.4 mm occurs as scattered, rounded, and angular grains (5%); the other consists of angular grains about 0.1 mm in size (80%). A few grains of plagioclase are visible (less than 1%). Interstitial minerals are sericite (7%), biotite, fibrous amphibole, and yellow-brown grains of epidote (2%).

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Blanket Hill. On the northeastern side of Blanket Hill, a small area of quartzite which is possibly at the bottom of the lower arenitic unit is bounded on the south by argillitic beds which dip conformably beneath it. At the northern boundary this quartzite is covered by or faulted against Silurian sediments (see Fig. 52); in the west it is separated by a minor fault from the Boltons Bed that form the western edge of Blanket Hill. The quartzite is dark to black, weathering grey. It is at least locally tightly folded and slightly overturned, with observed isoclinal dips of 60° in a direction 160° for bedding and axial planes.

## Upper argillitic unit

The upper argillitic unit is exposed in outcrops along Temperance Creek east of the Bolton Hill Fault, and along Bolton Creek west of the fault; it has an outcrop width of 500 m. and an estimated thickness of 475 m assuming no repetition by folding. The unit was not mapped north of Temperance Creek; possibly it is represented by a dominantly argillitic sequence in Tabletop Creek, and hornfelsed argillitic and arenitic beds on Four Mile Hill.

### Wagga Wagga and Tallangatta 1:250 000 Sheet areas

Bolton Creek and Temperance Creek. At Bolton Creek, the unit rests conformably between the lower and upper arenitic units. Presumably it does so along Temperance Creek, but the mapping there did not extend to its lower boundary.

Along Bolton Creek, bands of slate and shale are interbedded with arenite and are the dominant components in a belt 500 m wide. Some beds contain altered detrital grains probably of tuffaceous origin. Altered argillite and shale form a large proportion of the section along Temperance Creek. On the crest of Temperance Spur, the outcrops are mainly of argillitic siltstone or greywacke-siltstone. Banded and thin-bedded argillite crops out near the top of the unit 1100 m southeast of Skeleton Creek. One thin section consists of minute grains of quartz (30%) in a matrix of sericite, epidote, chlorite, and minor actinolite. Two grains of plagioclase were seen. The quartz has two size-grades, 0.01 mm and 0.02 to 0.04 mm. The smaller grains are angular and subrounded; some of the larger grains are embayed.

A nearby very fine-grained bed of altered argillite contains minute fibres (0.01 - 0.03 mm) of sericite and of pale green tremolite, and scattered grains of epidote. Probable quartz grains (0.03 mm) are obscured by penetrating fibres of sericite and tremolite. The first thin section is of fine-grained quartz siltstone-greywack, and the other a siliceous argillite. The epidote and actinolite in both suggest that the original sediment contained a fine-grained component of volcanic origin, possibly tuff, or detritus from the weathering and disintegration of volcanic rocks.

Tantangara 1:100 000 Sheet area

Four Mile Hill. Hornfelsed beds are present in outcrops on the peak of Four Mile Hill, where the track that runs along the ridge turns northeast and descends to the Eucumbene River. A thin section cut from an arenitic bed, possibly at about the upper boundary of the unit, consists of detrital quartz and argillitic matrix in about equal proportions. The quartz is in two size-grades; one with a modal diameter of 0.3 mm, about 4 percent of the rock, occurs as scattered, angular, and rounded grains; the other, of angular grains, with a modal diameter of nearly 0.1 mm forms about 45 percent. The matrix consists of biotite (30%), muscovite (5%), and yellow-brown, fairly highly refractive, irregularly shaped grains, probably of epidote.

Spotted argillitic beds form outcrops near the same locality, about 150 m farther east. A thin section consists of biotite, muscovite, cordierite, and detrital quartz. The biotite and muscovite are in the form of oriented flakes and laths 0.02 to 0.05 mm long, and each mineral forms more than 40% of the rock. The quartz occurs as angular grains 0.02 mm in size (10%). Opaques amount to less than 2%; minute crystals of sphene are scattered throughout (as they are in most thin sections from the unit). Porphyroblasts of cordierite show polysynthetic and sector twinning, alteration to sericite, and locally very faint pleochroism. A thin section of a finely banded argillite from an outcrop 400 m farther east is similar to the one just described. The banding, 0.5 to 2.0 mm wide, is due to differing proportion of biotite.

## Upper arenitic unit

The upper arenitic unit was mapped in the south of Bolton Creek and Bolton Hill, and in the north from Sawyers Hill to Tantangara Mountain.

Wagga Wagga and Tallangatta 1:250 000 Sheet areas

Bolton Creek and Bolton Hill. In the south (Plate 1) the unit strikes

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almost north and is 800 m thick. The lower (eastern) boundary lies 1600 m west of the southwest corner of the Tantangara Sheet area. The unit passes through the upper part of Bolton Creek and Bolton Hill to the Bolton Hill Fault, where it is displaced about 300 m to the east. The positions of the boundaries east of the fault are only approximately known, being based on mapping in Temperance Creek which, east of Scotch Creek, was on a reconnaissance scale only. The unit consists of quartz arenite and quartz siltstone (both with an argillitic matrix), quartzite and siltstone-quartzite, quartz argillite, and minor argillite. A thin section of siltstone that shows intricate slump folding was cut from an outcrop of interbedded quartz arenite or quartzite, siltstone, and slate, near the top of Bolton Creek. The siltstone consists of quartz (70%) about 0.04 mm in size, in an argillitic matrix; it contains fine bands or wisps that consist of argillite (85%) and quartz (5%). The argillite and argillitic matrix consists of sericite-muscovite, minor biotite, minor green-yellow-brown epidote and minute grains of sphene.

Outcrops on the crest of Bolton Hill consist of dark banded siltstone that is slump-folded, fine to medium-grained arenite which is dark but weathering off-white and cream-brown, and quartzite. A thin section (TS 72840201) of a slightly argillitic quartz arenite or impure quartzite is briefly described in Table 2.

Temperance Creek. Quartzite in the lower half of the unit in Temperance Creek, 900 m southeast of Skeleton Creek, consists of about 95 percent detrital quartz in two size-grades; one, of round and semi-round grains (10% of the rock) ranges from 0.05 to 1.0 mm; the other, of angular and in part interlocking grains, ranges from 0.002 to 0.01 mm. The slide contains sparse interstitial sericite and minor epidote.

Argillitic quartz sandstone or siltstone, with probably a small volcanic component in the matrix, crops out near the creek. A thin section consists of detrital quartz (60%) in a matrix of sericite, chlorite, epidote, and fibrous actinolite. A few grains of plagioclase are scattered through the slide. The quartz is present in two size-grades, with modal diameters of about 0.2 and 0.05 mm. The larger grains are mainly angular and form about 5% of the rock; the smaller grains are angular. A thin vein of quartz and chlorite is present.

Tantangara 1:100 000 Sheet area

Long Arm Creek and Four Mile Hill. Thin sections were cut from two outcrops of arenitic rock, probably near the upper boundary of the upper arenitic unit, at the crest of a ridge west of the source of Long Arm Creek. They consist of 70 to 80 percent quartz in two size-grades, one subangular to round with modal diameter of 0.2 to 0.6 mm, and the other angular with modal diameter of 0.05 to 0.1 mm. The matrix consists of sericite or muscovite (5-15%), opaques (0-2%), calcite (0-1%), and probable epidote (1-4%). One section contains poorly defined thin bands of detrital quartz, 0.01 to 0.03 mm in size, that were probably deposited from a turbidity current. The epidote suggests a possible small component of tuffaceous sediment.

A third thin section from the same locality consists of laths of plagioclase (25%) much pale green to pale yellow tremolite (20%), secondary calcite (5%), and epidote (15%). The matrix, which is clouded through weathering probably consists of the same minerals. The rock is andesite, probably narrow dyke-like intrusion.

Quartzite siltstone on the northern slope of Four Mile Hill, probably near the upper boundary of the unit, shows intricate small-scale slump-folding. A thin section consists of 80 percent detrital quartz (less than 0.1 mm) with minor sericite and irregular yellow-green-brown grains of epidote (the largest grains smaller than 0.2 mm).

Sawyers Hill to Tantangara Mountain. In the Kiandra area from Sawyers Hill to Tantangara Mountain, the outcrop of the upper arenitic unit appears to be wider than it is farther south, even though the base of the unit is cut off by the Boggy Plain Granite. Possible outcrops of smaller extent occur at Gooandra Inlier, west of Blanket Plain. At Sawyers Hill, the unit forms the upper part of the southeastern slope, from the crest down to the granite - a width of about 700 m. The boundary of the granite is roughly conformable with the bedding. The unit appears to consist of quartzite and quartz arenite, with argillitic interbeds within the top 50 m and minor chert bands lower in the sequence. Near its upper boundary the unit is very fine-grained, very thin-bedded or finely banded, and some beds are separated by thin bands or partings of argillite and very fine volcanic dust. On Sawyers Hill at G.R. 375269 and 381269 the banding is 1 to 8 mm wide; the modal grain size in the finer bands about 0.03 mm, in the intermediate bands about 0.05 mm, and in the coarser bands about 0.1 mm.

At a short distance from the boundary, thick-bedded quartzite is the dominant rock-type; it contains bands of thin-bedded finer-grained quartzite and quartz arenite in which there are interbeds of siltstone-quartzite and silty argillite. At G.R. 374263 near the crest of Sawyers Hill the most common grainsize in the siltstone-quartzite of the interbeds is 0.05 mm; in the silty argillite or argillitic quartz siltstone of the interbeds the common size of the quartz grains is about 0.01 mm. Thin-bedded quartzite at G.R. 381259 in the Highway cutting on Sawyers Hill consists of a sutured mosaic of angular quartz grains, bimodal in size; minor muscovite is present. In thin section the rock is indistinctly banded; the modal grain sizes (by inspection) in a typical coarser-grained band are about 0.4 and 0.15 mm and in a finer band 0.25 and 0.1 mm.

At Tantangara Mountain, the upper arenitic unit appears to have an outcrop width of about 1500 m; its upper boundary strikes easterly through Monaro Range at about 1000 m north of the mountain peak and the lower boundary is formed by granite, 500 m south of the peak. The unit appears to be comparatively free from argillitic material, both as interbeds and as matrix; this may be due in part to lack of outcrop of less resistant beds. The quartzite is predominantly fine-grained, dark but weathered grey in most outcrops, fairly thick-bedded with thin-bedded bands and interbeds of quartzite-siltstone. At G.R. 424286 on the eastern slope not far from Boggy Plain, the quartzite is fine-grained, bimodal (0.3 and 0.1 mm) and contains minor chlorite (1%), muscovite (1%), and plagioclase (1%).

Gooandra Inlier. An outcrop of quartzite in the eastern part of the Gooandra Inlier is possibly at the top of the upper arenitic unit, but could be a quartzite band within the tuffaceous unit. Where exposed it is dark, fine to very fine-grained, and includes bands of quartz siltstone.

## Tuffaceous unit

The upper unit of the Bolton Beds consists of quartz arenite and argillitic quartz siltstone, altered argillite, tuffaceous sediment, and lenticular beds of chert. Along Happy Jacks Road and Temperance Creek (Plate 1) the unit crops out in a northerly-trending belt about 650 m wide, at a distance of 2400 m west of the southwest corner of the Tantangara Sheet area. Its estimated thickness is 650 m, assuming no repetition by folding. In the Kiandra area, the tuffaceous unit extends from Sawyers Hill to Tantangara Mountain in a belt whose width as interpreted from the field mapping appears to differ considerably from place to place; farther north the tuffaceous unit appears to form the northwestern part of the small Gooandra Inlier.

### Wagga Wagga and Tallangatta 1:250 000 Sheet areas

Happy Jacks Road and Temperance Creek. Along Happy Jacks Road, the unit consists of quartz arenite (in part slightly tuffaceous), argillitic quartz siltstone, and minor argillite and silty argillite some of which is tuffaceous; impure chert enters the sequence near the top of the unit. The beds show intricate slump-folding. A thin section from an outcrop that shows contemporaneous deformation consists of bands 1 mm thick, predominantly argillitic but some containing as much as 80 percent of minute detrital quartz. The argillitic bands consist of sericite, pale-brown biotite, chlorite, carbonate, and minute fibres of actinolite. Along Temperance Creek, arenite beds near the base of the unit pass upwards into quartz siltstone, quartz arenite and tuffaceous siltstone, with minor chert and impure chert; a bed of tuff and agglomerate is present near the top of the unit. Slump-rolls are visible in the arenitic beds. The basal part of the unit is displaced 300 m to the east by the Bolton Hill Fault. A thin section at the lower boundary, east of the fault, consists of very poorly sorted, angular to rounded detrital quartz and scattered detrital plagioclase (1%) in an argillitic matrix. The margins of the detrital grains are penetrated by crystal growth from the matrix. The proportion of quartz ranges from 45 to 70 percent in different parts of the slide; it occurs in two size-ranges, one about 0.4 to 0.6 mm and the other 0.02 to 0.2 mm. The matrix consists of epidote, chlorite, sericite, pale brown biotite, and minute sphene. The rock is an argillitic quartz arenite; the epidote is possibly an alteration product of a small proportion of tuffaceous material.

Altered fine-grained tuffaceous quartz arenite crops out about 100 m above the base in a succession of interbedded tuffaceous sediment, quartz arenite, argillite, and chert on the western side of the fault. It consists of quartz (50%), orthoclase (less than 5%), plagioclase (less than 5%) muscovite and sericite (10%), opaques (5%), epidote (2%), and cloudy altered grains 0.2 mm and smaller (20%). A small proportion of the detrital quartz is in the form of scattered semi-rounded grains 0.4 mm in size but nearly all of it is smaller than 0.1 mm. The altered feldspar grains, together with sericite and epidote, form a matrix; they presumably represent altered tuffaceous fragments deposited with the sediment.

A thin section was cut from an outcrop in the top half of the unit, in interbedded black quartz siltstone, quartz arenite, and argillite; some of the beds are tuffaceous. The slide consists of very fine-grained banded quartz siltstone, and altered tuffaceous fragments. The matrix of the finer bands appears to consist partly of altered chert. Following is a description of the banding:

| Width of Band (mm) | Description |
|---|---|
| 10 | Fragments of altered tuff, detrital quartz, aggregates of minute grains of epidote (probably representing altered tuffaceous material) |

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| Width of Band (mm) | Description |
|---|---|
| 10 | Minute grains of detrital quartz, scattered small fragments of tuff, minor epidote as irregular grains and aggregates of minute grains; probable small interstitial areas of altered chert |
| 0.5 | Vein of finely granular epidote |
| 16 | Very fine quartz siltstone, with fibrous actinolite, sericite, and minor epidote |
| 8 | Fine siltstone with a few percent of the same minerals. |

The quartz grains range in size from about 0.03 mm in the coarser bands to about 0.01 mm in the finer bands. Actinolite fibres are up to 0.4 mm in length, and range from about 2 to 20 percent. Epidote ranges from less than 1% to an exceptional 30% in one part of the slide, where it could have been introduced from a vein of the mineral.

Tantangara 1:100 000 Sheea area

Sawyers Hill. At Sawyers Hill, much of the tuffaceous unit is hornfelsed by the nearby granite; the apparent great variations in its width are probably in part due to a failure to distinguish the hornfelsed bed from similar ones in the units above and, more particularly, below it. The unit consists of quartz arenite, quartzite, altered argillite, minor chert, and thin tuffaceous bands near the middle and the top of the unit. The argillite is altered to biotite and muscovite, and in many places is spotted with porphyroblasts of cordierite. A band of it that forms tor-like outcrops of hard, tough rock runs northeast a short distance below the crest of the ridge. Fragments of agglomerate indicate the presence of a thin pyroclastic band stratigraphically slightly above the argillite. A thin section of spotted hornfels from G.R. 384274 consists of porphyroblastic cordierite 0.5 to 1.5 mm large, crowded with minute crystals of sericite, biotite, epidote, and sphene, small flakes of biotite 0.01 to 0.03 mm, muscovite 0.02 to 0.05 mm, scattered grains of epidote (about 0.03 mm) and opaque grains of oxide and of pyrite (about 0.05 mm).

A thin section cut from fine-grained arenite or siltstone at G.R. 375272 consists of altered quartz siltstone and silty argillite in bands 0.5 to 10 mm thick.

The bands are composed of differing proportions of the same minerals - detrital quartz and altered clay minerals. The quartz is angular, 0.02 to 0.04 mm in size, and its matrix consists of sericite and biotite in fibres of about the same length. The argillite consists of fibres of sericite and biotite, slightly larger than 0.1 mm; it contains about 3% granular epidote.

A thin section was cut from a tuffaceous bed in a sequence of siltstone, arenite, argillite, and minor chert on the northern slope of Sawyers Hill, near the top of the unit. Ghost crystals or fragments of plagioclase up to 1.5 mm make up about half the slide, altered amphibole and pyroxene form a few percent, and the remainder is altered matrix. The rock now consists of a fine-grained felted and interpenetrating aggregates of chlorite, epidote, actinolite, and a small amount of secondary quartz. Clusters of epidote and chlorite in the matrix represent earlier mafic minerals. Indistinct interstitial areas are possibly altered chert.

Tantangara Mountain. On Tantangara Mountain the tuffaceous unit consists of fine-grained arenite or siltstone, quartzite, altered argillite, chert, minor tuffaceous beds associated with argillite in the middle of the unit, and a thin band of agglomerate at the top. Thin sections were cut from tuffaceous argillite and quartz argillite, and from banded argillitic siltstone and arenite at about the middle of the unit, half-way between Sawyers Hill and Tantangara Mountain at G.R. 388286. The siltstone consists of angular quartz (85%) mainly smaller than 0.1 mm, green-brown fibrous amphibole (5%), and epidote (5%). The argillite consists of minute fibres (0.01 mm) of biotite and sericite (50%), granular (to 0.03 mm) epidote (30%), detrital quartz obscured by crystallization of the matrix (10%) and fibrous amphibole (3%). The tuffaceous bands consist of altered crystal fragments (0.2 to 0.3 mm) of feldspar (50%), fibres (0.2 mm) of actinolite (less than 10%), epidote (10%), cloudy rounded patches of ?epidote (15%), and detrital quartz (10%).

Gooandra Inlier. In the Gooandra Inlier, the lithology of the tuffaceous unit is similar; for example, at G.R. 408369 the bedrock consists of tuff, argillite, chert, and quartzite or quartz arenite.

## ENVIRONMENT OF DEPOSITION

The considerable thickness and poor sorting of the Bolton Beds suggest an abundant supply of sediment, moved rapidly from its source to a nearby depositional area. The small grainsize of the sediments indicates a corresponding fineness of grain at the source. Angularity of the detrital grains suggests that they were derived from volcanic rocks, or little-abraded, first-cycle, sedimentary rocks. Ubiquitous contemporarneous deformation indicates accumulation on a sloping sea-floor, probably subject to seismic disturbances.

It is suggested that the source of the sediments was a landmass that was being elevated during an orogeny. The source may have consisted of interbedded volcanic rocks and little-abraded sedimentary rocks which, in turn, could have been derived from the denudation of slightly older acidic, perhaps dacitic, volcanics. The sedimentary rocks in the source area would have provided some of the argillaceous constituents, in particular those that are present as sericite, and most of the very abundant fine-grained detrital quartz. The weathered volcanic rocks in the source area would have provided the magnesian and ferromagnesian constituents that are present in the matrix as chlorite, actinolite, and epidote. The absence of lithic fragments suggests that the source-rocks were completely weathered; the volcanics must have been intermediate or basic, such as basic andesites, susceptible to rapid subaerial weathering; the interbedded sediments must have been poorly indurated.

As the orogeny progressed terrestrial volcanoes erupted along a tectonically active zone near the margin of the landmass, providing the tuffaceous sediment and tuff at the top of the Bolton Beds.

A possible alternative interpretation given in this Record under Structure suggests that the Bolton Beds rest conformably on the Temperance Chert, and the Chert on the Nine Mile Volcanics. If so, the supposed basic to intermediate volcanics of the source area could well have been the Nine Mile Volcanics, emerging as a landmass. The tuffaceous sediment and tuff in the Bolton Beds, near the boundary with the Temperance Chert, could have been erupted in the final stages of the volcanic activity that provided the tuffaceous beds of the Temperance Chert.

## THICKNESS

The lower part of the Bolton Beds is intruded by the Happy Jacks Granite, and the complete thickness is not exposed. The composite section of Fig. 4 indicates an apparent thickness of nearly 4000 m, not allowing for probable repetition by folding. The figure is approximate because of an unknown displacement on the (inferred) Bolton Hill Fault. Fairbridge et al. (1951) thought the thickness would be about 10 000 ft (3000 m). Moye et al. (1963), having seen tight, often isoclinal, folding in a tunnel through the beds, considered that the thickness would be much less.

The alternative interpretation given under Structure suggests that the Bolton Beds possibly correlate with, or pass up into, the Nungar Beds and, through a disconformity but no obvious lithological change, into the Tantangara Beds. If so, the thickness estimated would include the Nungar Beds and part of the Tantangara Beds.

## RELATIONS

The preferred interpretation of the succession indicates that the Bolton Beds pass up conformably into the Temperance Chert (?Darriwillian in age). Their basal part is intruded by the Happy Jacks Granite (of late Silurian age), and is not exposed. At Blanket Hill and Blanket Plain the Bolton Beds are in contact with the Early Silurian Tantangara Beds; the boundary is not exposed. Faults were inferred along lineaments that can be seen on the aerial photographs of the area; however, where the boundary between the Bolton and Tantangara Beds strikes easterly it is about parallel to the bedding, and may be a depositional boundary, presumably a folded unconformity.

The alternative interpretation, given under Structure suggests that the Bolton Beds conformably succeed the Temperance Chert, and that their boundary with the Tantangara Beds is a disconformity - a temporary break in deposition rather than a subaerial erosional unconformity. If so, the upper part of the Bolton Beds would correlate with, or pass up into, the Nungar Beds.

## AGE

The Bolton Beds have not yielded any fossils; their age can only be estimated approximately, from their relation with the overlying formation. Gisbornian fossils (Opik, 1952) have been found in the lava unit of the Nine Mile Volcanics (p. 141). A very considerable thickness of the volcanics and all of the Temperance Chert separates the fossiliferous strata from the Bolton Beds. Assuming that the fossiliferous strata correlate with the argillitic bed along Gooandra Creek, near the boundary between the andesite belt and the breccia belt, and assuming no repetition by faulting, the stratigraphic thickness amounts to 1500 m of volcanics (Fig. 16) and 1800 m of Temperance Chert (Fig. 6). Opik (1951) suggested that the base of the Temperance Chert, which rests conformably on the Bolton Beds, could be as old as Middle Ordovician (Darriwillian). If so, the Bolton Beds are Middle Ordovician or older.

The alternative interpretation given under Structure suggests that the Bolton Beds conformably succeed the Temperance Chert and pass up, disconformably, into the Tantangara Beds. If so, at least the upper part of the Bolton Beds would correlate with the Nungar Beds which are Eastonian.

## TEMPERANCE CHERT
(D.E.G.)

### NOMENCLATURE

Fairbridge et al. (1951) gave the name Temperance Chert to a formation of interbedded chert and volcanic rocks which overlies the Bolton Beds near the junction of the Happy Jacks and Tumut Rivers. The area is immediately west of the southwest corner of the Tantangara Sheet area, in the Wagga Wagga and Tallangatta 1:250 000 Sheet areas. Moye (1953) refers to the formation as the Temperance Cherts and states that it consists of interbedded cherts and tuffs, with cherts predominating. In the Tantangara Sheet area, layers of chert, tuff, agglomerate, and lava within the interbedded chert and tuff are sufficiently thick or distinctive to be mapped individually as rock units.

### DERIVATION OF NAME

The Temperance Chert was derived from Temperance Creek. a tributary of the Tumut River.

### TYPE SECTION

Fairbridge et al (1951) referred to the outcrop of the formation in Temperance Creek as the type area. A type section, representative of the lower half of the formation, is here proposed. It follows Temperance Creek, from 1100 m southwest of Skeleton Creek to 400 m east of Frenchmans Creek. A supplementary section for the upper half of the formation extends along Happy Jacks Road, from the bridge over the Tumut River to a point 1000 m west of the junction of the Happy Jacks River with the Tumut River.

### DISTRIBUTION

The Temperance Chert extends northward from the type area, to enter the Tantangara Sheet area on the northern side of Sawyers Hill; it continues northeast to Boggy Plain and north to about the latitude of Rules Point, where it dips conformably beneath the Nine Mile Volcanics. Another outcrop-area, a short distance farther north on the eastern side of Long

Plain, extends past McPhersons Creek to where the chert dips beneath the Kellys Plain and Nine Mile Volcanics; from its eastern side, a narrow southward extension from the eastern side of this area becomes broader near Tantangara Reservoir. Farther north, the Temperance Chert crops out east of Peppercorn Hill. There is also a smaller inlier within Silurian sediments at Dairymans Plain.

LITHOLOGY

The Temperance Chert can be divided into a unit of interbedded chert and tuff, containing a lava flow in the northern part of the Tantangara Sheet area, and a thick chert unit which includes a lenticular bed of agglomerate and another of tuff. The lava unit, the tuff, and the thin bed of agglomerate are distinguished on the map.

The unit of interbedded chert and tuff is well exposed west of the southern edge of the Tantangara Sheet area, in the type section within the Wagga Wagga 1:250 000 Sheet area along Temperance Creek, and along Happy Jacks Road both east and west of the junction of the Happy Jacks and Tumut Rivers. Along Peppercorn Creek in the north of the Tantangara Sheet area, a lava flow occurs within the upper part of this unit. The chert unit appears within the interbedded chert and tuff north of Sawyers Hill, splitting the latter into lower and upper parts. The lower part crops out east of Wild Horse Plain and extends north almost to the Murrumbidgee River. The upper part crops out in several discontinuous fault-blocks between the head of Gooandra Creek and Little Peppercorn Creek, north of Long Plain.

The chert unit forms five areas of outcrop in the west of the area, between Chance Creek in the south and Sallys Flat Creek (east of Peppercorn Hill) in the north. A distinctive agglomerate band within this unit forms prominent outcrops along Racecourse Creek; it is correlated with agglomerate along Happy Jacks Road. Bedded chert and less common impure chert on Happy Jacks Road is correlated with the chert unit in the Tantangara Sheet area. A lenticular tuff bed crops out within the chert unit at Dairymans Plain.

The lithology of the formation is summarized in Figures 7 and 9 and a suggested correlation is given in Figure 13.

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## Lithological subdivisions

### Interbedded chert and tuff (Otd)

### Wagga Wagga and Tallangatta 1:250 000 Sheet areas

#### (i) Temperance Creek and Happy Jacks Road

Structure. A nearly complete section of the unit of interbedded chert and tuff crops out along Happy Jacks Road and Temperance Creek. (Pl. 1 and Fig. 15). Here the beds have an outcrop width normal to strike of about 2000 m. Along the road, a sequence of beds about 500 m thick is missing from below the middle of the section, and along the creek about 700 m is missing at the top of the section. The missing beds are assumed to have been faulted out along faults whose positions are inferred from lineaments visible on aerial photographs. The faults are shown in Figure 15. One, here named the Nine Mile Junction Fault, appears to dip east and to strike south through the junction of Nine Mile Creek with the Tumut River. Another, the River Junction Fault, also probably strikes south through the junction of the Happy Jacks and Tumut Rivers, but apparently dips to the west. A branch fault runs northwesterly from the river junction towards the junction of Temperance Creek with the Tumut River. The M-Bend Fault is very steep or vertical; it strikes north-northwest passing through the M-bend in the Happy Jacks River.

Lithology: The unit consists essentially of tuff and chert, with thin beds of clastic sediment at intervals. The sedimentary beds are more prominentl near the top, where there is a transition into interbedded tuff and sediment at the base of the Nine Mile Volcanics. The boundary is arbitrary, defined at the level where the sedimentary beds form a large proportion of the section, and chert is only a minor constituent. The lithology is summarized in Fig. 6.

The lower half of the unit is exposed along Temperance Creek from 1100 m southwest of Skeleton Creek to the M-Bend Fault 400 m east of Frenchmans Creek. It consists of chert and impure chert, tuff, argillitic and arenitic interbeds, and a bed of coarse tuff with clasts up to 20 cm across 500m west ot the lower boundary. Part of this succession, including the coarse tuff, is repeated on the western side of the M-Bend Fault, between it and the River Junction Fault. In that short interval, a distance of about 200 m across the strike, the section consists of tuff and tuffaceous chert, with minor chert and tuffaceous slate. Between the River Junction Fault and the Tumut River is a sequence of tuff, impure chert, greywacke, and tuffaceous greywacke, with bedded chert and tuff near the top. From 600 to 200 m east of the river the sedimentary rocks have been intruded by numerous small dykes and ?sills; most of these are quartz porphyry, but some are of intermediate composition. Nearly all the outcrops here are of the intrusives, whose scree has almost completely covered the sedimentary beds. Tuff and tuffaceous chert at the bottom of this sequence appears to correlate with similar beds 150 m east of the River Junction Fault. Amongst the sedimentary beds exposed along Temperance Creek are thin argillitic beds distant 50, 150, and 350 m from the lower boundary, and quartz arenite or greywacke 150 m from it. There are also thin beds of black slaty tuffaceous argillite, at least 6 m thick below the mouth of Frenchmans Creek, and slaty tuffaceous greywacke at 650 m and 150 m east of the Tumut River.

Along Happy Jacks Road, tuff, chert, and impure chert at the base of the unit are exposed 150 m east of the M-Bend Fault, and again about 600 m west of the fault. The beds above them are predominantly tuff and chert, with interbeds of quartz siltstone and argillite. These sedimentary beds are shown in Fig. 6 only if they are also exposed along Temperance Creek.

The upper half of the unit is exposed along Happy Jacks Road, from the River Junction Fault west across the Nine Mile Junction Fault. Between the River Junction Fault and the Nine Mile Junction Fault, the section, exposed in the road cutting, consists mainly of very weathered interbedded chert and tuff. Chert is predominant at the base, over a stratigraphic thickness of 350 m, and near the fault it is interbedded with cherty argillitic greywacke. A bed of agglomerate is about 100 m thick near the middle of the section; within it is a band of interbedded chert and tuff nearly 15 m thick, and another of interbedded chert and impure chert about 10 m thick; 20 m below the agglomerate is a bed of black shale about 1 m thick. Over a stratigraphic interval of 250 m above the agglomerate chert is predominant; it consists of beds of pure and impure chert (probably silty, argillitic, and tuffaceous) chert along whose strike porphyry dykes have been intruded. This chert-rich sequence is exposed between 400 and 150 m east of the Nine Mile Junction Fault; it passes upwards into interbedded tuff, chert, and impure chert. The top of the Temperance Chert is exposed west of the Nine Mile Junction Fault; it crosses the road to the west of a sharp bend in the road (from southeasterly to westerly) and 600 m southeast of the top of the previous section. The boundary is at the base of a bed of black shale about 2 m thick. Tuff. chert, and impure (probably argillaceous) chert below the shale are correlated with the tuff, chert, and impure chert at the top of the main road section.

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Complete Stratigraphic Section. The complete sequence of interbedded tuff and chert can be obtained from part-sections that are exposed in the several fault-blocks. A composite section given in Fig. 6 was compiled from five sections along Temperance Creek and Happy Jacks Road, shown in the locality map of Fig. 15. The lower half of the unit as exposed in a section east of the M-Bend Fault is defined as the type section and described later in this report. Other sections used are the Frenchmans Creek section which passes the mouth of Frenchmans Creek; the Confluence Section ending at the confluence of Temperance Creek and the Tumut River; a section along Happy Jacks Road, from the River Junction Fault to the Nine Mile Junction Fault, which is described later in this report as a significant supplementary section; and West Bend Section which starts where the road turns to the west 600 m south-southeast of the top of the Happy Jacks Road section. Summary descriptions of outcrops along the type and Happy Jacks Road sections are given in Tables 8 and 9; summary descriptions for the other sections are given in Table 4.

The lower boundary of the interbedded tuff and chert crosses Temperance Creek at a point 1100 m west of Skeleton Creek; there, the basal beds (interbedded chert, impure chert, and tuff, with thin beds of very fine-grained quartz argillite) rest conformably on argillitic and slightly tuffaceous fine-grained arenite and siltstone of the Bolton Beds. The beds dip steeply, and the distance across their strike is only slightly greater than their thickness. Nearly 550 m to the west is the bed of coarse tuff; about 50 m farther west is a bed of finely banded tuffaceous slate; a layer of tuff and tuffaceous chert immediately below that is correlated with a similar layer 300 m west of the point where the River Junction Fault crosses Temperance Creek. It too is associated with argillitic sediments, which appeared in the field to consist of very fine-grained tuffaceous greywacke. Interbedded tuff, tuffaceous greywacke, and chert in Temperance Creek, 150 m east of the Tumut River, are correlated with a similar sequence west of the River Junction Branch Fault along Happy Jacks Road, 200 m northwest of the river junction. Tuff, chert, and impure chert in the dominantly tuffaceous beds at the top of this part of the section, near the Nine Mile Junction Fault, are correlated with similar beds on the western side of the fault. These beds are exposed 550 m to the southeast, where the road bends sharply from a southeasterly to a westerly direction. The uppermost beds of the Temperance Chert at this locality consist of interbedded tuff, chert, and impure (probably argillaceous) chert. They are overlain by the basal thin black shale and tuff of the Nine Mile Volcanics, which is succeeded by tuff and interbedded tuffaceous quartz arenite, dark siltstone, shale, or mudstone, pure and impure chert.

Detailed Petrography. A thin section cut from impure chert interbedded with chert at the base of the unit, 1100 m southwest of Skeleton Creek, is finely banded (0.2-2 mm). The bands consist of chert, and of quartz siltstone with a matrix of chert. The detrital quartz grains are 0.2 mm across in some bands, and in others less than 0.01 mm. There is also a tuffaceous band containing minute detrital quartz and fragments altered to epidote, chlorite, and secondary amphibole; the matrix consists of similarly altered fragments and chert. This rock was formed from very fine-grained sediment and volcanic dust deposited with chert in very quiet water. Another thin section was cut from a very fine-grained cherty andesitic tuff exposed 900 m north-northeast of the junction of the Tumut and Happy Jacks Rivers, on a spur rising northward from the junction to join Temperance Spur. The slide shows fragments of feldspar (30%) in a size range of 0.02 to 0.08 mm, mostly obscured by alteration; clinozoisite and epidote make up about 10%, in irregular grains and prisms smaller than 0.01 mm, and there are minute grains of sphene. The matrix is dusty impure chert. The rock is cut by very thin veins of quartz. At about the same stratigraphical position, but 300 m south of this tuff, is an outcrop seen in thin section to be a very fine-grained quartz siltstone, probably slightly tuffaceous. It consists of quartz (80%) in grains mostly about 0.01 mm in size, with a few about 0.04 mm. At least half of the remainder consists of irregular highly refracting grains of epidote up to 0.03 mm in size; they probably originated as fine volcanic dust or tuff. At the same locality is a fine-grained igneous rock, apparently a small dyke, that is prophyritic in needle-like prisms of a dark mineral; a thin section shows this to be a lamprophyre (vogesite). The phenocrysts, 40% of the rock, are pale brown hornblende as prisms 2 mm long and tabular euhedra up to 1 mm across: The groundmass contains hornblende about 30%, and altered feldspar to 0.4 mm across; there is a little interstitial quartz. Staining tests shows that at least half the feldspar is potassium-bearing.

Thin sections were cut from interbedded tuff, impure chert, and very fine-grained, slightly tuffaceous quartz-argillite exposed along Happy Jacks Road, at the junction of Happy Jacks and Tumut Rivers. The tuff consists of andesitic lithic and crystal fragments 1.5 mm and smaller in size, in a matrix of epidote, stilpomelane, and altered small fragments of feldspar. The tuffaceous quartz argillite is banded (1 to 4 mm) and very fine-grained. The banding appears to be due to the grainsize and the relative abundance of detrital quartz which is present as scattered grains (less than 2%) about 0.2 mm in size; these are partly masked by penetrating phyllosilicates from the matrix. Plagioclase occurs as rare angular fragments to 0.6 mm, much larger than the other minerals, and probably pyroclastic in origin. The matrix consists of 30% detrital quartz smaller than 0.1 mm, phyllosilicates 30%, epidote 15%, chlorite 15%, and probably chert (10%). The phyllosilicates occur as flakes and fibres about 0.005 mm long, and are probably mainly a calcium-bearing brittle mica, such as the stilpnomelane of the tuff.

(2) Temperance Creek to Eucumbene River

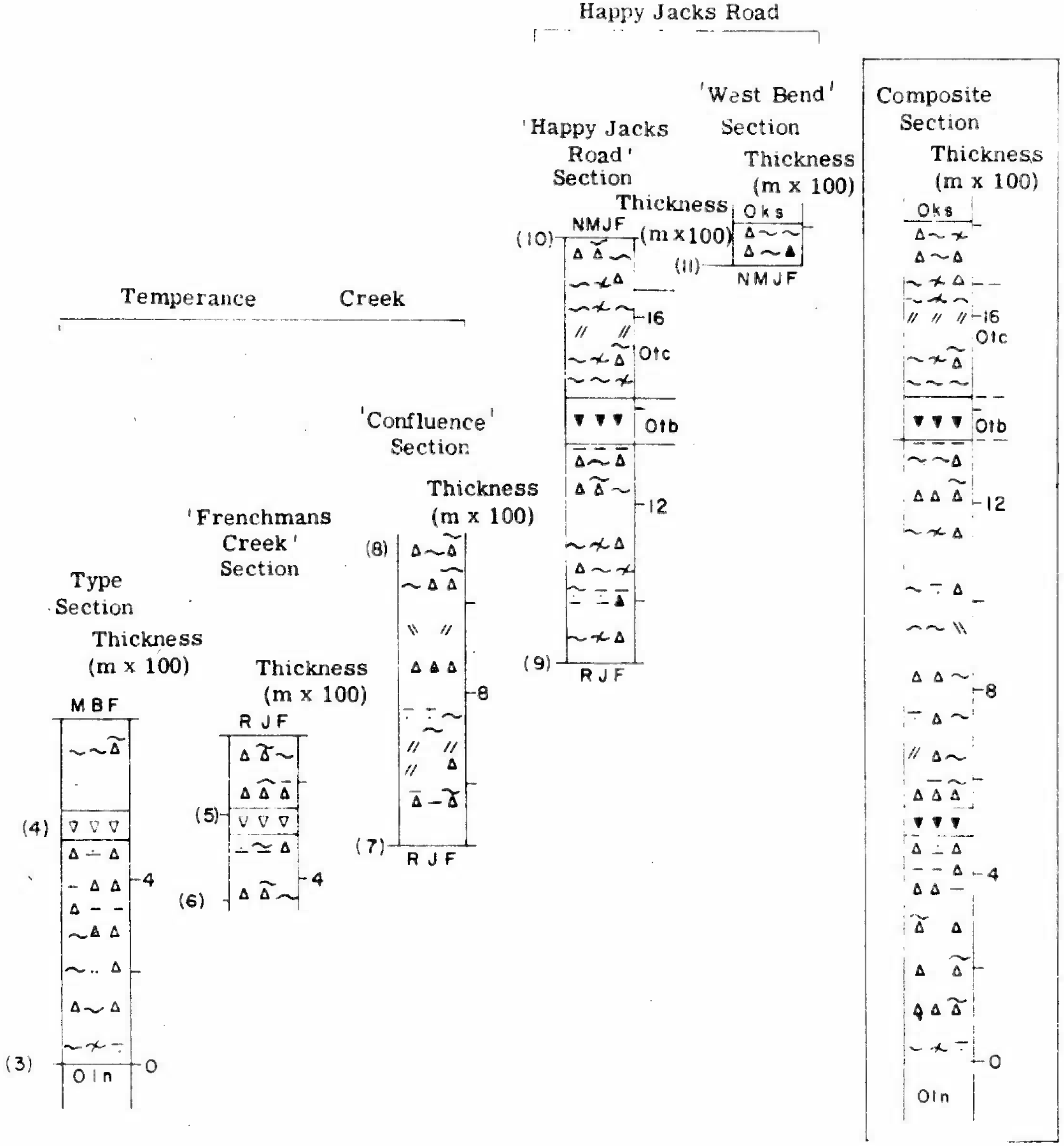
Reconnaissance mapping between Temperance Creek (Plate 1) and the Eucumbene River south of Sawyers Hill shows that the unit of interbedded chert and tuff passes through the upper part of Milkmans Creek, and the ridge between Four Mile and Bloomfield Creeks. A very approximate boundary has been drawn for the base of the unit, but insufficient information is available to draw an upper boundary. South of the Eucumbene River, the Temperance Chert lies almost entirely west of the Tantangara Sheet area.

Three specimens from the area between Four Mile Creek and Bloomfield Creek have been sectioned. They consist of crystal and lithic fragments of andesitic tuff in a matrix of chert, clouded with probable altered volcanic dust; the fragments form 30 to 70 percent of the slides; the largest ones range from 0.4 mm, in a slide in which the modal grain size is less then 0.1 mm, to 3 mm in another slide in which the mode is about 0.5 mm. The fragments are of feldspar, with minor altered ferromagnesians; in one slide there is about 20% clino and orthopyroxene. Many grains appear to be relatively fresh and unaltered.

TABLE 4. FRENCHMANS CREEK, CONFLUENCE AND WEST BEND SECTIONS OF THE TEMPERANCE CHERT

Location: Wagga Wagga and Tallangatta 1:250 000 Sheet areas (Fig. 15)

| Approx. distance to ref. point (m) | Reference points | Lithological description |
|---|---|---|
| | 'Frenchmans Creek' section | |
| 0 | Start of section: Temperance Creek, 100 m SE of mouth of Frenchmans Creek | tuff; minor tuffaceous chert |
| 20 | Temperance Creek flows around end of minor spur, 50 m above mouth of Frenchmans Creek | shows slump-folding and tight tectonic folding |




## REFERENCE

| | |
|---|---|
| ▵ | Tuff |
| ~ | Chert |
| ≁ | Impure chert |
| ·· | Arenite |
| — | Argillite |
| ▿ | Coarse tuff |
| ▼ | Agglomerate |
| ▵̃ | Tuffaceous chert, cherty tuff |
| ▵ | Tuffaceous arenite |
| ▵̄ | Tuffaceous argillite, argillitic tuff |
| — | Argillitic arenite, arenitic argillite, greywacke |
| ▲̄ | Tuffaceous greywacke |

Minor intrusions

| | |
|---|---|
| // | Quartz porphyry |
| \\\\ | Intermediate |

Faults

| | |
|---|---|
| MBF | 'M-Bend' |
| RJF | 'River Junction' |
| NMJF | 'Nine Mile Junction' |

Nine Mile Volcanics

Oks Sediment and tuff

Temperance Chert

| | |
|---|---|
| Otc | Chert |
| Otb | Agglomerate |
| Otd | Interbedded tuff and chert |

Oln Bolton Beds

Reference Points

(3) 1100 m SW of Skeleton Creek

(4) 750 m ESE of Frenchmans Creek

(5) 100 m SW of Frenchmans Creek

(6) 100 m SE of Frenchmans Creek

(7) 450 m WSW of Frenchmans Creek

(8) At confluence of Temperance Creek and Tumut River

(9) Happy Hacks Road bridge over Tumut River

(10) 1100 m WNW of junction of Happy Jacks and Tumut Rivers

(11) 700 m W of junction of rivers

FIG. 6. Stratigraphic sections of Temperance Chert in the type area.





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TABLE 4 (cont'd)

| Approx. distance to ref. point (m) | Reference points | Lithological description |
|---|---|---|
| 70 | Almost opposite Frenchmans Creek | Quartz argillite or fine-grained quartz greywacke, slightly tuffaceous and cherty; silty shale (TS 72840152, Table 10) |
| 160 | | Tuff, coarse tuff (clasts to 8 cm), chert; passes into slightly tuffaceous chert |
| 180 | | Tuff, some tuffaceous chert; in part finely banded |
| 210 | Opposite gully on northern side of Temperance Creek | Finely banded slaty tuffaceous argillite, 6 to 20 m thick. Tuff, slightly tuffaceous chert |
| 290 | Creek turns from W to SW | |
| 390 | End of section; creek turns W at minor gully | Soil contains fragments of banded tuff and tuffaceous chert |
| | 'Confluence' section | |
| 0 | Start of section: Temperance Creek 450 m WSW of mouth of Frenchmans Creek and 40 m west of minor gully | Slaty fine-grained tuff or tuffaceous argillitic greywacke, banded tuff, tuffaceous chert, minor chert. Small intrusions of 'quartz porphyry' |
| 160 | To a second gully. Outcrops on E. side of gully | Outcrops of minor acidic intrusions ('quartz porphyry') fragments on slope are nearly all from the |

TABLE 4 (cont'd)

| Approx. distance to ref. point (m) | Reference points | Lithological description |
|---|---|---|
| 160 | | intrusions; a few of tuff and tuffaceous chert, banded silty cherty (?argillitic) greywacke, and banded slightly impure chert |
| 460 | Opposite clearing high above creek on N. side | Tuff, tuffaceous argillitic greywacke, tuffaceous chert, becoming more abundant in last 50 m. Scree mainly of intermediate igneous rock with some 'quartz porphyry' |
| 620 | End of section: Confluence of Temperance Creek with Tumut River | Chert, tuff, tuffaceous chert. From about 500 to 550 m, chert probably predominates. From 550 m to end of section tuff is probably predominant |
| | West Bend section | |
| 0 | Start of section: Happy Jacks Road 700 m due W. of junction of Happy Jacks and Tumut Rivers; almost around sharp bend in road; bearing of section line about 260° | Finely banded tuff and thin beds of chert followed by minor tuffaceous quartz arenite and thin beds of finely banded chert |
| 30 | End of section | Thin beds of banded chert in tuff, and silty chert or fine-grained cherty greywacke |
| | | 2-m band of black fissile shale in tuff: Nine Mile Volcanics |

Tantangara 1:100 000 Sheet area

Within the Tantangara Sheet area, the unit of interbedded tuff and chert is divided into upper and lower parts by a northward-expanding wedge of chert Fig. 13. The lower part extends northeast from near Kiandra, past the northern side of Sawyers Hill, to the Monro Range. Here it turns north, and continues almost to the Murrumbidgee River. The outcrop is of varying width, being intersected by three sets of faults that strike northeast, north, and northwest; thus it is about 3000 m wide across the Monaro Range and from 1000 to 2000 m wide in fault-bounded blocks farther north. From Sawyers Hill to the Monaro Range, the interbedded chert and tuff rests conformably on the Bolton Beds. In a fault-block in the southwest, the unit passes conformably up into the chert unit. North of the Monaro Range, the unit is faulted in the west against the Nine Mile Volcanics, and in the east against the Silurian Tantangara Beds or fault-blocks containing Temperance Chert and Bolton Beds. East of the Monaro Range, the unit is faulted against granite. The upper part of the interbedded chert and tuff crops out in fault-blocks at the head of Gooandra Creek, in an area southeast of Rules Point, on the northern side of McPhersons Creek, and between the northern end of Long Plain and Little Peppercorn Creek. At several localities north of Long Plain, at McPhersons Creek, and possibly at the head of Gooandra Creek, a conformable junction with the chert unit is exposed. East of Peppercorn Hill, north of McPhersons Creek, and southeast of Rules Point, it is conformably overlain by the Nine Mile Volcanics. North of McPhersons Creek the unit includes a chert layer 400 to 500 m thick; along Peppercorn Creek it contains lava flows at least 500 m thick.

Sawyers Hill. Near Sawyers Hill, the basal part of the unit of interbedded chert and tuff consists of argillitic quartz arenite, quartz siltstone, and andesitic tuff and chert. There is a bed of coarse tuff at least 3 m thick above the boundary with the Bolton Beds. Andesite tuff at G.R. 382281 northwest of Sawyers Hill, and at G.R. 401298 northwest of Tantangara Mountain consists of crystal and lithic fragments of andesite in a matrix of chert. Tuff at G.R. 394286 has a matrix of altered argillitic material and chert. Tuffaceous quartz greywacke from G.R. 409306, at the outcrop of coarse tuff north of Tantangara Mountain, is similar but it contains a larger proportion of very fine-grained clastic material - probably quartz and volcanic dust - in the matrix. Banding 1 to 8 mm thick in chert northwest of Sawyers Hill near the Eucumbene River (G.R. 382280) is due to varying proportions of very small quartz grains, silt-size and smaller.

Very fine-grained quartz siltstone with a chert matrix forms outcrops at least 120 m wide, 250 m north of the highway bridge over the Eucumbene River. Scattered fragments of feldspar are volcanic in origin;

numerous silt-size particles in the matrix do not appear to be individual mineral fragments, but possibly consist of devitrified volcanic dust. These outcrops are not obviously bedded; they are closely and irregularly jointed, and break into hard, brittle wedge-shaped fragments. The argillitic arenite near the base of the unit is commonly thinly bedded, and interlayered with thin beds of quartz siltstone and tuff; thicker beds of argillitic arenite occur, for example a 50-cm band at G.R. 382281.

About 100 m above the base of the unit clastic quartz and argillitic material decrease in amount and become minor constituents. Chert becomes dominant in the unit as a whole, and tuff is interbedded with it in beds a few millimetres to a metre thick. Locally tuff is dominant; a layer at least 200 m thick that consists predominantly of tuff in beds up to 3 m thick is well exposed in the cliff above the Eucumbene River east of Kiandra; another layer at least 30 m thick passes through G.R. 355274. Tuff beds up to 3 m or more thick occur in a belt at least 200 m wide near the upper third of the unit.

At a few localities, thin bands of argillite or argillitic quartz siltstone a few millimetres to a few centimetres thick are interbedded with chert and tuff; they cause a fine banding in the chert.

The chert in most outcrops is well bedded and banded; beds range in thickness from a few centimetres to more than a metre, and are commonly 20 to 50 cm; the banding ranges from a millimetre or less to several centimetres. At G.R. 361282 the bedding ranges from 15 to 25 cm and the banding from 1 to 5 cm.

North of Sawyers Hill. At least one more bed of coarse tuff is present in the unit, forming four outcrops between G.R. 404329 and 407338. Additional outcrops occur 500 to 800 m to the west, on either side of Kiandra Creek, but the structure of this area is obscure. North of Long Plain the upper part of the interbedded chert and tuff contains a lava flow which separates the unit into two fault-bounded belts, each about 600 m wide. The tuff in these northern outcrops is pale green, commonly cherty, and chert interbeds are 20 cm thick. An agglomeratic crystal tuff or flow breccia from G.R. 453597 consists of volcanic fragments up to 5 cm across, containing euhedral pyroxene and andesine in a cryptocrystalline groundmass. These fragments, as well as pyroxene and andesine fragments up to 1.5 mm across, are set in a groundmass of devitrified brown glass.

At McPhersons Creek and southeast of Rules Point, the unit consists of tuff, chert, tuffaceous chert, and interbeds of cherty siltstone; there is a thick bed of chert possibly 400 m thick at McPhersons Creek. An area at the head of Gooandra Creek is largely covered by soil, but it is inferred from an outcrop of tuff at G.R. 379344 that the bedrock consists of the unit of interbedded tuff and chert.

Contemporaneous deformation. Contemporaneous deformation is characteristic of the interbedded tuff and chert. Slump-folding with contorted bedding is present in banded siltstone, fine-grained tuff, and chert at G.R. 366279 near the crest of the ridge immediately north of the highway bridge over the Eucumbene River. Similar contorted bedding can be seen in banded chert and tuff at G.R. 405328 near the northern end of the Monaro Range; and in chert at G.R. 399381, in the northern part of Tantangara Plain. Slump-folding is present at G.R. 405313 north of Tantangara Mountain in coarse tuff containing large chert clasts; the clasts are mostly angular, a few are rounded.

Structure. The interbedded chert and tuff have undergone strong tectonic deformation. At many localities the beds are tightly folded, and are overturned with northerly dips of 45 to 75°. Where the beds are thick and the rock brittle, tight folding has resulted in close irregular jointing which obscures the bedding. In a large outcrop of tightly folded beds near G.R. 409306, bedding is recognizable only in the thinner-bedded northern part. Tightly folded bedded chert is also visible at G.R. 405446 southeast of Rules Point.

## Chert unit (Otc)

The chert unit crops out in five discrete areas: one in the southwest around Racecourse Creek and the upper part of Chance Creek; a second near the junction of Tantangara Creek with the Murrumbidgee River; the third a large area between Boundary and McPhersons Creeks, east of Long Plain, with a southeastward extension across Dairymans Plain; a fourth on the northern side of Zinc Ridge; and the fifth in the north in the upper valley of Sallys Flat Creek east of Peppercorn Hill. A southerly extension of the unit was mapped along Happy Jacks Road.

Racecourse Creek. The Racecourse Creek outcrops extend northeast from the western edge of the Sheet area. They are almost entirely surrounded by faults separating them from interbedded chert and tuff to the east and south, and from the Nine Mile Volcanics on the west and north. In the east some exposures of chert rest conformably on interbedded chert and tuff, and in the northwest chert appears to pass up conformably into the upper part of these beds. The unit consists almost exclusively of chert, but includes a distinctive agglomerate bed. The chert is banded rather than bedded, possibly because of the absence of clastic sediment to form interbeds. Bedding has been seen extending westwards for about 60 m from G.R. 365304. No slump structures were observed. Tectonic deformation is evident at G.R. 365313 where the chert is tightly folded.

Tantangara Creek. In the fault-block at the junction of Tantangara Creek with the Murrumbidgee River, the chert unit includes a tuffaceous sequence, perhaps 50 m thick, 200 m downstream from the creek junction. Tightly folded chert is exposed at G.R. 417421.

McPhersons Creek to Boundary Creek. Near Boundary Creek the chert unit is faulted at its western edge against the Nine Mile Volcanics and the Silurian Goobarragandra Beds; in the north it passes up conformably into the interbedded chert and tuff, and in the east and southeast the chert is in some places faulted against, and in others unconformably overlain by, Early Silurian Tantangara Beds and Silurian volcanics. Throughout most of the area of outcrop, chert alone forms the bedrock. Widely spaced probably lenticular bands of tuff are interbedded with the chert between Black Hill and McPhersons Creek, and near the faulted boundary west of Black Hill; a band of fine tuff at G.R. 421525 is about 10 m thick. Where it is free from interbeds the chert is thick bedded as at G.R. 421526 and G.R. 436476; where the chert beds are tuffaceous, they are 4 to 10 cm thick and separated by interbeds of altered volcanic dust. Bedding in the chert is uniform and distinct at many localities, e.g. G.R. 419518; at others e.g. G.R. 409487, the beds are closely or tightly folded, and usually only an approximate attitude can be determined.

Dairymans Plain. Across Dairymans Plain, the chert is in contact in the west and south with Silurian Tantangara Beds, and in the northeast and east with Silurian volcanics; the outcrop area is 3500 m wide. The boundaries in the west and northeast are depositional; the rest faulted. The chert encloses several fairly large areas of tuff. The precise stratigraphic position of this chert and associated tuff is not known; it is thought to be below the chert at Boundary Creek and is so shown diagrammatically in Fig. 13.

Zinc Ridge. The triangular area of chert north of Zinc Ridge has been faulted down into the Tantangara Beds. Dips are very steep, giving a thickness (without folding) nearly equal to the outcrop width of 2000 m.

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Sallys Flat Creek. East of Peppercorn Hill in an area drained by Peppercorn Creek and a tributary, Sallys Flat Creek, are outcrops of silty chert with a few beds of tuffaceous chert and some sandy beds with a chert matrix. The best exposure is at G.R. 492625. The sandy beds probably consist of reworked andesitic tuff; they are commonly only 1 to 2 cm thick and are intercalated between silt beds up to several metres thick; otherwise the exposures are of massive silty chert, commonly pyritic. This becomes tuffaceous towards the top of the sequence and grades upwards, through a thickness of 20 m, into the upper interbedded tuff and chert. Bedding is subvertical with a strike of 042 to 050°. The chert is intruded by small dykes and sills which appear to be intermediate in composition and by a monzonite stock 400 x 300 m at G.R. 482617.

Happy Jacks Road (Wagga Wagga 1:250 000 Sheet area). Along Happy Jacks Road, the thick chert unit as mapped in the Tantangara Sheet area is not present. Tuff is dominant except at a locality 700 m northwest of the Happy Jacks and Tumut Rivers junction where chert is predominant on either side of an agglomerate bed, and extends from about 20 m east to 250 m west. This is thought to be a southerly extension of the chert and agglomerate mapped at Racecourse Creek.

## Agglomerate (Otb)

Racecourse Creek. At Racecourse Creek there is an agglomerate bed perhaps 10 m thick in a belt of tuff and interbedded chert which may be about 200 m wide. Locally, as at G.R. 385325, the agglomerate consists of large angular blocks up to 2 m across of andesite and tuff; more generally the pyroclasts range in size from a few to 30 cm and are embedded in a matrix of smaller particles and of chert. The tuff is well bedded, in beds that may be more than 1.5 m thick. At G.R. 380312 tuff beds up to 60 cm thick are separated by chert interbeds as thick as 4 cm. Bands of andesite arenite 1 to 2 mm thick at G.R. 370303 appear to be water-sorted, possibly in a turbidity current. A thin section from an outcrop at G.R. 368307 shows fragments of andesite, and crystals and crystal fragments of altered plagioclase and fresh clinopyroxene, in a matrix of chert.

Happy Jacks Road. An agglomerate bed about 100 m thick, exposed along Happy Jacks Road, is correlated with the agglomerate of Racecourse Creek. Within it are layers of interbedded chert and tuff nearly 15 m thick, and banded chert and impure chert about 10 m thick. The outcrop along the road cutting is thoroughly weathered and decomposed; those original pyroclasts still distinguishable range up to about 25 cm in size. A thin section from a less-weathered 'kernel' consists of lithic and crystal andesitic fragments 2mm in size and smaller; they show minor alteration to epidote.

Other Localities. Coarse pyroclastics were not found in the other outcrops of the chert unit. Near Mc Phersons Creek, the agglomerate is possibly represented by one of the thin lenticluar tuffaceous beds in the chert; one such is exposed at G.R. 428511.

## Tuff (Ott)

Tuff forms fairly extensive oval-shaped outcrop areas within the chert unit at Dairymans Plain; the largest area has a width of 800 m. Its boundaries, and those of the surrounding chert, together with the general attitude of the bedding, suggest that the tuff is here exposed in the crest of an anticline.

## Lava (Otl)

A lava exposed at Peppercorn Creek is in conformable contact with overlying interbedded tuff and chert, and is faulted against tuff and chert at its lower boundary. The thickness of the lava is not accurately known, but the outcrop width, 600 m is probably close to it. The lave is a pale green vesicular andesite with abundant phenocrysts of pyroxene up to 5 mm in size. Flow-banding is clearly visible at G.R. 465607, in Peppercorn Creek, where the rock is little-altered. Angular blocky structures and a clinker-like surface indicate subaerial flows. A thin section of altered andesite from G.R. 459601, at the northern end of Long Plain, comprises 10% andesine laths up to 1 mm across and a similar proportion of irregular chlorite clots up to 1 mm across in a groundmass of brown devitrified glass. Alteration to calcite is extensive, the calcite occurring as irregular patches up to 3 mm across and making up 10% of the rock. No pyroxene is present. A pyroxene-bearing andesite from G.R. 471614 along Peppercorn Creek consisting of euhedral zoned augite phenocrysts up to 2 mm across (20%), a few plagioclase phenocrysts up to 1 mm, intergrowths of two chlorites (one yellow-green, the other blue-green), and calcite, pseudomorphing probable hornblende, up to 1 mm (10%), in a groundmass of plagioclase microlites, chlorite, and granular opaques. The rock was probably a pyroxene amphibole andesite before the hornblende alteration. Vesicular pyroxene andesite from G.R. 460601 at the northern end of Long Plain consists of weakly aligned euhedral phenocrysts of augite (2 mm)

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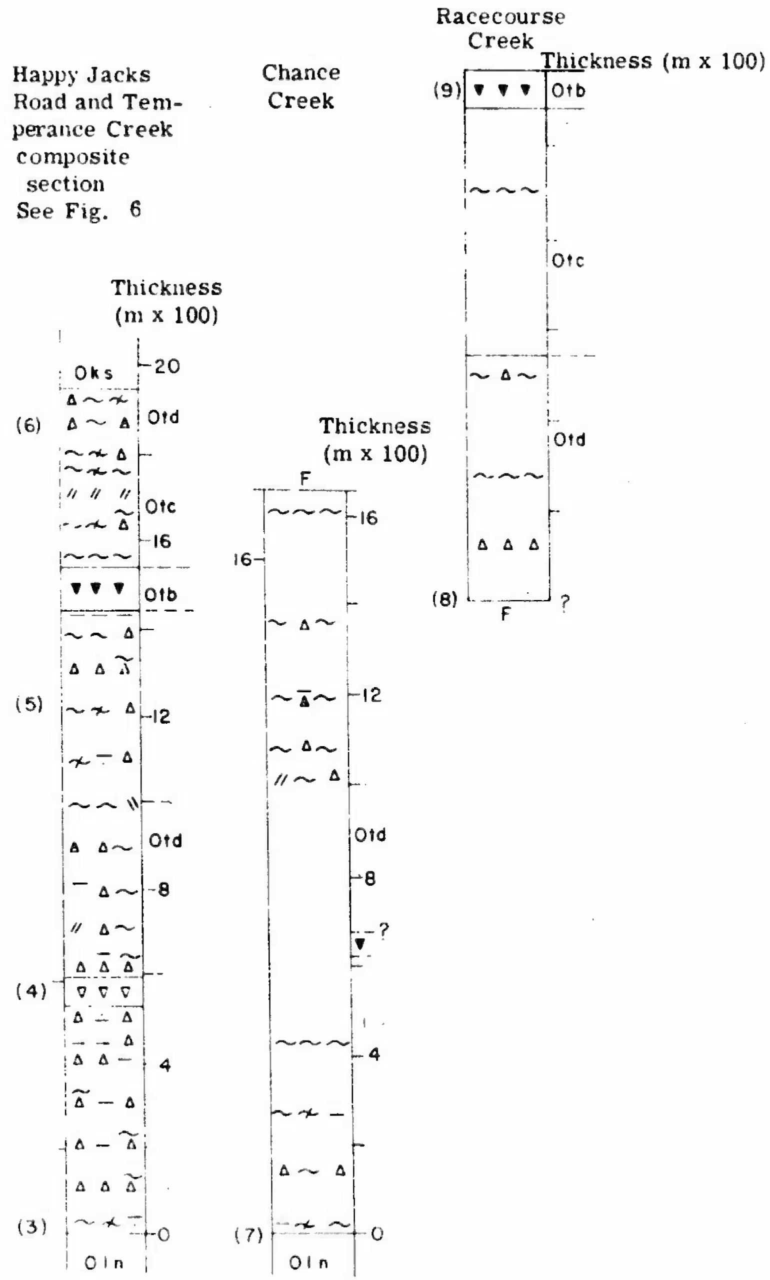
in a groundmass of plagioclase microlites, granular ?magnetite, and brown-green chlorite. Plagioclase phenocrysts are rare. Vesicles up to 4 mm across (10%) are filled with deuteric albite cores and calcite rims. Calcite is also present in the groundmass as clots up to 0.5 mm across. Vesicular pyroxene andesite from G.R. 465605, along Peppercorn Creek 700 m northeast of the last locality, has a groundmass of brown glass and unoriented plagioclase microlites. The vesicles, up to 3 mm across (3%), are filled with calcite which may be accompanied by albite, or by albite and chlorite. Clots of calcite and chlorite occur as an alteration product throughout the thin section.

## SUMMARY OF LITHOLOGIES

The lithology of the Temperance Chert along several stratigraphic sections in the Tantangara Sheet area is compared, in Figs. 7 and 9, with that in the areas around Happy Jacks Road and Temperance Creek where the formation was originally defined. The locations of the sections are shown in Figs 8, 10, 11, and 12; summary descriptions of outcrops along the section lines are given in Tables 5 and 6. Figures 7 and 9 suggest that there are higher proportions of tuff and clastic sediments in the south than in the Tantangara Sheet area. In the latter there are higher proportions of chert, which increases in abundance towards the north and thickens to form a discrete chert unit.

An upper limit is placed on the stratigraphic section at Tantangara Creek by the correlation made with the McPhersons Creek area. The upper limits determined for the Racecourse Creek and Chance Creek sections follow in turn from this initial correlation. From this it is deduced that between Happy Jacks Road and Chance Creek the depositional surface sloped steeply to deeper water, in which the thick chert was deposited. The chert unit is wedge-shaped, thinning southwards presumably against a steeply-rising sea-floor; it ceases to be a single discrete unit not far south of Racecourse Creek. Along Happy Jacks Road, there is only a sequence 250 m thick of chert and impure chert, intruded by small dykes and probably sills of 'quartz-porphyry'. This locality is shown in Fig. 5. As the chert unit thickens northwards, the original dip of its boundary is steeper than the local bedding surface. The massive chert gives way southwards to interbedded tuff and chert; the boundary is transitional, with some tuff beds extending far into the chert. Examples are the agglomerate at Racecourse Creek, the tuffaceous beds at Tantangara Creek, and the tuff of Dairymans Plain. The boundary of the chert unit shown on the geological map, along the eastern side of Wild Horse Plain, was drawn to contain rock which consists almost exclusively of chert. It could as well have been placed stratigraphically lower, to include that part of the interbedded chert and tuff in which chert is markedly predominant.




REFERENCE

| | | | |
|---|---|---|---|
| ▵ | Tuff | | Nine Mile Volcanics |
| ~ | Chert | Oks | Sediment and tuff |
| | Impure chert | | Temperance Chert |
| — | Argillite; siltstone | Otb | Agglomerate, with interbedded tuff and minor chert |
| | Argillitie arenite | | |
| ▿ | Coarse Tuff | Otc | Chert |
| ▾ | Agglomerate | Otd | Interbedded chert and tuff |
| | Tuffaceous chert, cherty tuff | | |
| | Tuffaceous arguillite, argillitic tuff | Oln | Bolton Beds |
| | Tuffaceous arenite | ? | Stratigraphic position not accurately known. |
| F | Fault | | |

Reference Points

(3) Temperance Creek. 1100 m SW of Skeleton Creek

(4) Temperance Creek 750 m ESE of Frenchmans Creek and 100 m SW of Frenchmans Creek (See Fig 15)

(5) Temperance Creek. 150 m east of Tumut R., and Happy Jacks Rd. 200 m NNW of jnctn of Happy Jacks and Tumut Rivers

(7) 1600 m NW of Tantangara Mountain Trig. Stn

(8) At inferred fault. 1950 m ENE of jnctn of Racecourse Creek and Chance Creek

(9) 600 m NE of jnctn of Racecourse and Chance Creeks

Fig 7 Stratigraphic sections of lower part of interbedded tuff and chert (below the agglomerate unit)

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TABLE 5. STRATIGRAPHIC SECTIONS OF THE TEMPERANCE CHERT BELOW THE AGGLOMERATE UNIT. (The stratigraphic column is shown in Fig. 7)

Location: Tantangara 1:100 000, Canberra 1:250 000 Sheet areas (Fig. 8)

| Approx. distance to ref. point (m) | Reference points | Lithological description |
|---|---|---|
| | Chance Creek section | |
| 0 | Start of section: at boundary with Bolton Beds, 1600 m NW of Tantangara Mountain Trig. station. Section line runs 345° | Siltstone, cherty siltstone tuff, chert |
| 40 | | Three beds of tuff 1 to 2 m thick |
| 60 | | Altered fine-grained tuff (TS 1840069), chert, minor siltstone |
| 180 | At fence; section line turns to (040°) | Beds of tuff to 50 cm thick; banded chert and siltstone |
| 480 | Section line turns to 345° | Chert, siltstone, cherty siltstone |
| 640 | | Banded chert |
| 750 | Section line crosses Chance Creek | |
| 1240 | Section line turns to 310° | Small dacite dyke, intruding chert and fine-grained tuff |
| 1320 | Section line turns to 257° | Interbedded chert and fine-grained tuff |
| 1980 | Section line turns to 318° | Chert; minor tuffaceous greywacke |
| 2180 | Section line turns to 298° | Boulders of chert and tuff |
| 2500 | Section line crosses tributary of Chance Creek | |
| 2530 | | Massive chert; no bedding |
| 2570 | End of section | Inferred fault |
| | Racecourse Creek section | |
| 0 | Start of section: 40 m east of track, and 1950 m ENE of junction of Racecourse and Chance Creeks. Section line runs 282° | Fault inferred at start of section |
| 40 | Track (Nungar Trail) | |
| 120 | Section line turns to 213° | Tuff; boulders of bedded tuff |
| 370 | Section line crosses track | |

TABLE 5 (Continued)

| Approx. distance to ref. point (m) | Reference points | Lithological description |
|---|---|---|
| | Racecourse Creek section | |
| 860 | Section line turns to 234° | Banded chert |
| 1300 | Section line turns to 318° | Chert and interbedded fine-grained tuff |
| 1600 | Section line crosses track | |
| 1800 | | Chert |
| 2000 | End of section of lower part of Temperance Chert; 600 m NE of junction of Racecourse and Chance Creeks* | At boundary between chert and base of agglomerate unit (Otb) |

* This is the start of the section of the upper part of the Temperance Chert in the map area (see Table 6, Figs 8, and 9)

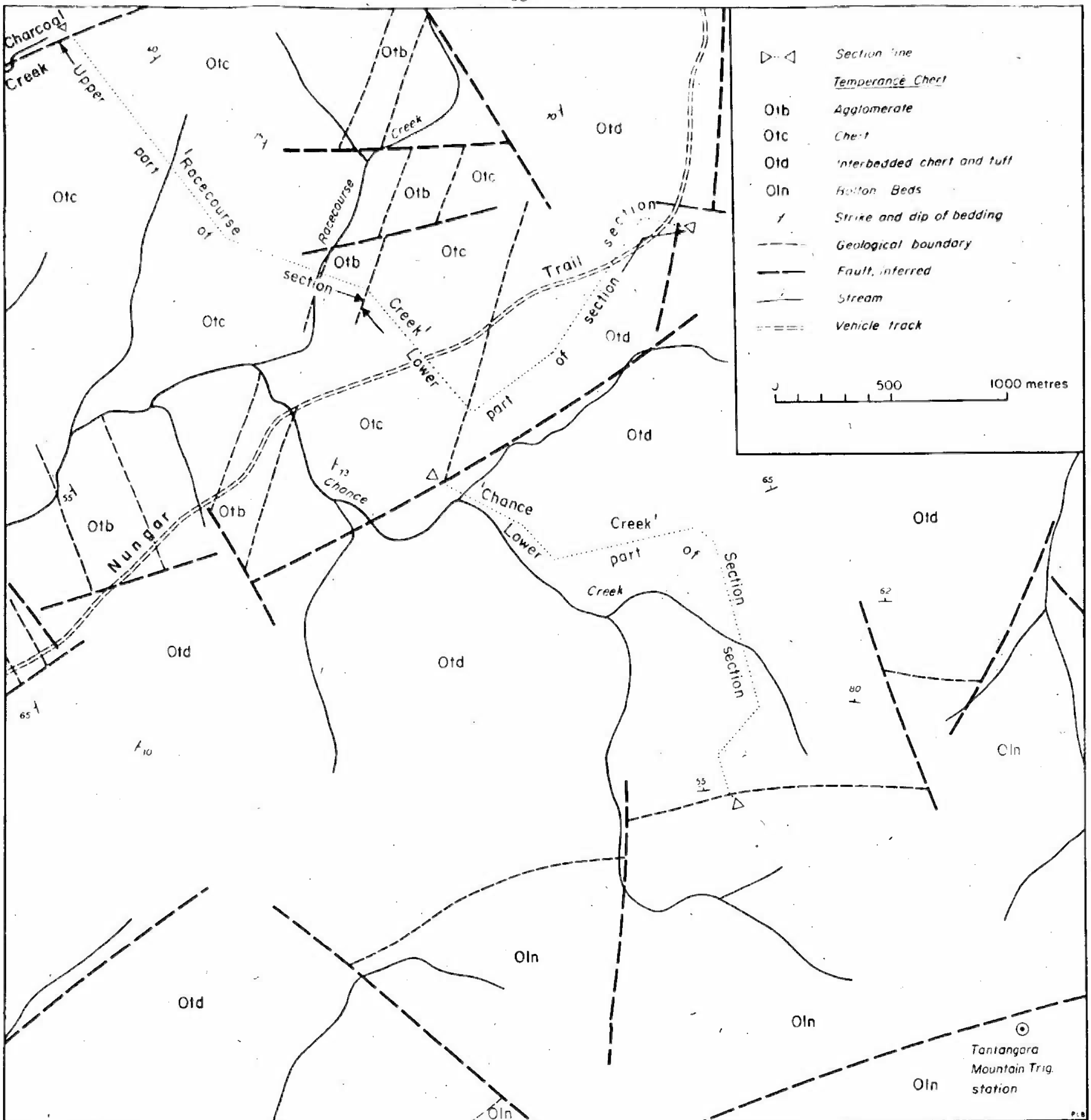


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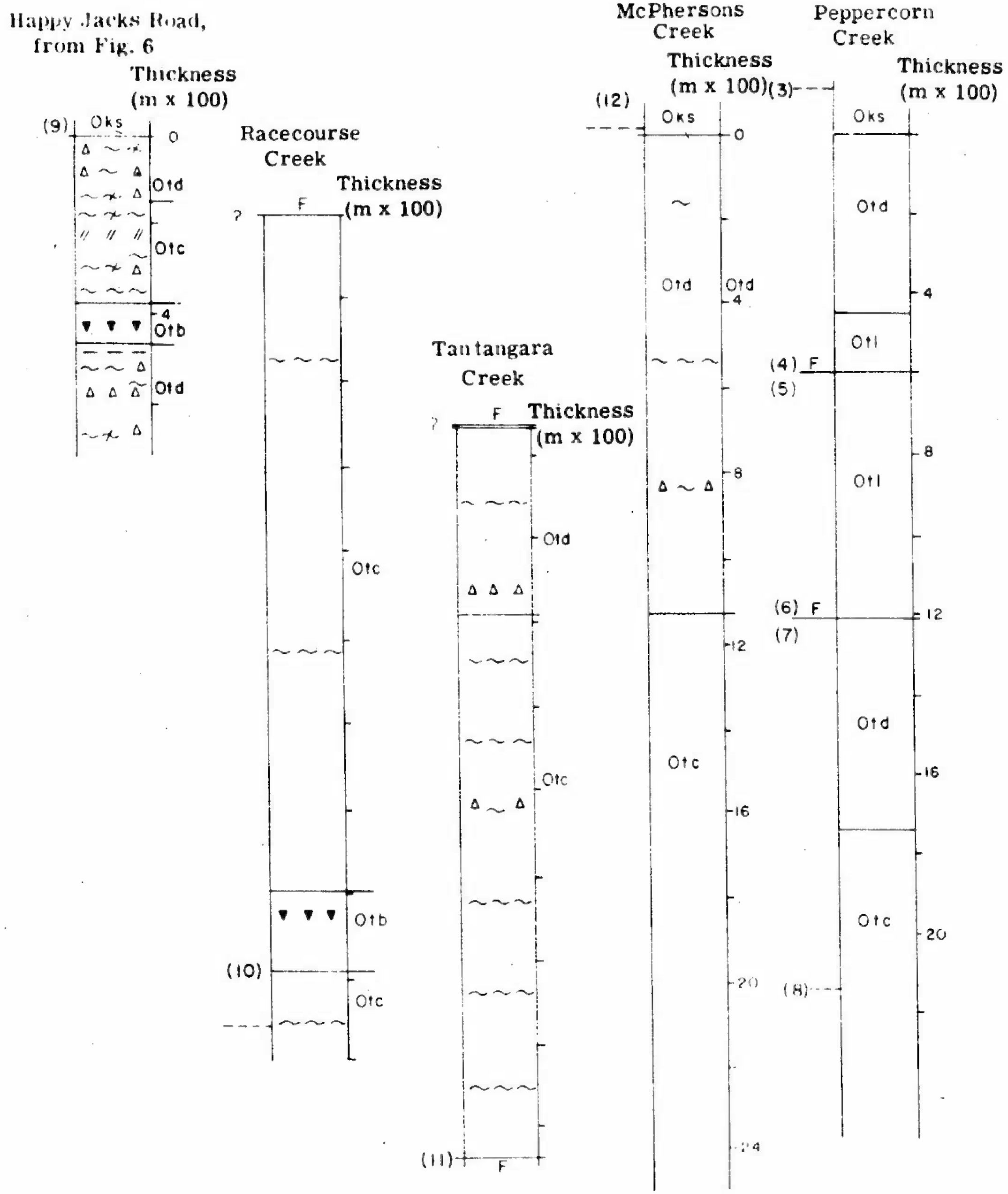
**Fig. 8.** **Location of 'Chance Creek' and 'Racecourse Creek' sections.**

TANTANGARA 1:100 000 Sheet area




| | |
|---|---|
| Δ | Tuff |
| ~ | Chert |
| | Impure chert |
| — | Argillite |
| ▼ | Agglomerate |
| | Tuffaceous chert, cherty tuff |
| ▲ | Tuffaceous arenite |
| F | Fault |
| ?— | Stratigraphic position not accurately known |

## Reference

**Nine Mile Volcanics**

| | |
|---|---|
| Oks | Sediment and tuff |

**Temperance Chert**

| | |
|---|---|
| Otl | Lava |
| Otb | Agglomerate, with interbedded tuff and minor chert |
| Otd | Chert and tuff, interbedded |
| Otc | Chert |

## Reference Points

(3) 1150 m WNW of jnctn of Peppercorn & Little Pepperc. Creeks
(4) 350 m NW of jnctn of Peppercorn & Little Pepperc. Creeks
(5) 2400 m WSW of Peppercorn Hut
(6) 2250 m SW of Peppercorn Hut
(7) 1200 m WSW of Peppercorn Hut
(8) 500 m S of Peppercorn Hut
(9) 650 m W of jnctn of Happy Jacks and Tumut Rivers
(10) 600 m NE of jnctn of Racecourse and Chance Creeks
(11) 1200 m SE of jnctn of Tantangara Creek & Murrumbidgee River
(12) 2000 m NE of jnctn of McPhersons Creek & Murrumbidgee River

Fig. 9. Stratigraphic sections of upper part of interbedded chert and tuff (including the agglomerate unit).

TABLE 6. STRATIGRAPHIC SECTIONS OF UPPER PART OF TEMPERANCE CHERT, INCLUDING THE AGGLOMERATE UNIT (diagrammatic stratigraphic columns are shown in Fig. 9

Location: Tantangara 1:100 000, Canberra 1:250 000 Sheet areas

| Approx. distance from ref. point (m) | Reference point | Lithological description |
|---|---|---|
| | 'Racecourse Creek' section | |
| | For location, see Fig. 8 | |
| 2000* | Start of section: 600 m NE of junction of Racecourse and Chance Creeks. Sect. line runs 290° | At base of agglomerate unit. Andesite agglomerate on west grading to coarse-grained tuff on east |
| 2200 | | Top of agglomerate unit, and boundary with chert. Chert fragments in soil |
| 2220 | Section line crosses Racecourse Creek | |
| 2640 | Section line turns to 323° | |
| 2800 | | Outcrop of chert along slope |
| 3040 | Section line crosses tributary of Chance Creek | |
| 3550 | | Banded chert, attitude 49°/315° |
| 3900 | End of section at the head of the south branch of Charcoal Creek | Inferred fault |

* At end of section of lower part of Temperance Chert (Table 5)

| | | |
|---|---|---|
| | Tantangara Creek section | |
| | For location, see Fig. 10 | |
| 0 | Start of section: north bank of Murrumbidgee River 1200 m SE of junction of Tantangara Creek with River. Section line runs 315° | Inferred fault; Tantangara Beds to south |
| 200 | Section line turns to 006° | Chert |
| 420 | Section line turns to 310° | Chert |
| 710 | Section line turns to 322° | Chert |
| 850 | Section line crosses river | |
| 930 | Section line turns to 287° | Tuff, chert |
| 1270 | Section line turns to 345° | Chert |
| 1500 | | Chert |

TABLE 6 Continued

| Approx. distance from ref. point (m) | Reference point | Lithological description |
|---|---|---|
| 1610 | | Boundary with interbedded chert and tuff |
| 1690 | Section line turns to 025° | Tuff |
| 1970 | Section line turns to 290° | Chert |
| 2170 | End of section, 450 m NE of mouth of unnamed creek that flows south into the Murrumbidgee River | Inferred fault; interbedded chert and tuff to north |
| | McPhersons Creek section | |
| | For location, see Fig. 11 | |
| 0 | Start of section: 500 m NNE of the junction with the Murrumbidgee River of an unnamed gully parallel to and north of McPhersons Creek, and about 800 m from it. Section line runs 157° | Quartz siltstone of the Nine Mile Volcanics |
| 130 | | Upper boundary of Temperance Chert |
| 210 | Section line at gully; turns to 120° at gully | Tuff, chert; probably tightly folded |
| 670 | Section lines turns to 128° | Chert |
| 1080 | Section line turns slightly to 100° | Tuff, silty chert |
| 1240 | Section line crosses McPhersons Creek | |
| 1540 | | Boundary with chert unit |
| 2880 | End of section, 950 m SSE of a small tributary of McPhersons Creek (See Fig. 11) | Chert |

'Peppercorn Creek' Section

The area is closely faulted, and a complete uninterrupted section is not available; this is a composite, generalized section prepared from three subsidiary sections at the localities shown in Figure 12.

| | | |
|---|---|---|
| | Lower Part of Section (line 7-8) | |
| 0 | Start: At point 8, 500 m S of Peppercorn Hut. Section line runs 270° | In outcrop area of chert unit |
| 440 | Vehicle track | |

TABLE 6 Continued

| Approx. distance from ref. point (m) | Reference points | Lithological description |
|---|---|---|
| 470 | | Upper boundary of chert unit; section line enters outcrop area of interbedded chert and tuff |
| 1040 | | Fault bringing lava against chert and tuff |
| 1050 | End of section (point 7, 240 m ENE of junction of gully with Peppercorn Creek) | In lava |
| | Middle Part of Composite Section | |
| | (section line 5-6) | |
| 0 | Start: At point 6, 2250 m SW of Peppercorn Hut; section runs to 305° | Fault; interbedded sediment and tuff to SE, lava to NW |
| 730 | Finish: 2400 m SW of Peppercorn Hut (point 5, 80 m SE of track) | Fault; interbedded sediment and tuff to NW |
| | Upper part of Composite Section | |
| | (section line 3-4) | |
| 0 | Start: At point 4, 350 m NW of Peppercorn and Little Peppercorn Creeks, and 100 m SW of mouth of minor gully. Section line runs 270° | Fault; lava to E and W |
| 160 | | Upper boundary of lava; section enters outcrop area of interbedded chert and tuff |
| 700 | | Upper boundary of interbedded chert and tuff. Section enters outcrop area of Nine Mile Volcanics |
| 870 | End of section: point 3, 200 m ENE of sharp westward bend in track | In outcrop area of sediment and tuff of Nine Mile Volcanics |

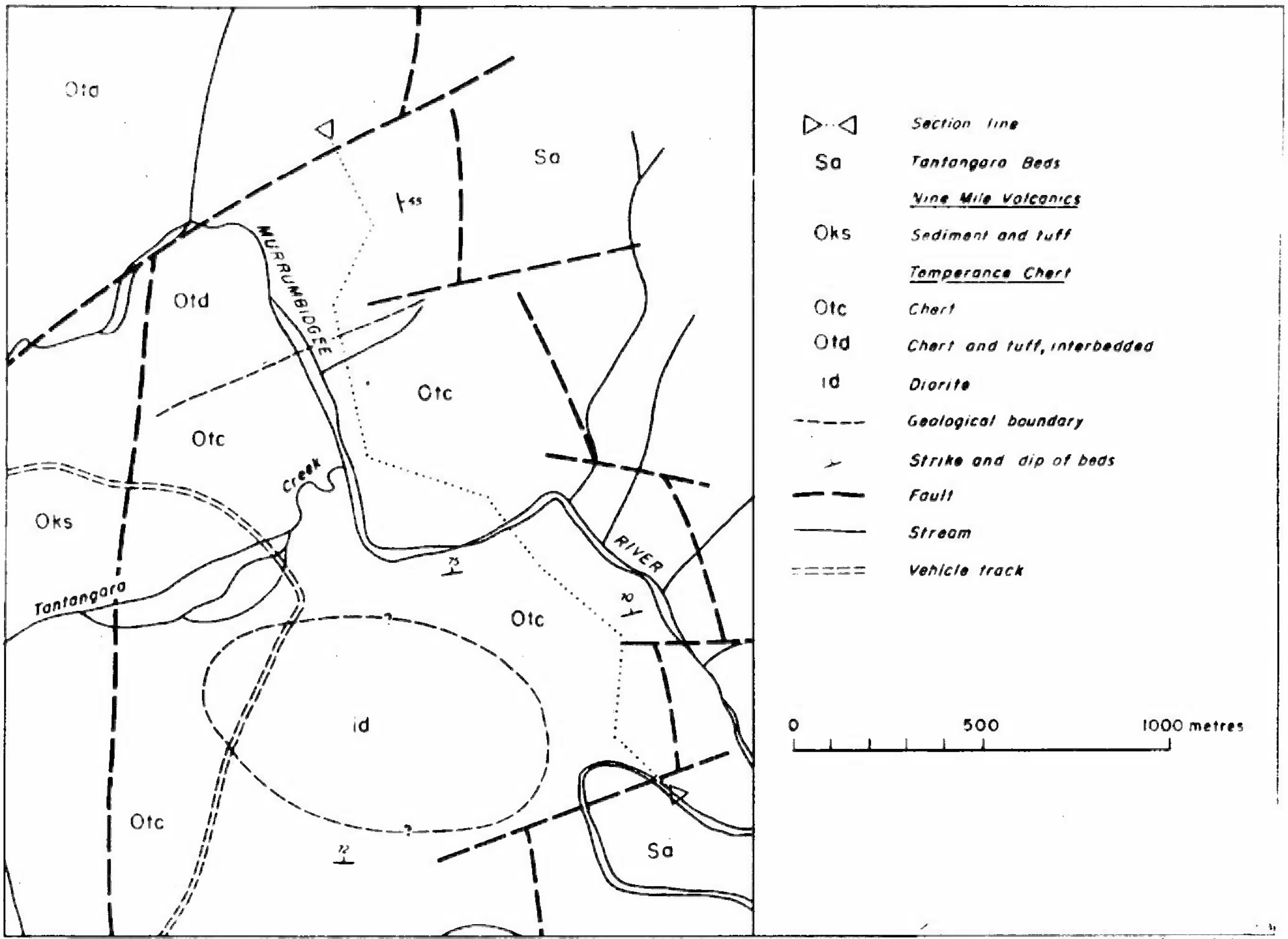



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**Fig. 10.** **Location of 'Tantangara Creek' section.**
TANTANGARA 1:100 000 Sheet area

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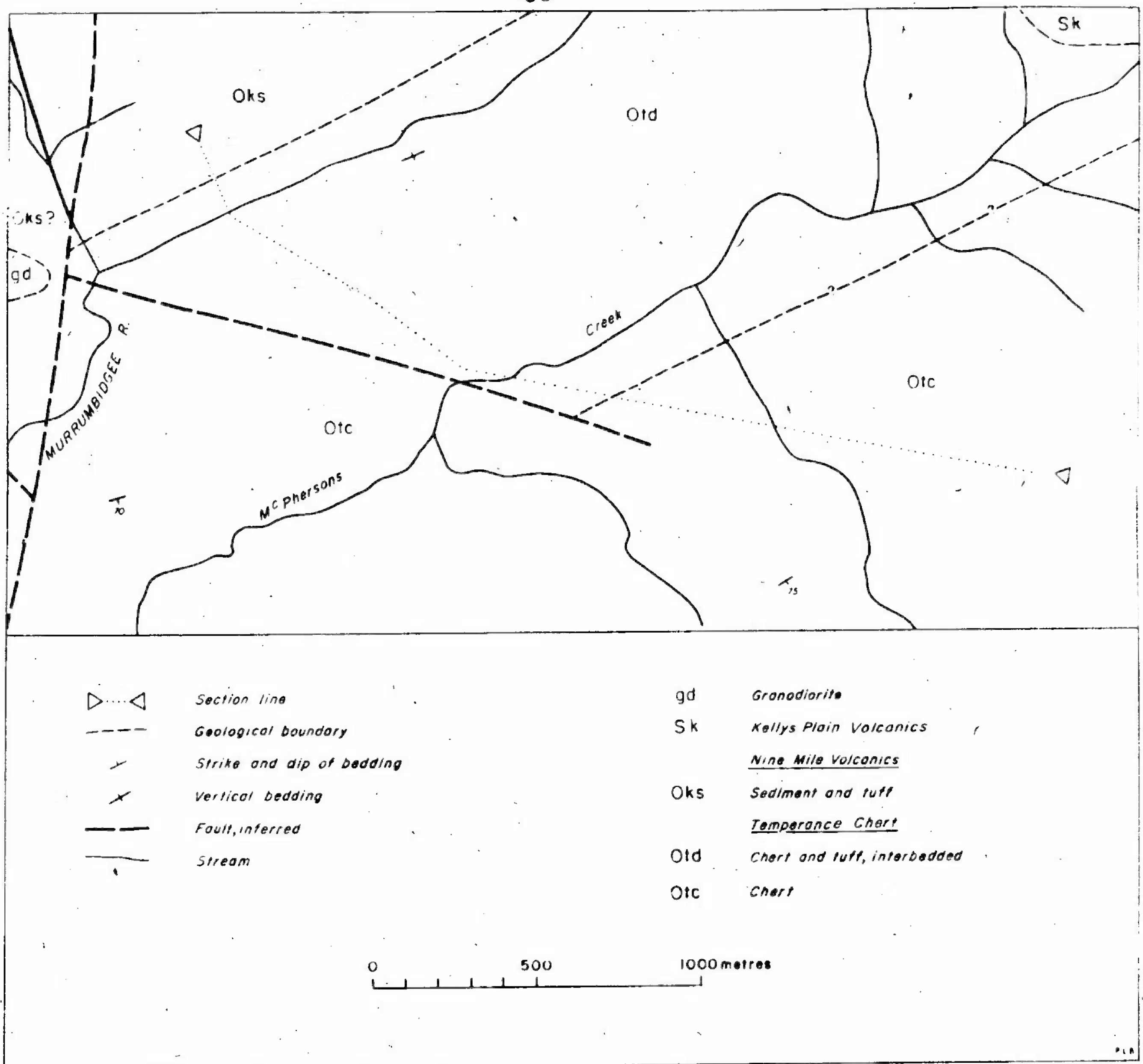


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**Fig.II. Location of 'McPhersons Creek' section.**
TANTANGARA 1:100 000 Sheet area.

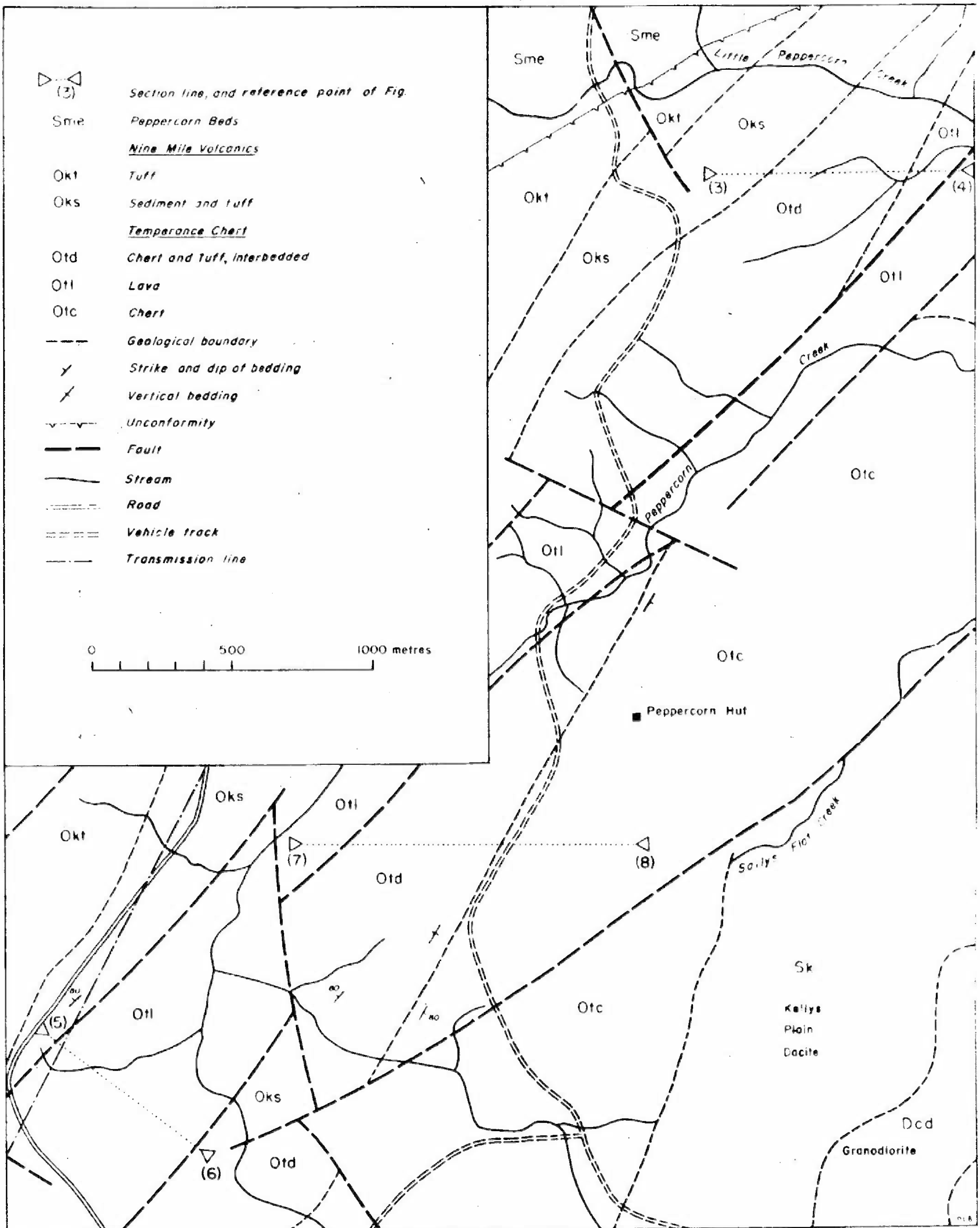


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**Fig. 12.** **Location of 'Peppercorn Creek' sections.**
TANTANGARA 1:100 000 Sheet area

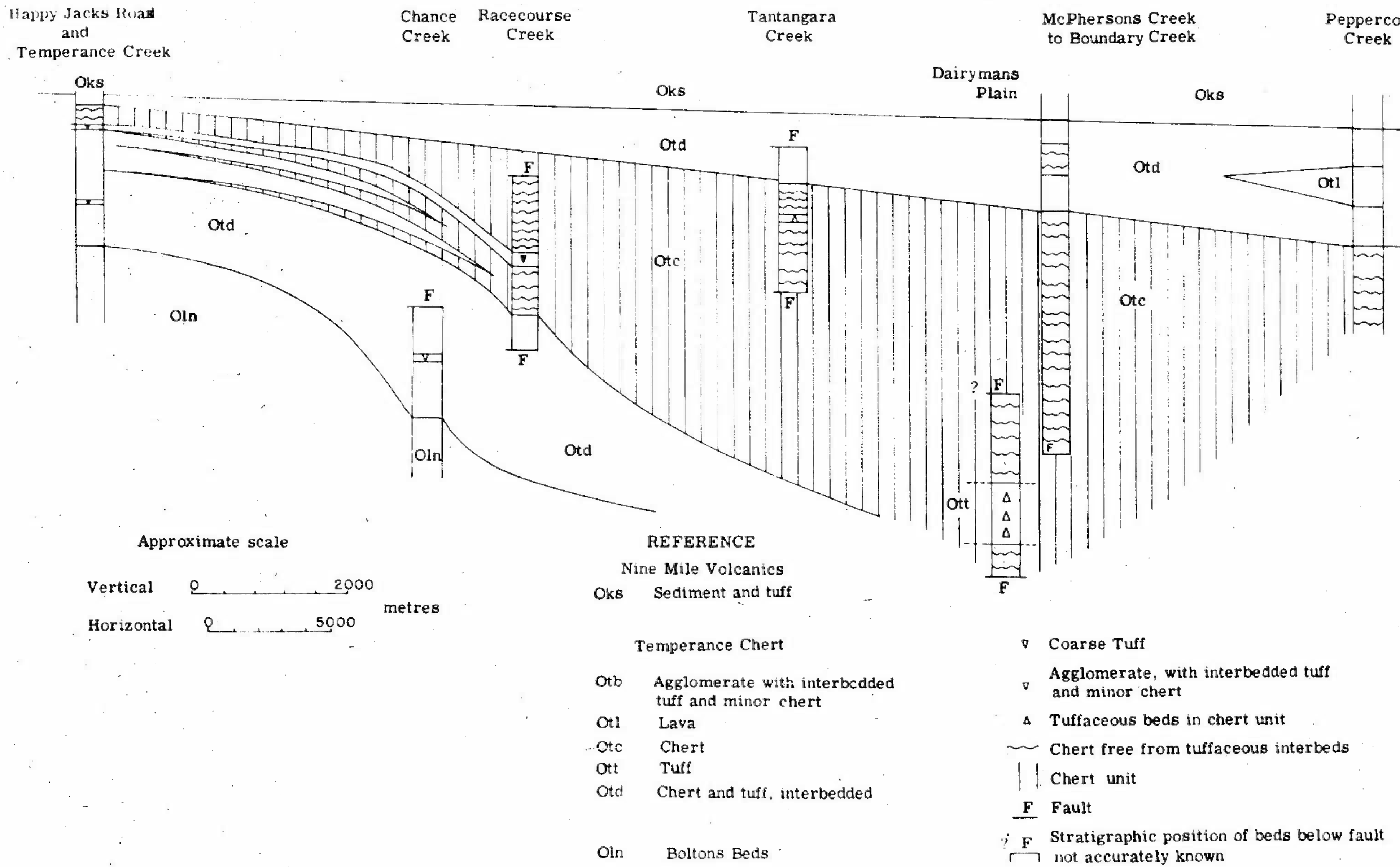


Fig. 13. Suggested correlation of Temperance Chert in mapped areas; based on data of Tables 5 and 6.

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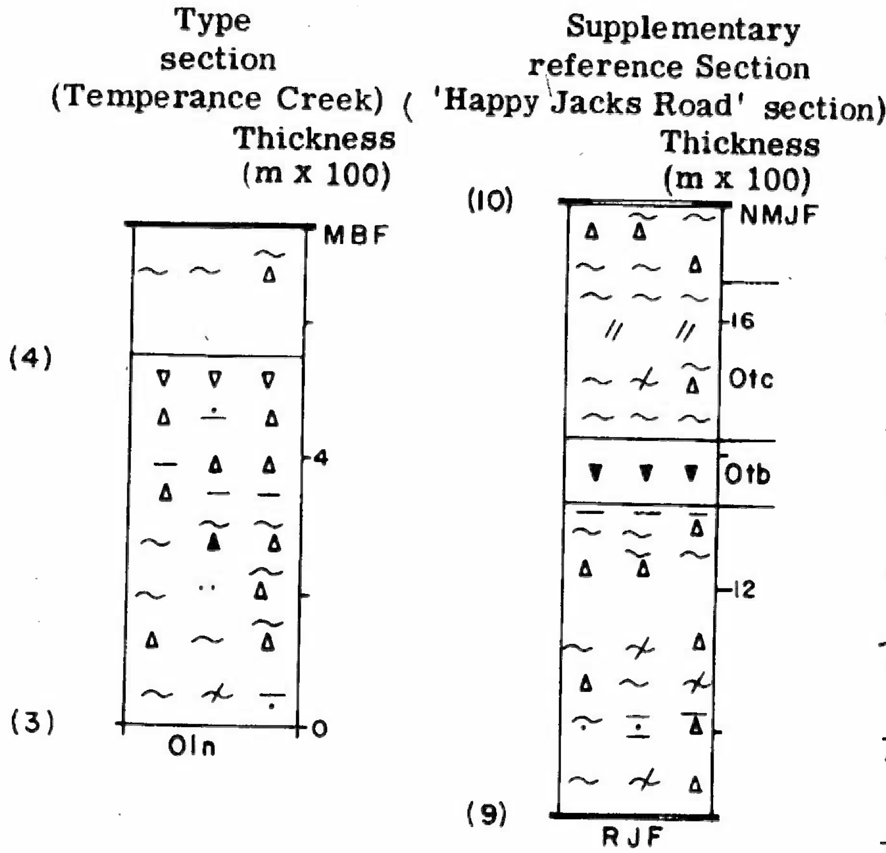



- Tuff
- Chert
- Impure chert
- Arenite
- Argillite
- Agglomerate, with interbeds of tuff and chert
- Coarse tuff
- Tuffaceous chert; cherty tuff
- Tuffaceous argillite; argillitic tuff
- Argillitic arenite; arenitic argillite; greywacke
- Tuffaceous greywacke; tuffaceous argillitic greywacke
- // Minor intrusions of quartz porphyry

Reference Points

(3) 1100 m SW of Skeleton Creek

(4) 750 m ESE of Frenchmens Creek

(9) Happy Jacks Road bridge over Tumut River

(10) 1100 m WNW of junction of Happy Jacks and Tumut Rivers

| | |
|---|---|
| Otc | Chert unit |
| Otb | Agglomerate |
| Oln | Bolton Beds |

Faults

| | |
|---|---|
| MBF | M-Bend |
| RSF | River Junction Fault |
| NMJF | Nine Mile Junction Fault |

Fig. 14. Type section and supplementary reference section of Temperance Chert

## CORRELATION BETWEEN OUTCROP AREAS

A correlation between several of the areas of outcrop is given diagrammatically in Fig., 13. The method used is summarized in Table 7.

### TABLE 7. CORRELATION OF STRATIGRAPHIC SECTIONS OF TEMPERANCE CHERT

| Sections correlated | Boundaries or beds used |
|---|---|
| 'Happy Jacks Road' and 'McPhersons Creek' | (a) Boundary between the interbedded chert and tuff and the Nine Mile Volcanics<br>(b) Chert-rich beds above the agglomerate at Happy Jacks Road correlated with top of chert unit of McPhersons Creek |
| 'McPhersons Creek' and 'Tantangara Creek' | Upper boundary of chert unit |
| 'Chance Creek' and 'Racecourse Creek' | Approximate matching of interbedded chert and tuff across fault |
| 'Chance Creek' and 'Happy Jacks Road' | Boundary between the interbedded chert and tuff and the Bolton Beds |

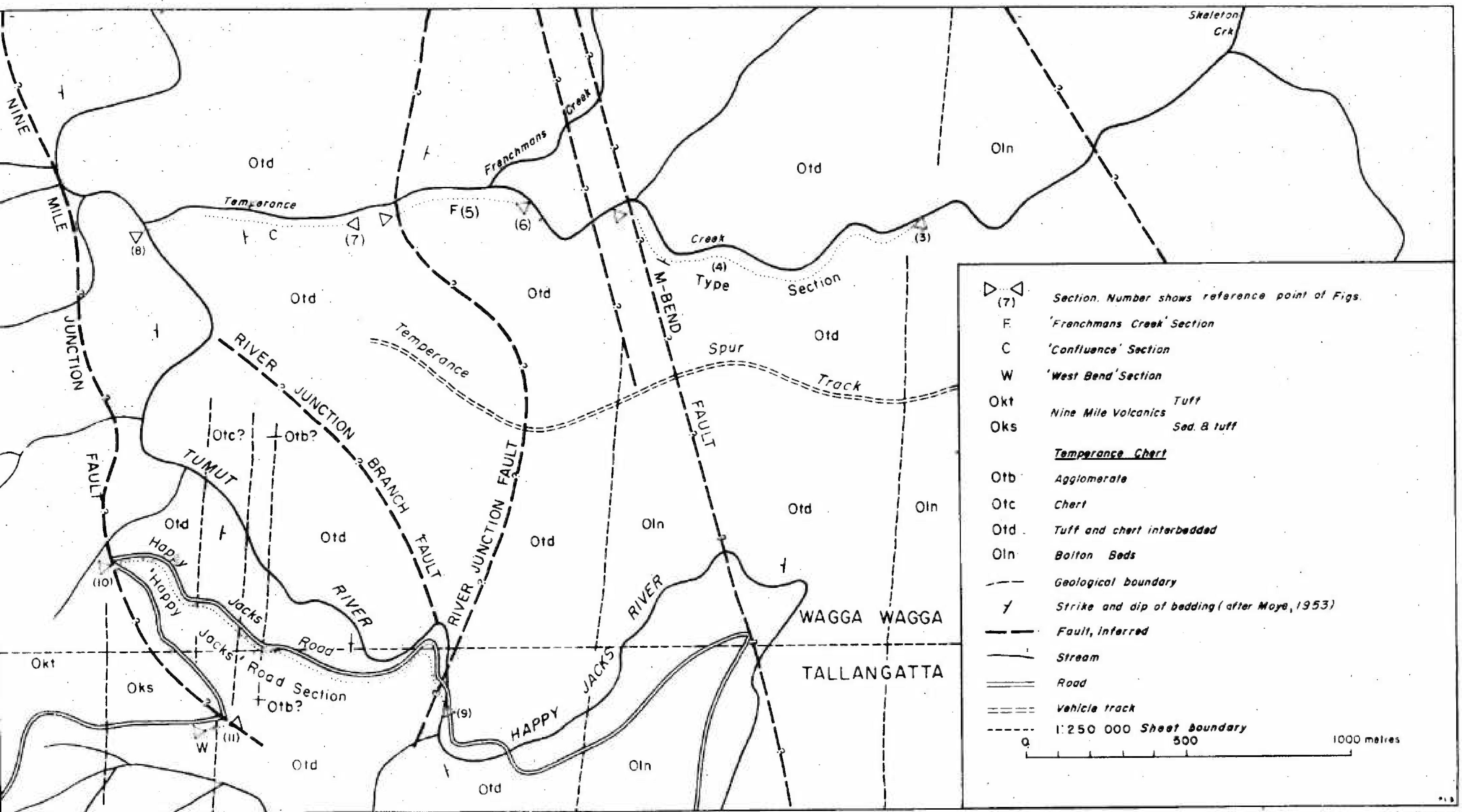
In the largest areas of outcrop, at Racecourse Creek and from Boundary Creek to McPhersons Creek, the attitude of the bedding suggests a folded structure, whose axis would trend between northeast and north-northeast. This possible structure was not allowed for in estimating the thicknesses, which may therefore be too great in these areas.

TYPE SECTION AND OTHER STRATIGRAPHIC SECTIONS

A section exposed along Temperance Creek from 1100 m south-west of Skeleton Creek to 400 m east of Frenchmans Creek is named the type section of the Temperance Chert; it covers the lower half of the formation, and is within the type area of Fairbridge et al.(1951). It consists of interbedded chert and tuff, and widely spaced interbeds of siltstone, very fine-grained quartz arenite or greywacke, and black silty argillite. Contemporaneous deformation is common, mainly as slump-folding. The bedding dips west, generally at angles of at least 80°, and strikes north except locally near the top of the section, where the strike is west-northwest. A supplementary reference section, the 'Happy Jacks Road' section, covers the upper part of the formation; it extends along Happy Jacks Road from the bridge over the Tumut River 50 m north of the junction of the Happy Jacks river, to a point 1000 m west-northwest of the river junction, where the road bends sharply from a westerly to a southeasterly direction. The two sections are shown as stratigraphic columns in Fig. 14 and their location is shown in Fig. 15; they are described in Tables 8 and 9. The positions of the sections in a composite stratigraphic column of the Formation are shown in Fig. 6.

The chert unit is represented by beds of chert and impure chert 250 m thick, overlying the agglomerate in the 'Happy Jacks Road' section. This is not typical of the chert as developed farther north in the Tantangara Sheet area, and so, reference localities for the chert unit are proposed. The Racecourse Creek area is proposed for the lower part of the chert, including the agglomerate bed. A section extends across the strike from the eastern boundary at G.R. 389316 to about the position of the possible fold axis, near Chance Creek at G.R. 374321. The best exposures are along Racecourse Creek and near the crests of the steeper hills. The upper part of the unit is best exposed in the McPhersons Creek area, where it includes a few tuffaceous interbeds. A section across the strike runs south-southeast from the northern boundary of the chert unit at G.R. 403523. The bedrock is best exposed in outcrops on the steeper slopes and on the crests of ridges, especially from the mouth of McPhersons Creek southeastwards past Boundary Creek.

The chert of Dairymans Flat is probably typical of the middle part of the unit. The intercalated tuff is not, so far as is known, exposed elsewhere in the area mapped. A suggested correlation of the several reference localities is given in Fig. 13.




84 **Fig. 15. Locations of type section and other sections of the Temperance Chert.**

WAGGA WAGGA and TALLANGATTA 1:250 000 Sheet areas.

TABLE 8. TYPE SECTION OF TEMPERANCE CHERT

Location: Wagga Wagga 1:250 000 Sheet area (Fig. 15)

| Approx. dist. from ref. point (m) | Geographic description | Geological description; thin sections described in Table 10 |
|---|---|---|
| 0 | Start of section: on south side of Temperance Creek, 1100 m SE of Skeleton Creek. Longitude 148°28', latitude 35°59'19" on Snowy Mountain Authority topographic map (S.M.A., 1960). Section runs parallel to creek in downstream direction | Chert and impure chert; interbeds of siltstone-quartzite |
| 30 | | Large outcrop of very finely banded chert and cherty tuffaceous quartz siltstone |
| 170 | Opposite crest of spur | Interbedded tuff, chert and tuffaceous chert |
| 290 | SW from crest of spur | Massive banded chert; cherty silty greywacke and fine-grained cherty tuff (TS 72840267). Interbeds of very fine-grained quartz arenite or quartz greywacke, in part tuffaceous (TS 72840162) |
| 410 | Across gully that joins Temperance Creek | Tuff predominant |
| 430 | | Soil fragments of black slaty argillite and very fine-grained tuff |
| 650 | A minor spur, where creek curves W | Coarse tuff with clasts of andesite and chert up to 20 cm. Poorly exposed but probably extends for 100 m to E |
| 770 | Across minor gully that flows into Temperance Creek | Fragments of chert and tuff |
| 800 | | Chert and very fine-grained tuffaceous chert |
| 820 | End of section, opposite mouth of unnamed creek that flows into Temperance Creek from NE. Longitude 148°27'27", latitude 35°59'18" on Snowy Mountains Authority topographic map (S.M.A., 1960) | Inferred 'M-Bend' Fault. Tuff, tuffaceous chert and chert on E, soil on W |

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## TABLE 9. SUPPLEMENTARY REFERENCE SECTION OF TEMPERANCE CHERT (THE 'HAPPY JACKS ROAD' SECTION)

Location: Tallangatta and Wagga Wagga 1:250 000 Sheet areas (Fig. 15)

| Approx. distance (m) | Locality | Description (Thin section descriptions are given in Table 10) |
|---|---|---|
| 0 | Start of section: On Happy Jacks Road, at bridge over Tumut River. Road runs NNW and curves sharply to SW | Silty chert, and fine-grained tuff with thin interbeds of chert; banded and thin-bedded; small basic intrusions |
| 200 | 160 m SW of curve | Banded chert, tuff |
| 230 | | Cherty argillitic greywacke, tuffaceous greywacke, tuff, impure chert |
| 340 | Road curves W | Silty chert, chert, fine-grained tuff |
| 400 | Road curves WNW | |
| 460 | | Impure chert, fine-grained tuff |
| 530 | | Fine-grained tuff, in part sheared and slaty; cherty tuff. Banded tuff and chert |
| 640 | | Chert and tuff. The weathered chert has a porcellanous rather than a vitreous appearance. Bed of black slate (about 1 m). Black tuffaceous shale, fine-grained tuff and banded chert |
| 660 | Road curves to right | Agglomerate (decomposed) crosses road at start of curve |
| 700 | | Banded chert and tuff |
| 715 | | Agglomerate |
| 720 | Gully at righthand curve of road | Agglomerate (TS 72840212) |
| 750 | | Banded cherty siltstone, chert (weathered) |
| 760 | | Agglomerate |
| 840 | Halfway round curve to left | Banded chert or cherty siltstone |
| 860 | | Tuff, minor chert |
| 865 | | 'Quartz porphyry' (minor intrusion) |
| 890 | | Chert and cherty siltstone |
| 930 | Road crosses gully at curve to right | 'Quartz-porphyry' (minor intrusion) |
| 950 | | Bedded and banded chert |

TABLE 9 Continued

| Approx. distance (m) | Locality | Description (Thin section descriptions are given in Table 10) |
|---|---|---|
| 980 | | 'Quartz-porphyry (minor intrusion) |
| 1000 | | Chert, cherty siltstone |
| 1020 | | 'Quartz-porphyry' (minor intrusion) |
| 1060 | Part way around curve to left | Chert, cherty siltstone, fine-grained tuff |
| | End of curve | Finely banded chert, tuff, and cherty siltstone visible in road drain; chert probably predominates. Weathered outcrop at roadside appears to consist predominantly of tuff |
| 1170 | End of section, at sharp curve to left | Poor outcrop: tuff, tuffaceous chert, chert |

## TABLE 10. THIN SECTION DESCRIPTIONS FROM THE TEMPERANCE CHERT

TS 72840152. Temperance Creek, opposite mouth of Frenchmans Creek

Very fine-grained, finely banded, altered quartz argillite or quartz greywacke. Consisting of fibres of sericite (0.01 to 0.02 mm), scattered grains of quartz (mainly smaller than 0.01 mm), minute grains of epidote or zoisite, and a few small altered grains of plagioclase; the matrix is probably altered chert. The minor plagioclase and epidote are possibly of volcanic origin, either tuff or reworked andesite.

TS 72840162. Temperance Creek 1050 m east from Frenchmans Creek

Weathered, very fine-grained quartz arenite or quartz greywacke, with thin tuffaceous bands, consisting of 55% quartz about 0.01 to 0.02 mm across, epidote (about 15%), chlorite (about 5%), laths of tremolite 0.1 to 0.3 mm long, and small patches of carbonate and chlorite. The tremolite occurs in bands and may locally constitute 25% of the rock. Opaque grains of iron oxide, some apparently pseudomorphing sulphides, amount to about 3%.

TS 72840267. Same locality

A band of fine-grained tuff or silty tuff consists of andesite fragments 0.2 mm and smaller (40%) in a matrix of chert (60%).

TS 72840212. Agglomerate bed 600 m northwest of junction of Happy Jacks and Tumut Rivers

Crystal and lithic fragments of andesite tuff, 2 mm smaller is size; there is minor alteration to chlorite and epidote.

TS 72840257. Temperance Creek 1150 m southwest from Skeleton Creek

Interbedded pure and impure chert contains fine bands (0.02 to 2 mm) of pure chert, chert containing siltsize particles of quartz, fine-grained siltstone, tuff, and tuffaceous argillite. The argillitic bands of fine fibres of sericite, clusters and grains of chlorite, epidote and secondary amphibole, and detrital quartz. The quartz ranges in size from 0.02 to less than 0.01 mm. The rock is a fine-grained tuffaceous sediment deposited with chert in very quiet water.

ENVIRONMENT OF DEPOSITONION

The interbedded tuff, chert, and fine-grained clastic sediment low in the Temperance Chert suggest deposition at a considerable distance from any shore-line. In the area mapped, these deposits extend northwards from near the junction of the Happy Jacks and Tumut Rivers at least as far as the Boggy Plain Fault, and the Gooandra Inlier near Tantangara Plain. Contemporaneous deformation through slump-folding is common. Farther from the shore-line, the sea deepened significantly, as is suggested in Fig. 13. A great thickness of chert, almost free from clastic sediment, was deposited at Dairymans Plain and Boundary Creek.

Tectonic warping resulted in a southward migration of the deep part of the ocean floor to about the locality of Chance Creek, and deposition of chert above the basal interbedded tuff, chert, and clastic sediment. South of here, the ocean floor rose steeply to about the locality of Sawyers Hill, and then at a more moderate gradient to the locality of Happy Jacks and Tumut Rivers. Explosive eruptions on the fairly distant landmass provided numerous deposits of fine tuff between Happy Jacks River and Sawyers Hill; these became interbedded with chert and minor amounts of fine-grained clastic sediment. An eruption from a closer volcano provided the agglomerate at Racecourse Creek and Happy Jacks Road. Siliceous springs at the volcanic centres, and the release of silica from weathering pyroclastics are the presumed sources for the increasingly widespread deposition of chert.

Increasing proportions of clastic sediment interbedded with the chert and tuff in the upper part of the Temperance Chert suggests the emergence of a landmass. It may have been an island arc, consisting of fine-grained sediments and volcanic rocks, growing partly through uplift, and partly through the deposition of lava and pyroclastics. East of Peppercorn Creek, lava was extruded from a volcano that had probably built up sufficiently high to form an island. Increasing proportions of sediment and tuff mark the change from the Temperance Chert to the Nine Mile Volcanics

THICKNESS

The composite stratigraphic column for the Temperance Chert Formation compiled in Figure 6 shows an estimated thickness of 2000 m. This figure makes no allowance for repetition of beds by the tight folding at many localities; it indicates an upper limit to the possible thickness of the formation, and is probably much greater than the true thickness.

RELATIONS

The Temperance Chert rests conformably on the Bolton Beds, and passes up conformably into the Nine Mile Volcanics. These relations are shown in Figs. 6 and 15 for the outcrop of the formation along Happy Jacks Road and Temperance Creek; for the Tantangara Sheet area, it is illustrated in Figures 7 and 9.

AGE

Graptolites of Gisbornian age have been found in the upper part of the Nine Mile Volcanics (Opik, 1952; Moye, 1953); no other fossils are known in either the Temperance Chert or the underlying Bolton Beds. Opik (1952) suggests that the base of the Temperance Chert may be as old as Darriwillian.

ALTERNATIVE INTERPRETATION

Relations and Environment of Deposition

In the alternative interpretation of the structure of the area, the stratigraphic sequence is reversed: The interbedded sediment and tuff of the Nine Mile Volcanics is considered to be at the top of the volcanics, passing conformably into interbedded chert and tuff at the base of the Temperance Chert; the interbedded tuff and chert at the top of Temperance Chert would then pass conformably into the Bolton Beds. The thick chert unit was possibly deposited in a deep oceanic trough, contemporaneously with the middle part of the unit of interbedded chert and tuff. The lava and the tuff of the Nine Mile Volcanics were deposited when volcanic activity was most intense. The volcanism became intermittent at the time the interbedded sediment and tuff was deposited; it remained so throughout the deposition of the Temperance Chert, and ceased shortly thereafter.

Age

Under the alternative interpretation, assuming that the Bolton Beds are equivalent to the Nungar Beds of Eastonian age, a large part of the Nine Mile Volcanics and all of the Temperance Chert must have been deposited in the Gisbornian and perhaps part of the Eastonian. The time available for the deposition of these rock-units is very short. However, the apparent thickness is exaggerated by contemporaneous and subsequent deformation. Again the thickest units are the lava, tuff, and chert, and they could have been deposited very rapidly. If the alternative interpretation is correct, the base of the Temperance Chert would be at about the boundary between the Gisbornian and the Eastonian, and its top would be within the Eastonian.

## NINE MILE VOLCANICS
(D.E.G.)

### NOMENCLATURE

Fairbridge et al. (1951) mapped along the Tumut and Happy Jacks Rivers and their tributaries, a short distance west of the join of the Wagga Wagga, Tallangatta, Canberra, and Bega 1:250 000 Sheet areas. Fairbridge et al. gave the name 'Nine Mile Shale' to a sequence of 'dominantly argillaceous rock often tuffaceous, with some chert and minor quartzite...'. 'Also characteristic of the formation in the region of the junction of Nine Mile Creek and the Tumut are andesite flows'. They remarked that 'it was first thought appropriate to name this formation the "Nine Mile Tuff", but in view of the presence of many shales, slates, and schists not yet demonstrated to be positively tuffaceous the term "shale" is deemed more descriptive'.

Moye (1953) found that the sequence is dominantly andesitic, consisting of andesite tuffs, flows and igneous breccia, chert, shale, slate, and phyllite. He re-named it the 'Nine Mile Volcanics'. This name is adopted here.

### DERIVATION OF NAME

The name is derived from Nine Mile Creek, a tributary of the Tumut River, which it enters 2.7 km north-northwest of the mouth of the Happy Jacks River.

### REFERENCE SECTIONS

A type section designated by Fairbridge et al. (op. cit.) is along the valley of the Tumut River up and downstream from its junction with Nine Mile Creek'. Moye (1953), in a report on the geology of the Eucumbene-Tumut tunnel line, drew the boundary with the Temperance Chert across the Tumut River at the mouth of Temperance Creek. In the text of this report he states that the dividing line between the Nine Mile Volcanics and the Temperance Chert is not well defined, and is apparently gradational: 'The boundary is

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placed within a band of shales, slates, cherts, and tuffs, 1750 feet [500 m] wide at the surface which becomes increasingly tuffaceous to the west'. The main rock types at the surface, west from about tunnel Station 586 (Plate 1, this Record), is stated by Moye to consist of 2630 ft [800 m] of interbedded tuff, shale, and chert, followed by 1330 ft [400 m] chiefly of andesite in thick flows, andesitic igneous breccia and tuff, and some interbedded chert. The volcanic rocks end at a belt of intrusive igneous rocks about 150 m wide, which are succeeded on the west by Silurian Tumut Pond Beds.

The type section given by Fairbridge et al. is generalized and the boundaries of the volcanics are not defined. Moreover, a considerable thickness of lava that crops out in the Tantangara 1:100 000 Sheet area is not present in the area described by both Fairbridge et al. and Moye; presumably it has been faulted out against the Tumut Pond Beds. For these reasons, reference sections are proposed to supplement the original type section of Fairbridge's 'Nine Mile Shale'. A section through a basal unit of sediment and tuff, and another through the overlying tuff unit are exposed in the Tallangatta 1:250 000 Sheet area along Happy Jacks Road west of the junction of the Happy Jacks and the Tumut Rivers. Reference sections of the lower and the upper parts of the lava unit are shown on the Tantangarra 1:100 000 Sheet. The reference sections are described in a separate section of this Record; they are illustrated diagrammatically and their locations shown in the text figures listed in Table 11.

TABLE 11. REFERENCE SECTIONS OF THE NINE MILE VOLCANICS

| Lithological unit | Illustration (Fig.) | Location (Fig.) |
|---|---|---|
| Sediment and tuff | 18 | 19 |
| Tuff | 20 | 21 |
| Upper half of lava unit | 16 | 22 |
| Lower half of lava unit | 16 | 22 |

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## LITHOLOGY

The Nine Mile Volcanics includes three lithological units: the lowest consists of interbedded clastic sediment, andesitic tuff, and chert; the middle unit is of tuff and subordinate sediment; and the upper of andesitic lava with some interbedded tuff and minor sediment. Along the Happy Jacks and Tumut Rivers the three units form a continuous depositional sequence which rests conformably on the Temperance Chert; the boundary with the Temperance Chert crosses the Happy Jacks Road at a point 5500 m west of the southwest corner of the Tantangara Sheet area. Within the area of this map, the Nine Mile Volcanics extends northwards from Chance Creek through Long Plain, and past the eastern side of Peppercorn Hill to Little Peppercorn Creek. The outcrop area is fairly broad in the south, but it becomes narrower northwards as the Long Plain Fault is approached; north of Rules Point, the volcanics are restricted to narrow fault-blocks. In the map area, outcrops of the two sediment and tuff units tend to be poor and highly weathered. The lava commonly forms large oval outcrops, elongated in the direction of flow-banding and foliation. The sediment and tuff unit are well exposed in cuttings along Happy Jacks Road.

### Sediment and tuff (Oks)

Along Happy Jacks Road, the unit of interbedded sediment and tuff crops out in a belt about 350 m wide. In the Tantangara Sheet area, it crops out in small fault-blocks, one along Chance Creek, another west of the junction of Tantangara Creek with the Murrumbidgee River, and several along the eastern side of the Long Plain Fault from Rules Point northward to 3 km northeast of Peppercorn Hill. At some localities the sediment and tuff unit rests conformably on the interbedded tuff and chert of the Temperance Chert, and at some it passes up gradationally into the tuff unit.

#### Tallangatta 1:250 000 Sheet area

Happy Jacks Road. The sequence exposed along Happy Jacks Road is proposed as a reference section for this unit, and is summarized in Fig. 18. It consists of interbedded sediment and tuff with sediment predominant above the basal 70 m. The basal dominantly tuffaceous sequence starts with a 2-m bed of black shale, followed by thin bands of tuffaceous quartz arenite, dark siltstone, shale, chert, and impure chert; these are interbedded with andesitic tuff. Some argillitic beds are very finely banded and cherty, and locally have been intricately folded through pene-contemporaneous deformation. The predominant

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rocks above this tuffaceous sequence are fine-grained quartz arenite, siltstone, shale and silty shale, chert and impure chert. Recurring sequences of arenitic and argillitic sediment suggest cyclic deposition throughout the section, and the sequences are interbedded with tuff. Argillitic beds possibly predominate for 200 m, and then arenitic beds for the remaining 100 m at the top of the unit. This unit of sediment and tuff grades up into the tuff unit; the boundary has been drawn at the level where tuff becomes predominant in the sequence; this is 1000 m west of the junction of the Happy Jacks and Tumut Rivers.

Tantangara 1:100 000 Sheet area

In this area, the interbedded tuff and sediment are only poorly exposed in road cuttings and on the steeper slopes. At most localities, the boundaries shown are therefore approximate, drawn on the basis of small weathered outcrops, and of rock fragments in the soil. Where chert occurs but other sedimentary rocks are lacking, either in outcrop or in the soil, the bedrock has been assumed to be the Temperance Chert. The presence of clastic sedimentary rocks has been taken to indicate the unit of interbedded sediment and tuff, while exclusively tuffaceous outcrops or fragments have defined the area of the tuff unit.

Away from the section along Happy Jacks Road, the sedimentary unit where exposed contains more chert and less interbedded sediment; tuff remains a prominent component. Lithologically, the lower part of the unit is not markedly different from the interbedded tuff and chert of the Temperance Chert; the boundary between the two is placed where sedimentary interbeds enter the sequence, and is only approximately located in areas of poor outcrop. Probably the sediment and tuff passes up into the tuff unit, as at the type locality, by an increase in the proportion of tuff. However, this lithological change becomes indistinct away from the type area, and in some places the tuff unit has not been distinguished.

Chance Creek. Near Chance Creek, samples from G.R. 359312 consist of altered fine-grained andesite tuff which contains a small proportion of silt-size detrital quartz, tuffaceous altered argillite (sericite, chlorite, and minor epidote), and tuffaceous quartz siltstone. A sample from G.R. 358314, 200 m to the west-northwest, consists of sheared chert which is slightly tuffaceous, silty, and argillitic. At a short distance from the creek there is little outcrop; the approximate boundary with the tuff unit is based on the presence of fragments of tuff in the soil.

Tantangara Creek to Rules Point. About 600 m west of the junction of Tantangara Creek with the Murrumbidgee River a narrow, northward elongate wedge of the unit of interbedded sediment and tuff is thought to be bounded on the west by a reverse fault and on the east by a normal fault. It contains interbedded chert and impure chert, cherty tuff, quartz arenite, and siltstone. From the northern end of this wedge, northwards to about the latitude of Rules Point, the unit of interbedded sediment and tuff forms an outcrop area that is essentially continuous, although displaced by faults. In a southern fault-block that includes G.R. 394430, the unit appears to pass conformably into the tuff unit; in two fault-blocks to the north, it rests apparently conformably on interbedded tuff and chert of the tuffaceous unit of the Temperance Chert. The outcrop areas shown on the map have a width, across the strike, of at least 1000 m; this seems to be excessive in comparison with the type area, even though the unit was probably 'thickened' by greater deposition of chert. The lithologies of the upper and lower beds of this unit here resemble, respectively, those of the units above and below. Possible the eastern part of this middle area should have been mapped as the underlying unit, the interbedded tuff and chert of the Temperance Chert, while the western half of the northern and southern areas could be the overlying unit, the tuff unit of the Volcanics.

The tuff-sediment unit in this belt consists of interbedded tuff, fine-grained quartzite, quartz siltstone, chert, and very fine-grained siliceous quartz argillite or greywacke. Tuff and cherty tuff predominate near the top and impure chert, tuff, and chert lower down. There are small outcrops of quartzite and quartz arenite, for example at G.R. 400437, and of very fine-grained quartzite or siltstone at G.R. 392453. Generally the sedimentary interbeds are finely banded, siliceous, and very fine-grained; they were not clearly distinguishable in the field from banded fine-grained cherty tuff.

At G.R. 395445, 2 km southeast of Rules Point, a finely banded rock consists of alternating laminae less than half a millimetre to a few millimetres thick of fine-grained andesitic arenite, andesitic siltstone, and chert; the matrix in the clastic layers is chert.

Long Plain. Farther north, in the Long Plain, the sedimentary unit is present in small fault-blocks within the Long Plain Fault system, with bounding faults trending both north-northeast and northeast. In the southernmost fault-block, northeast of Rules Point, fine-grained siliceous sediment forms good outcrops in the east bank of the river, where it is crossed by a road that runs east, south of Boundary Creek. East and northeast of Jennetts Hut the unit consists of a sequence of tuff, argillitic quartz-arenite or greywacke, argillite, quartzite, impure chert, and chert. In a thin section (TS 71840369, G.R. 408504) from an outcrop 1200 m northeast of the hut, bands of tuffaceous chert 0.2 to 3.2 mm (and one of 7.8 mm) thick alternate with bands of argillite 0.1 to 1.7 mm thick. There is one band of chert and a few of argillitic chert 0.4 to 1.7 mm thick. The tuffaceous bands consist of crystal fragments of andesitic origin, embedded in chert. In the coarser bands these fragments are 0.2 to 0.4 mm across and amount to about 40 percent of the band; minor mafic constituents are altered to epidote and chlorite. In the finer bands, the crystal fragments are about 0.02 mm and smaller, and form 20 percent or less of the band. The argillite is altered to isolate or aggregate fibres (0.02 mm) os sericite (about 30%), clear grains of quartz with ragged boundaries (about 40%), minor feldspar, and a chert matrix (about 30%). The argillaceous chert consists of fibres of sericite (10-30%) with feldspar and quartz (up to 20%) in a matrix of chert (60-80%). The chert has a dusty appearance, because of submicroscopic inclusions.

An outcrop at G.R. 414518, about 2500 m north-northeast of Jennetts Hut, is seen in thin section to be an altered cherty, silty quartz argillite or greywacke; it consisted initially of andesite dust, argillaceous sediment, and silt-size particles of detrital quartz, all in a matrix of chert.

North of McPhersons Creek. North of McPhersons Creek, the unit in a large area of outcrop rests conformably on the Temperance Chert. It consists of tuff, tuffaceous quartz siltstone, silty quartz argillite, fine-grained quartzite, chert, and impure chert. The area was not mapped in detail. Its width, 800 m from base to faulted upper boundary, across beds that dip very steeply, is large in comparison with the width of outcrop in the type area, and suggests that the sediment and tuff unit probably passes into the tuff unit before the faulted boundary is reached. To the west and north, small fault-blocks along the Long Plain Fault are almost entirely obscured by soil; the few weathered outcrops consist of andesitic rock, (presumably tuff), chert, impure chert, and minor quartz-arenite and siltstone. Their location on the western (downthrown) side of the fault indicates that they are younger than the Temperance Chert; given that, their lithology places them in either the sediment and tuff unit or in the tuff unit.

East of Peppercorn Hill. East of Peppercorn Hill, the basal unit of the volcanics in some places rests conformably on, and in other places is faulted against, the Temperance Chert. It is overlain conformably by the tuff unit, and at the northern limit of outcrop is unconformable beneath the Middle Silurian Peppercorn Beds. Vertical cleavage, striking at 200-210°, is well developed. The lower beds, best exposed at G.R. 459617, consist of fine-grained tuffaceous sandstone, weathering to pale brown, and siltstone interbedded with 20-cm beds of black and pyritic chert. Beds presumed to be higher in the unit are faulted against the tuff unit on their eastern side, and against the Silurian Goobarragandra Beds on the west. The best outcrop, at G.R. 450603, consists of grey-black cherty shale.

## Tuff Unit (Okt)

### Tallangatta 1:250 000 Sheet area

Happy Jacks Road. The tuff unit is well exposed for about 1250 m along Happy Jacks Road, and this section is designated the reference section for the unit (Fig. 20). As the beds commonly dip at 80° or more, the total thickness is about 1250 m. The unit consists of tuff, with some interbedded sediment. The basal 100 m consists of thick-bedded tuff and fine to medium-grained banded tuff, with interbeds of tuffaceous greywacke, shale, impure chert, and chert. This is followed by about 100 m of bedded and banded tuff, with only two beds of shale each about 1 m thick. This is overlain by a 700-m thick predominantly tuffaceous sequence that extends to about 900 m above the base of the unit; it consists of bedded and banded tuff, tuffaceous greywacke and quartz greywacke, cherty greywacke, quartz siltstone, fine-grained quartz arenite, and minor thin beds of chert. For ease of reference, this 700-m sequence will be termed the 'tuff-greywacke'. The cherty and quartzose beds in it are very hard and brittle, while the tuff is mostly cleaved and in places slaty. The greywacke consists of poorly sorted angular grains of quartz and rare feldspar with the size-range of silt to fine sand in an abundant argillitic matrix; it is thinbedded and finely banded, and shows contemporaneous deformation. Thin beds of chert are sparingly present in the lower 400 m of the tuff-greywacke, and tuffaceous chert persists to the top. From 400 to 550 m above the base of the tuff-greywacke, layers of bedded tuff several metres thick alternate with equally thick layers of interbedded sediment and tuff. The tuff is medium to fine-grained, and is generally sheared or cleaved. The interbedded layers of sediment and tuff consist typically of tuffaceous greywacke, tuff, tuffaceous chert, and tuffaceous quartz arenite. Above this interval, thinner layers of interbedded sediment and tuff alternate with thicker tuff layers through a thickness of about 150 m. The tuff-greywacke is overlain by bedded tuff nearly 150 m thick, above which again appear interbeds of banded tuffaceous greywacke and some dark shale, all well exposed in a roadside quarry. About 20 m or so west of the quarry, the interbedded tuff and sediment gives place to nearly 100 m of tuff at the top of the unit. Ths is conformably overlain by lava and tuff of the lava unit.

Tantangara 1:100 000 Sheet area

Within the Tantangara Sheet area the tuff unit forms small outcrop areas, partly bounded by faults, on the western side of the Murrumbidgee River southeast and northeast of Rules Point, and from the northern end of Long Plain northwards past the eastern side of Peppercorn Hill to Little Peppercorn Creek. Possible small areas occur farther south near Charcoal Creek, towards the western edge of the Sheet area.

Near Rules Point. Southeast of Rules Point, the eastern margin of the tuff is thought to show a conformable transition into the interbedded sediment and tuff that form the basal unit of the formation. The western boundary is concealed beneath basalt, but is considered to be a faulted contact with the lava unit. In this region the tuff is a fine to medium-grained andesitic rock, generally deeply weathered but recognizably tuffaceous at two localities where it is bedded and laminated (e.g. G.R. 389418).

Northeast of Rules Point, one narrow belt of andesitic rock appears to pass conformably westward into the overlying lava unit, and another is faulted against the lava; on their eastern sides, both belts are faulted aginast the basal unit of the volcanics. In these narrow outcrop belts weathered fine-grained andesitic rock is clearly tuffaceous at the few good exposures where bedding is visible; it is assumed that the remaining poor outcrops are similarly tuffaceous.

Long Plain. In the northern half of Long Plain, west of Skains Hill, outcrops are poor and deeply weathered, and detailed mapping was not done. Outcrop areas which appeared to be of tuff are interpreted as small fault-blocks, faulted against the unit of sediment and tuff on their eastern side, and against Silurian Goobarragandra Beds in the west. Between the northern end of Long Plain and Little Peppercorn Creek, the tuff forms good outcrops up to 20 m across. It overlies the basal unit of the volcanics, and is unconformably overlain by the Silurian Peppercorn Beds.

Charcoal Creek. There are possible outcrops of the tuff unit farther south, but they have not been mapped separately from the lava unit; the areas in which they occur are faulted down against the Temperance Chert to the east; in the west they are either conformable with the lava unit, or lie within it. Exposures are poor and deeply weathered. The rock is fine-grained and sheared or cleaved; it is finely banded at Chance Creek (G.R. 364320), and indistinctly bedded at Charcoal Creek (G.R. 367332); in the upper part of Gooandra Creek (G.R. 379353), the apparent bedding is almost obscured by shearing. Nearby outcrops with a porphyritic appearance, such as at G.R. 365336 near Charcoal Creek and G.R. 371334 near the source of Gooandra Creek, represent lava flows; the tuffaceous-looking outcrops could be of sheared flow-banded lava, or tuff interbedded with the lava, or may be part of the tuff unit, conformably overlain by the lava.

## Lava unit (Okl)

Besides andesitic lava, this unit contains interbedded flow-breccia and tuff, and a thin bed of black slate with associated siltstone and arenite. The base of the unit is exposed along Happy Jacks road, and a thick section which probably includes the base can be seen within the Tantangara Sheet area.

### Tallangatta 1:250 000 Sheet area

Happy Jacks Road. Along Happy Jacks Road interbedded lava and tuff rest conformably on the tuff unit about 2250 m west of the junction of the Happy Jacks and Tumut Rivers. A thickness of 450 m is exposed; the higher part of the section, west of this licality, is covered by Tertiary basalt. The rock in the road cutting is deeply weathered; together with the foliation, this makes it difficult to distinguish between lava and massive or thick-bedded tuff. Graptolitic slate is interbedded with the andesites 1100 m west of the junction of Nine Mile Creek with the Tumut River (Moye, 1953).

### Tantangara 1:100 000 Sheet area

The lava unit extends into the Tantangara Sheet area along a faulted boundary at Chance Creek and extends to the north-northeast and north. The unit is bounded on the northwest by the Long Plain Fault which crosses into the Sheet area north of Bullock Hill; several hundred metres north of Rules Point, a cross-fault cuts off the unit. At Chance Creek the lava is faulted against the sediment and tuff unit of the volcanics; from there northwards to a major northeasterly-trending fault east of Bullock Hill, it is faulted against the Temperance Chert. North of Bullock Hill, it is in part faulted against, and in part rests conformably on, the tuff unit of the volcanics.

The lower half of the unit is made up almost entirely of andesite lava, and the upper half of lava and flow-breccia. For convenience, the lower half will be termed the 'andesite belt', and the upper half the 'breccia belt'. Interbedded with these volcanic rocks are minor layers of andesitic arenite in the breccia belt; throughout the unit there are thin beds of argillitic greywacke or quartz arenite, slate, and chert.

Tuffaceous-looking outcrops are interbedded with the andesite at several localities between Chance Creek and the head of Gooandra Creek, and

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resemble the weathered outcrops along Happy Jacks Road. A tuffaceous bed near the base, shown in Table 17 which illustrates the reference section of the lower half of the lava unit, is correlated with a similar bed in the section at Happy Jacks River.

'Andesite belt'

The andesite belt which forms the lower half of the lava unit is about 1.5 km wide; it extends north-northeasterly from Chance Creek to the western edge of Tantangara Plain, where it is faulted against tuff and chert of the Temperance Chert Formation. It appears again in a downfaulted block west of Bullock Hill, and north of the hill to about Rules Point.

Chance Creek to Tantangara Plain. South of the northwesterly-flowing upper part of Gooandra Creek, the andesite belt consists of fine to medium-grained andesite lava, both porphyritic and equigranular. North of the creek there is a narrow bed of flow-breccia about the middle of the andesite. Porphyritic andesite at G.R. 383368 consists of feldspar phenocrysts up to 1.0 mm long in a matrix of flow-orientated feldspar laths 0.1 to 0.2 mm long. This is typical of flows that are obviously porphyritic in outcrop; similar porphyritic lava is seen in the south at G.R. 365327. Fine-grained porphyritic andesite crops out at G.R. 391363 and at G.R. 361333 in the south. In the north, east of the boundary with the main flow-breccia belt, medium-grained holocrystalline nonporphyritic lava forms a belt about 400 m wide.

Flow-banding is present in the lava at many localities; it is seen in porphyritic andesite at G.R. 364316 in the south and G.R. 391363 (Table 12, TS 71840101) in the north. Measurements at four localities give dips of about 50° to 290° - 315°; more often the banding is masked by shearing or foliation, as at G.R. 376353, and the attitude cannot be determined. The lava may be finely banded as in the fine-grained andesite at G.R. 366132, or forms massive outcrops 5 to 6 m across such as the porphyritic andesite at G.R. 363318.

Sedimentary rocks are not common in the andesite belt. Well bedded fine to medium-grained arenite probably of tuffaceous origin crops out in the south at G.R. 373346. In the north a thin layer of fine-grained argillitic greywacke and slate trends north-northeast through G.R. 380367 and 382364; it rests on a thick flow of mediumgrained porphyritic andesite and is overlain by a similar though finer-grained flow. Laminae of andesitic grains, silt-size and smaller, are possibly tuffaceous; alternatively they could represent

## TABLE 12. THIN SECTIONS FROM THE ANDESITE BELT

| TS 71840098 GR 380365 | Andesite | Percentage |
|---|---|---|
| Texture: | Flow-banded, porphyritic | |
| Phenocrysts: | plagioclase, sericitized, to 8 mm | 20 |
| Matrix: | Plagioclase, sericitized 0.v5 - 0.1 mm | 55 |
| | Chlorite, epidote, opaques | 20 |

| TS 71840099 G.R. 381368 | Tuffaceous argillite | |
|---|---|---|
| Texture: | Laminated, granular, with fine matrix; laminae 1 - 4 mm | |
| Grains: | Fragments of sericitized andesite, in places altered to calcite. Some laminae fine-grained, grains less than 0.2 mm; others coarser, grains not more than 0.4 mm | 20 - 40 |
| Matrix: | Minute particles of altered andesite, chlorite, epidote, quartz, sericite, and chert | 50 - 70 |
| | Amorphous and cryptocrystalline material | 10 |

The rock is a tuffaceous argillite, or an argillite in which fine fragments of flow-breccia have been deposited.

| TS 71840101 G.R. 391363 | Andesite | |
|---|---|---|
| Texture: | Granular, flow-banded, cleaved | |
| Phenocrysts: | plagioclase not more than 2 mm, commonly 1 mm | 10 |
| Matrix: | Plagioclase laths, 0.2 mm | 60 |
| | Intersitial chlorite, opaques, and epidote | 35 |
| | Quartz | 1 |

| TS 71840509 G.R. 378371 | Andesite | |
|---|---|---|
| Texture: | Matrix with aligned laths (flow-banding) | |
| Phenocrysts: | Plagioclase (andesine) to 2.5 mm | 10 |
| Matrix: | Plagioclase laths mildly sericitized, 0.1 mm | 75 |
| | Chlorite | 14 |
| | Minor epidote and opaques | 1 |

Rock traversed by several small veins of quartz redistributed fine particles of flow-breccia. The slate bands are possibly at the same level as the graptolite slate 1100 m west of the junction of Nine Mile Creek with the Tumut River. Farther north at G.R. 388384, probably in the same layer of fine sediment, a finely banded siliceous or cherty andesite tuff or siltstone displays intricate slump-folding suggestive of a turbidite. At G.R. 384379, finely banded fine-grained tuff and thinbedded medium-grained tuff or arenite are interbedded. Three separate measurements of bedding attitude are similar; dips range from 60 to 70° and direction of dip from 270 to 280°.

West and north of Bullock Hill. On the western and northwestern sides of Bullock Hill, and east of Rules Point, the andesite belt consists mainly of fine-grained lava, not obviously porphyritic; medium-grained and porphyritic lava are subordinate. The andesite is nearly all fine-grained west of Bullock Hill and in the Murrumbidgee River valley near Rules Point, where some is amygdaloidal. At G.R. 385459 and 389463, 500 m west of the river, the andesite is porphyritic and fine and medium-grained. Northeast of Bullock Hill the andesite is medium-grained with minor fine-grained and porphyritic bands. West of a spur of Tertiary basalt that runs north from Bullock Hill, the andesites have a width across the strike of about 2000 m. The western 1000 m of this, along the faulted western boundary, was not closely examined; presumably within this area the andesite belt passes upwards into the breccia belt.

'Breccia belt'

The lava and flow-breccia forming the breccia belt rest conformably on the andesite belt from Charcoal Creek north-northwest for 6 km, as far as a large easterly-flowing tributary of Gooandra Creek. North of the tributary, and on the western side of Gooandra Creek the outcrop is covered by colluvium and Tertiary basalt scree. The lava in the breccia belt is pale-coloured and predominantly fine-grained, with few phenocrysts; noticeably porphyritic lava, such as at G.R. 369351, and medium-grained equigranular lava, e.g. at G.R. 375365 are subordinate. In the lower part of the breccia belt the lava is vesicular; an outcrop of this was found at G.R. 363344. Near the boundary with the andesite belt is a northeasterly-trending fine-grained porphyritic lava; a sample from G.R. 378371 consists of sparse feldspar phenocrysts, up to 1.5 mm, in a matrix of feldspar laths about 0.1 mm long. The rock is not obviously porphyritic in outcrop. Throughout, the lava contains bands or beds and incorporated fragments of flow-breccia that range in size from 10 cm at G.R. 375369 to 25 cm at G.R. 380372; at several localities the fragments are rounded, and range from granules and pebbles at G.R. 370351 to cobbles 15 cm across at G.R. 376370. If much larger blocks of andesite, larger than the joint-spacing of most outcrops, are incorporated in this breccia they would be difficult to recognise.

The larger breccia fragments are commonly elongated in the direction of foliation of the rock; where they are rounded they simulate a tectonically 'stretched' conglomerate. The orientation of the fragments is presumably a response to tectonic stress; their elongation need not have been.

TABLE 13. THIN SECTIONS FROM THE BRECCIA BELT

| TS 71840105 GR 370351 | | Percentage |
|---|---|---|
| Texture: | Porphyritic; indistinct flow-banding | 7 |
| Phenocrysts: | Plagioclase, 1 mm | |
| | Clinopyroxene 3 mm (and chlorite) | 1 |
| Matrix: | Plagioclase laths 0.1 - 0.2 mm, felted, indistinctly banded | 80 |
| | Pyroxene and epidote, irregular grains | 10 |
| | Quartz, interstitial | 1 |
| **TS 71840106 GR 367354** | | |
| Texture: | Granular, with devitrified matrix; flow banded; veined with quartz | |
| Grains: | Plagioclase in small laths 0.1 - 0.2 mm | 45 |
| | Epidote, chlorite | 25 |
| | Quartz, in large patch surrounded by resorbed edges (?volcanic breccia) | 5 |
| Matrix: | Devitrified glass | 20 |
| **TS 71840122 GR 358343** | | |
| Texture: | Porphyritic; indistinct flow banding; quartz veining | |
| Phenocrysts: | Plagioclase not more than 2 mm; shows undulose extinction and granulation | 3 |

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TABLE 13 Continued

| | | |
|---|---|---|
| Matrix: | Plagioclase laths 0.05 - 0.1 mm | 65 |
| | Chlorite | 20 |
| | Epidote | 10 |

TS 71840508 GR 375369

| | | |
|---|---|---|
| Texture: | Granular, with sparse matrix | |
| Grains: | Plagioclase 0.4 mm | 70 |
| Matrix: | Actinolite and epidote | 20 |
| | Opaques | 5 |
| | Quartz | 1 |

The large clasts are accompanied by smaller fragments, down to sand-size and probably silt-size; some have been incorporated in the lava (Table 13, TS 71840106) while others appear to have been water-sorted and re-deposited, for example as thin-bedded arenite at G.R. 353339.

In places the lava appears to be devoid of directional structures; at G.R. 370351, a 4 x 3 m outcrop shows no sign of banding; vesicular lava at G.R. 371353 appear massive in outcrops. At other places, an indistinct banding can be recognized, as at G.R. 358343 and 375365 where there is a slight textural banding, but the attitude is masked by foliation. The attitude could be measured by alignment of vesicles at G.R. 371360 dip 70° towards 295° and by banding of lava adjacent to flow-breccia at G.R. 354358 dip 65° towards 280°.

A stratigraphic column of the lava unit is given in Figure 16; it is made up from the type section along Happy Jacks Road, two supplementary reference sections near Gooandra homestead and the uppper part of Gooandra Creek, a 'Eucumbene' section that crosses the headwaters of the Eucumbene River, and a 'Bullock Hill Saddle' Section at a topographic saddle on the southwestern side of Bullock Hill. Summary descriptions of outcrops along the reference sections are given in Tables 17 and 18, and along the 'Eucumbene' section in Table 14. There is practically no outcrop along the 'Bullock Hill Saddle' section line. A decomposed outcrop below the basalt at G.R. 359387

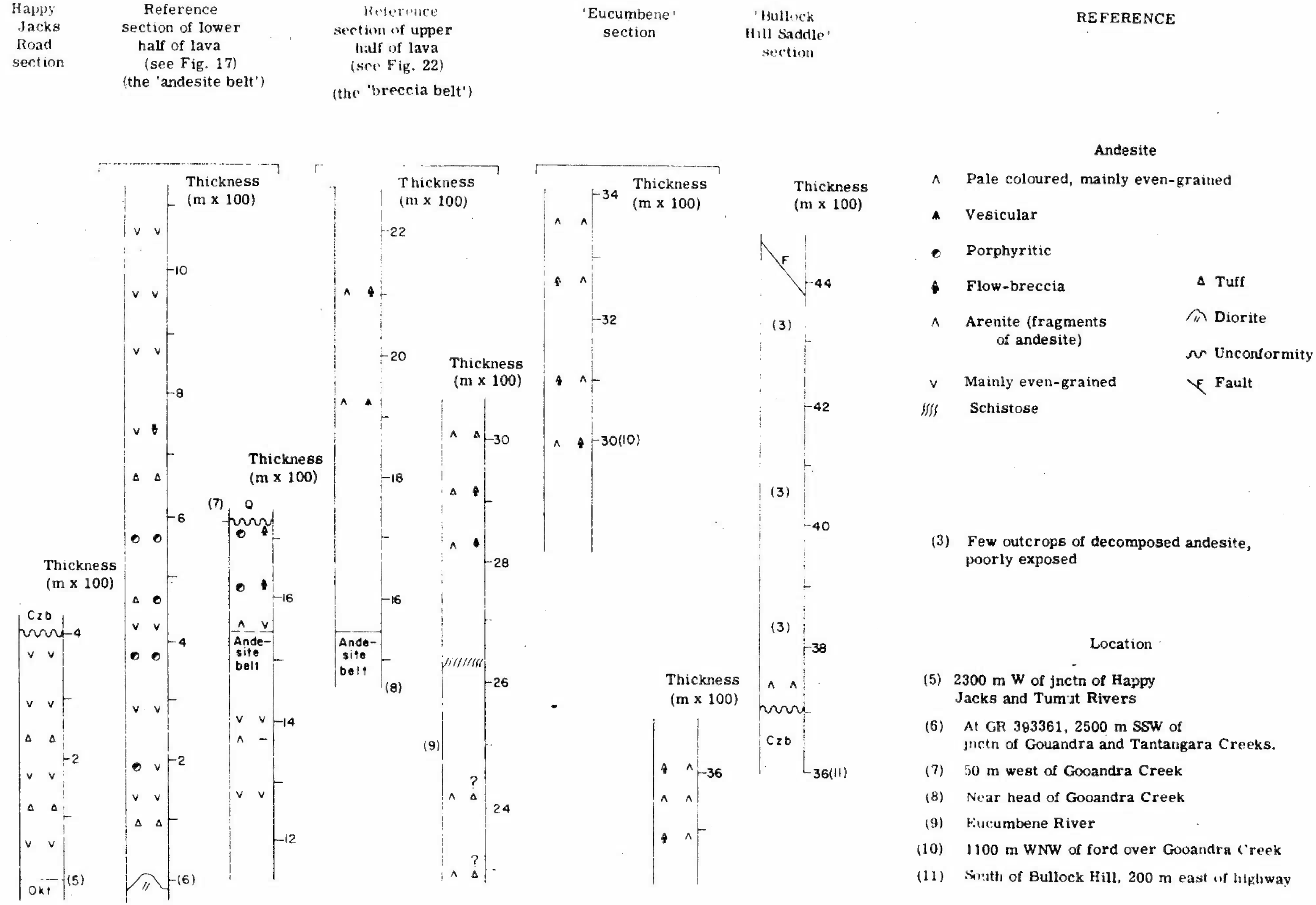


FIG. 16. Stratigraphic sections of lava unit (Okl).

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M(S)312

consists of sheared andesite; it is 200 m above the top of the 'Eucumbene' section, projected along strike, and 900 m east of the faulted boundary with andesite of the andesite belt. The section along Happy Jacks Road consists of both lava and interbedded tuff, but deeply weathered and foliated or cleaved, and not readily distinguishable. At slightly more than 400 m from the base, the section is obscured by Tertiary basalt.

## TABLE 14. THE 'EUCUMBENE' SECTION NINE MILE VOLCANICS

Location: Tantangara 1:100 000 Sheet area, near source of Eucumbene River, starting 650 m northeast of mouth of tributary (Fig. 22)

| Reference Points (Fig. 22) | Geological Description |
|---|---|
| Start of section: On slope below ridge of Tertiary basalt (and gravel) Section runs 312°. | Colluvium |
| At 200 m: On strike with top of reference section of upper half of lava unit | Flow-breccia; fragments generally smaller than 10 cm; banded ?lava and bedded andesitic fragments of the size of small sand (probably water-sorted and deposited after fragmentation) |
| At 550 m turns to 342° | Banded flow-breccia (and ?lava); resembles tuff, fine to coarse-grained |
| At 200 m after turn; end of section-line | Flow-breccia in fragments to 15 cm, with banded ?lava and beds of finely granular andesite fragments |

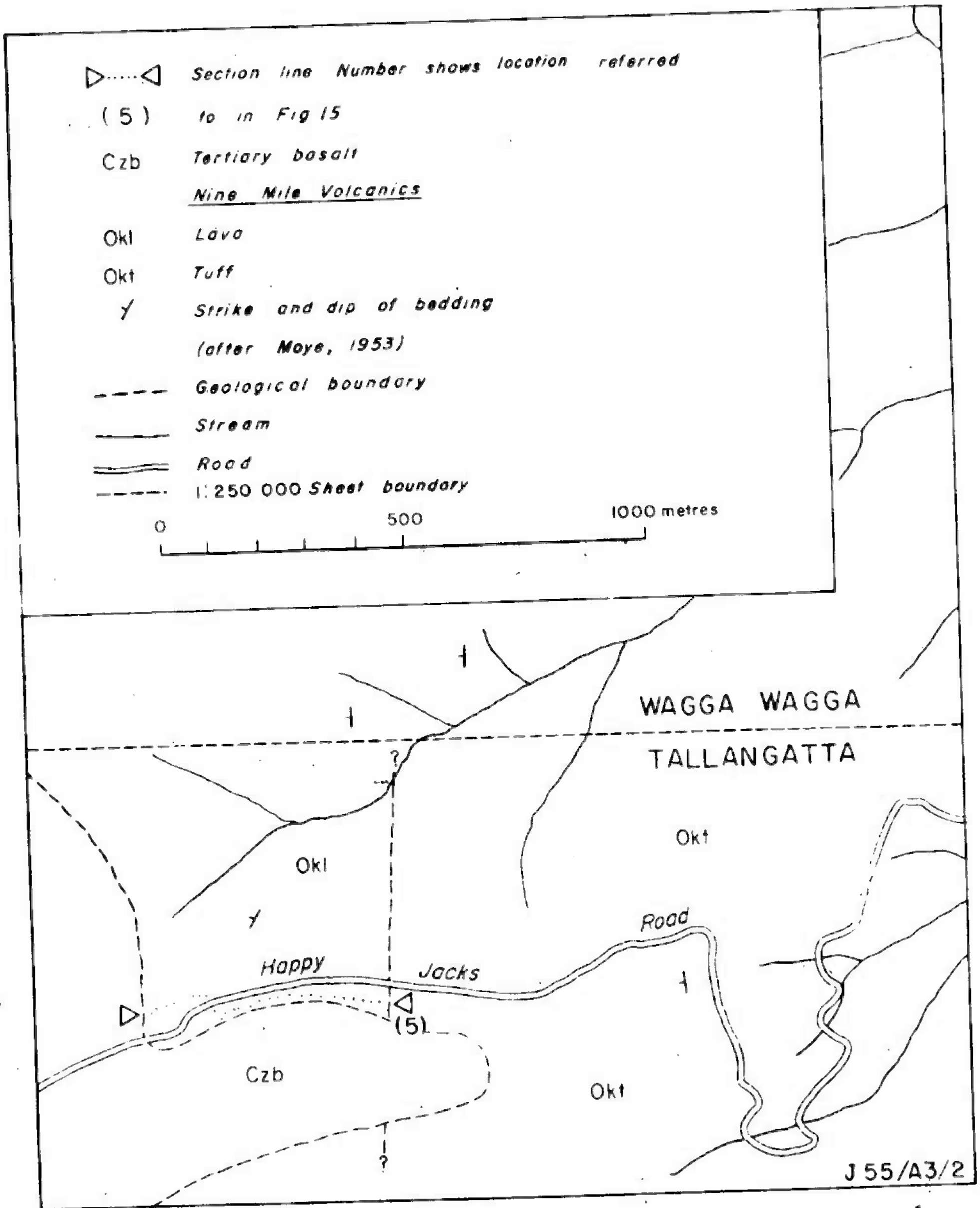


**Fig.17. Location of section of basal part of lava unit along Happy Jacks Road.** (see Pl.1)
TALLANGATTA 1:250 000 Sheet rea

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## REFERENCE SECTIONS

The three lithological units of the Nine Mile Volcanics are illustrated by reference sections, which supplement the type section of the 'Nine Mile Shale', designed by Fairbridge et al. (1951). The interbedded sediment and tuff, and part of the lava are exposed along Happy Jacks Road in the Tallangatta 1:250 000 Sheet area. Two reference sections are given for the lava unit in the Tantangara 1:100 000 Sheet area: one for the lower half of the unit is located a short distance south of Gooandra homestead; that for the upper half of the unit starts near the source of Gooandra Creek.

### Sediment and tuff (Oks)

The reference section of the interbedded sediment and tuff is shown diagrammatically in Fig. 18 and its locality in Fig 19. Its base is 650 m west of the junction of the Happy Jacks and Tumut Rivers, where the road heads westerly after a sharp bend from a southeasterly direction. The section extends for 350 m across beds that dip at angles of 80° and steeper; this gives a thickness of about 345 m. The section starts with a bed of black shale 2 m thick, overlain by 70 m of tuff and thin interbeds of clastic sediment and chert. In the remaining 273 m, the sedimentary beds are generally predominant over the tuff except for thin intervals at about 150, 200, and 250 m above the base. The sediments are mainly thin-bedded and banded. They consist of fine-grained quartz arenite and siltstone, tuffaceous and cherty quartz arenite, silty shale and shale, chert with or without varying proportions of argillitic and arenitic sediment, and tuff. Many beds show contemporaneous deformation. A summary description of the bedrock exposed along the section-line is given in Table 15.

### Tuff (Okt)

The reference section of the tuff unit is shown diagrammatically in Figure 20, and its locality in Figure 21; a summary description of the exposures along the section-line is given in Table 16. The base of the unit is exposed on Happy Jacks Road at a point 1000 m west of the junction of the Happy Jacks and Tumut Rivers; there, tuff replaces sediment as the dominant rock type. The section is 1275 m long across the strike of the beds; dips of 80° and steeper indicate a thickness of at least 1250 m. Sedimentary beds up to several metres thick are interbedded with the tuff except in the intervals

More detailed information on the lithology is given in Table 15

**REFERENCE**

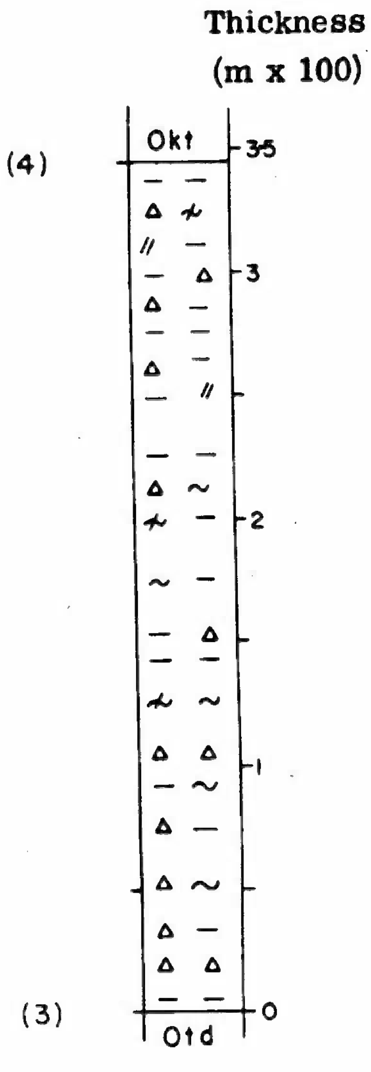
_ Clastic sediment

~ Chert

≁ Impure chert

△ Tuff

// Minor intrusions of quartz porphyry




Okt Tuff unit of Nine Mile Volcanics

Otd Interbedded tuff and chert of Temperance Chert

Location

(3) 650 m W of junction of Happy Jacks and Tumut River

(4) 1100 m W of junction of rivers

Fig. 18 Reference section of interbedded sediment and tuff

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## TABLE 15. REFERENCE SECTION OF INTERBEDDED SEDIMENT AND TUFF

Location: Tallangatta 1:250 000 Sheet area, on Happy Jacks Road, starting 650 m west of the junction of the Happy Jacks and Tumut Rivers. (Fig. 19)

| Approx. distance along road (m) | Road features | Geological description |
|---|---|---|
| 0 | Around sharp bend in road from SE to W | Black fissile shale 2 m thick, intercalated in tuff |
| 20 | | Mainly tuff, fine to medium-grained, and thin interbeds of tuffaceous quartz arenite, dark siltstone, shale, or mudstone, chert, and cherty siltstone |
| 70 | | Thin sedimentary layers interbedded with tuff. The sediment consists of banded silty quartzite or silty arenite, cherty siltstone, chert, and fine-grained greywacke, probably tuffaceous and cherty. The tuff is weathered and soft; the arenite beds are hard and brittle |
| 90 | | Tuff; thin cherty greywacke and shale |
| 120 | At start of left-hand curve | Mainly sediment: silty quartz arenite or quartz greywacke, silty shale, shale |
| | Around curve | Quartz arenite (probably tuffaceous); cherty siltstone, minor chert |
| 260 | Left-hand curve merges into right-hand curve | Minor intrusion of quartz porphyry at start of right-hand curve; then quartz greywacke or quartz arenite, tuff, tuffaceous quartz arenite |
| 310 | Leading up to a second right-hand curve | Poorly exposed silty greywacke or arenite, thin beds of cherty greywacke and minor chert, black slate, fine-grained quartz arenite and quartz siltstone, tuff, and a minor fine-grained acidic intrusion |
| 350 | End of section | |
| | Basal beds of tuff unit | Tuff, fine to medium-grained |

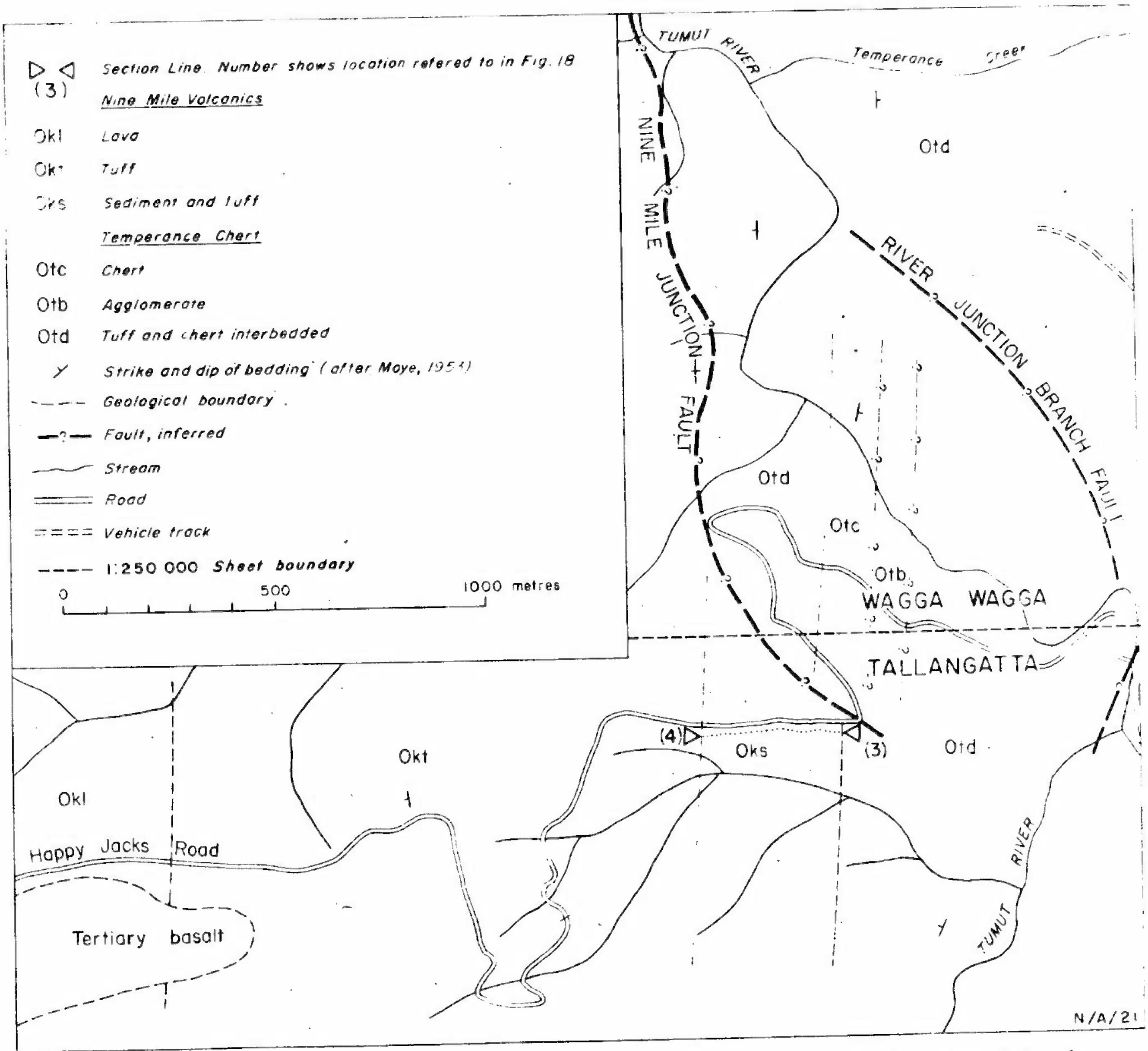


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**Fig. 19. Location of reference section of interbedded. sediment and tuff (Oks)**

TALLANGATTA 1:250 000 Sheet area

150 to 200 m and 1200 to 1275 m. From 600 to 750 m tuff beds several metres thick alternate with layers of interbedded sediment and tuff of about the same thickness. The sediment consists generally of tuffaceous greywacke with varying proportions of quartz arenite and siltstone, shale, chert, and impure chert. Tuffaceous quartz arenite, quartz arenite and siltstone are present at intervals between 350 and 900 m above the base. Chert and impure chert an appreciable proportion of the sedimentary beds in the basal 100 m, and thin chert beds appear sporadically up to about 600 m. Shale and slate are present in thin beds at intervals throughout the section. From 1150 to 1200 m, the section consists of tuff and tuffaceous greywacke, with thin interbeds of dark slate.

## Lava (Okt)

In the Tantangara Sheet area, only the top of the lava unit is missing, faulted out by the Long Plain Fault. The rest crops out between Chance Creek and Rules Point. The complete sequence consists of andesite lava and tuff, with a width across the strike of 1700 m, overlain by pale-coloured andesite and flow breccia in a zone at least 2400 m wide. Reference sections are proposed for each lithological unit, the 'andesite belt' and the 'breccia belt'. All available sections for the lava unit are shown in Fig. 16.

Lower part of lava unit. A reference section for the andesite belt that forms the lower part of the lava unit is given in Fig. 16. This section also exposes the basal part of the breccia belt. The location is shown in Fig. 22.

The section lies generally west-northwest, and passes 200 m south of Gooandra homestead. It ends 200 m west of Gooandra Creek. A summary of the sequence along the section-line is given in Table 17. A tuff 100 m above the base is correlated with tuff near the base of the section along Happy Jacks Road, also shown in Fig. 16. If this correlation is correct, the diorite exposed southeast of Gooandra homestead has intruded the volcanics at the base of the lava unit. Banded argillite with fragmental grains of andesite, exposed near the bottom of the steep slope down to Gooandra Creek, is probably equivalent to a band of black slate exposed 650 m to the north, also near the bottom of the slope.

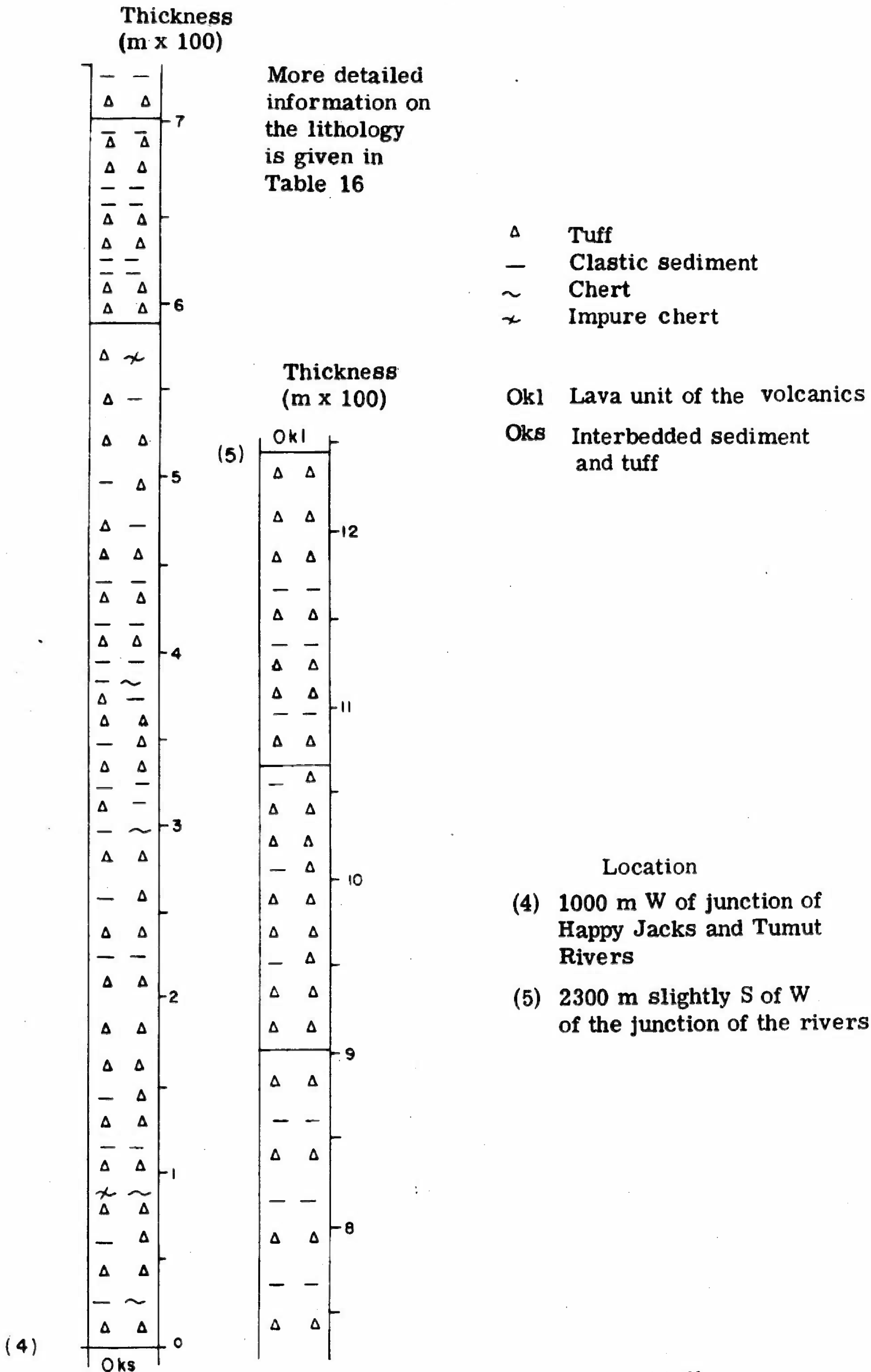


Fig. 20. Reference section of tuff.

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TABLE 16. REFERENCE SECTION OF TUFF UNIT

Location: Tallangatta 1:250 000 Sheet area, on Happy Jacks Road, starting 1000 m west of junction of Happy Jacks and Tumut Rivers. (Fig. 21)

| Approx. distance along road (m) | Road features | Geological description |
|---|---|---|
| 0 | Road curves from WSW to WNW | Tuff, fine to medium-grained |
| | | Tuff, thick bedded |
| 20 | | Banded tuff; fine-grained tuffaceous greywacke |
| | | Banded tuff, fine to medium-grained; shale or slate, cherty siltstone, minor chert |
| 150 | Around slight curve to right | Predominant tuff, with tuffaceous ?cherty greywacke and minor chert |
| | | Finely banded chert, cherty siltstone or impure chert, tuff |
| | | Tuff |
| 200 | Around sharp curve from WNW to SSW | Banded tuff and greywacke or arenite |
| 210 | | Deeply weathered shale, about 80 cm thick |
| 220 | | Shale, 1 m thick, intercalated in tuff |
| | | Tuff, medium and fine-grained; minor tuffaceous greywacke |
| 370 | Slight curve to left, merging into curve to right | Few outcrops. Sheared or cleaved tuff, mostly finely banded |
| | | Some tuffaceous greywacke, in part very finely banded and cherty |
| 590 | Curve to left | Tuff and tuffaceous greywacke |
| 650 | Curve to right | Tuffaceous quartz greywacke, and cherty greywacke |
| 730 | Curve to left | |
| 1000 | Start of curve to left | Thin-bedded and finely banded tuffaceous greywacke, tuffaceous quartz greywacke, quartz siltstone, minor quartz arenite, tuff |
| 1090 | Road curves sharply, SW to W | |
| 1250 | Road curves sharply W to NNE | Finely banded tuffaceous greywacke (3m); tuff, sheared or cleaved and minor tuffaceous quartz siltstone (15 m); finely banded tuff and tuffaceous quartz siltstone (1 m) |

TABLE 16 Continued

| Approx. distance along road (m) | Road features | Geological description |
|---|---|---|
| 1270 | | Predominantly banded tuff with periodic sequences of interbedded finely banded tuff and tuffaceous chert, and tuff and tuffaceous quartz siltstone |
| 1680 | Curve in road NNW to WSW | Alternating layers, each several metres thick, of bedded tuff and of interbedded sediment and tuff. The tuff is medium to fine-grained. A typical sedimentary sequence consists of tuffaceous greywacke, tuff, tuffaceous chert, and tuffaceous quartz arenite |
| 1850 | A right-hand curve of road merges into a left-hand curve | Banded tuff alternates with finely banded sediment |
| 2000 | A second curve to right | Mainly tuff |
| 2140 | | Predominantly tuff; minor sedimentary interbeds |
| 2240 | Roadside quarry | Predominantly bedded tuff, with bedded and banded tuffaceous greywacke and minor dark slate |
| 2260 | End of section | |
| | | Lava and tuff of lava unit |

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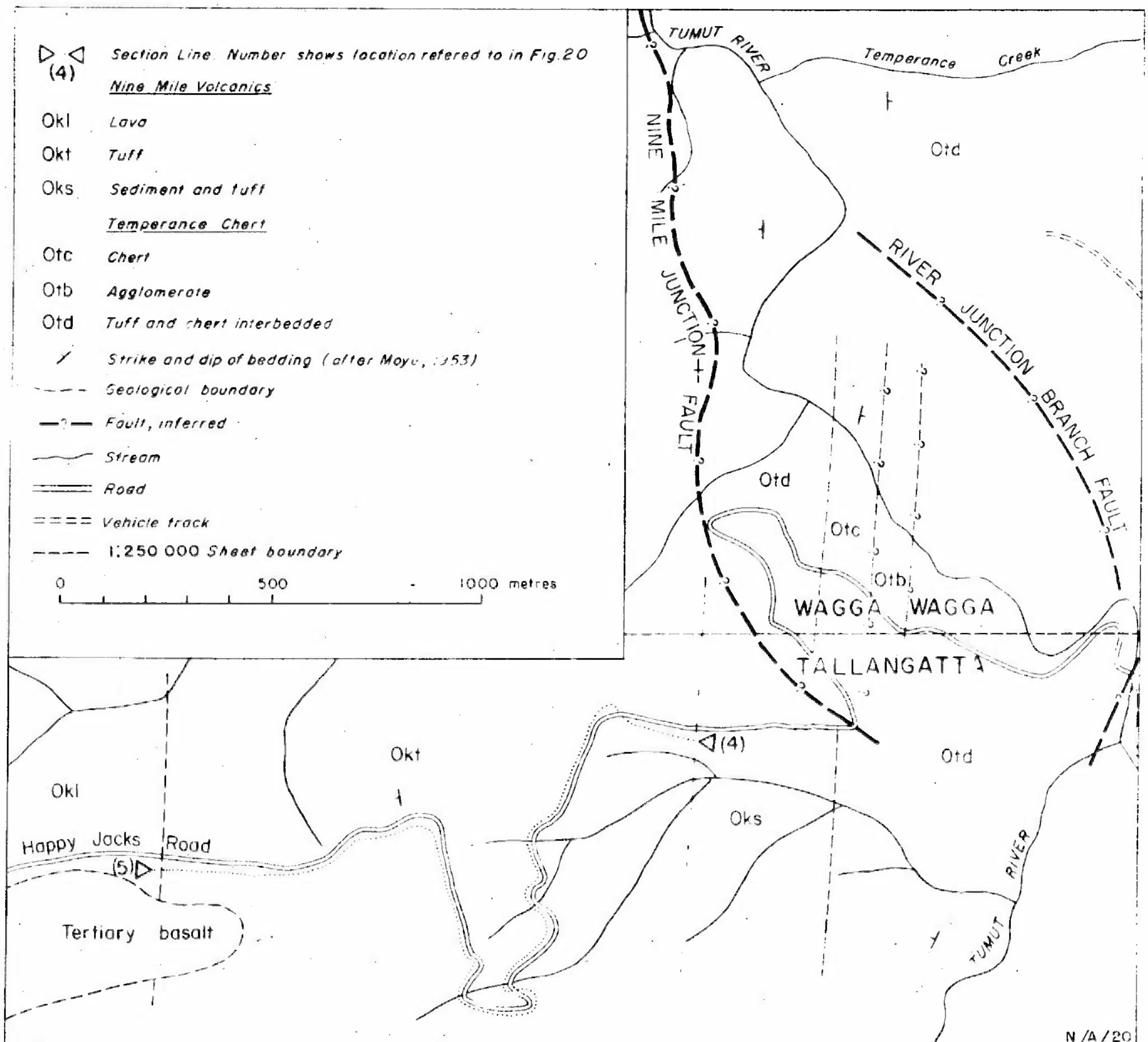


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**Fig. 21. Location of reference section of tuff unit (Okt)**

TALLANGATTA 1:250 000 Sheet area

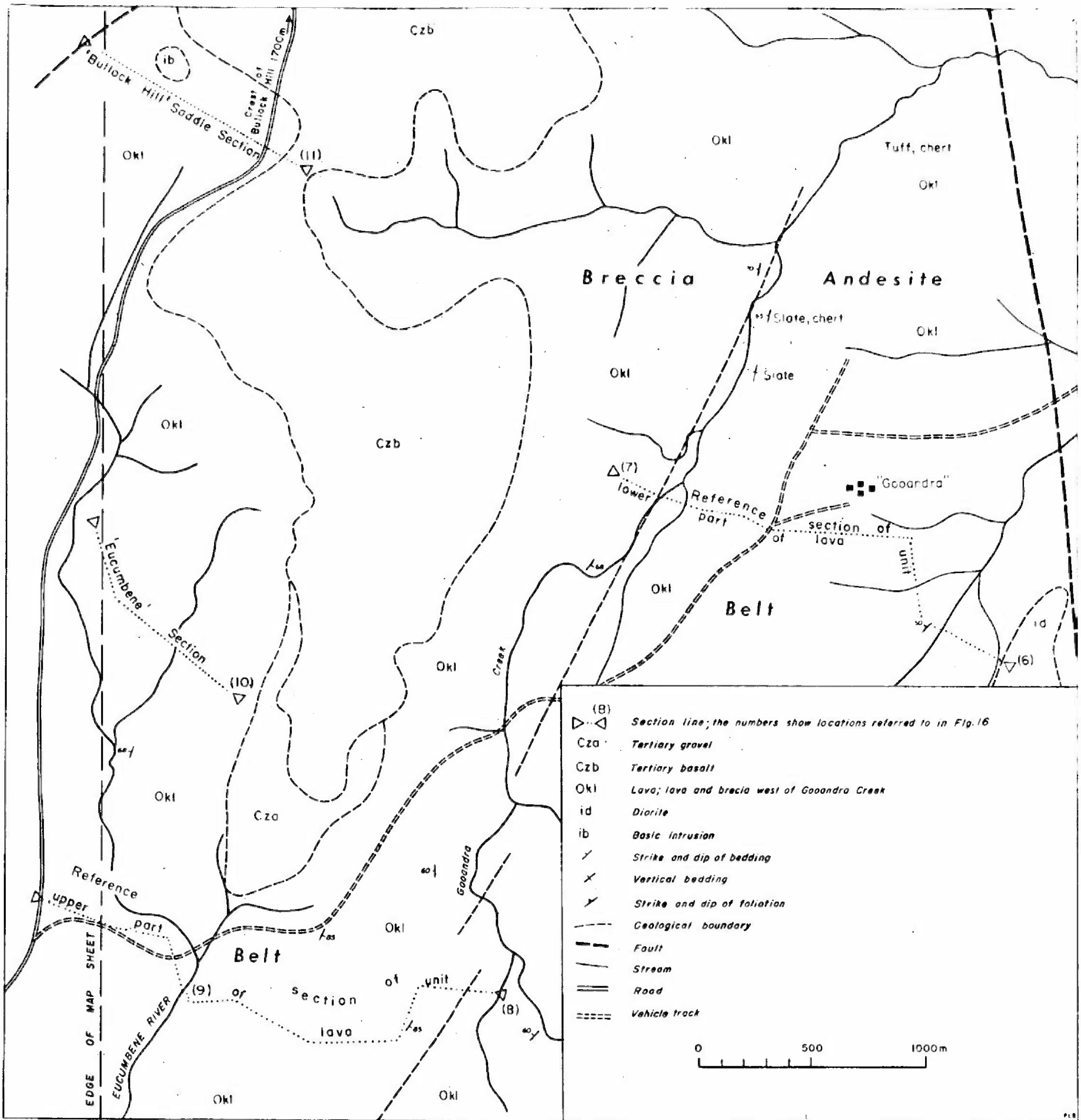


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**Fig.22. Locations of reference and other sections of the lava unit.**
TANTANGARA 1:100 000 sheet

## TABLE 17. REFERENCE SECTION OF THE LOWER HALF OF THE LAVA UNIT (THE ANDESITE BELT)

Location: Tantangara 1:100 000 Sheet area, starting 1000 m southeast of Gooandra homestead, in bed of tributary of Tantangara Creek (See Fig. 22)

| Reference points | Geological description |
|---|---|
| Start of section: 1000m SE of Gooandra homestead. Section runs 300° | At the boundary of a diorite intrusion at the base of the lava |
| At 100 m | Weathered tuff |
| At 350 m, turn to 348° | Andesite; flow-banding appears to dip 50° towards 315° and is masked by foliation that dips 70° towards 295° (see Table 12, TS 71840101) |
| At 400 m turn W | Porphyritic lava |
| Track to Gooandra homestead | Sheared lava |
| 200 m W of track | Sheared porphyritic lava |
| Down the steep slope to Gooandra Creek | Andesite lava, in small weathered outcrops. |
| Bottom of slope | Sheared banded argillite with numerous grains of andesite (see Table 12, TS 71840099) |
| End of section, 160 m W of Gooandra Creek | Flow-breccia with oval-shaped 'cobbles' 15 cm, elongate in direction of foliation |

The andesite is mainly fine to medium-grained, and locally porphyritic. Tuff is recorded at the middle as well as near the base of the unit in the reference section. Near Charcoal Creek, 4 km south-southwest of the section line, there is tuff at 600 and 800 m below the top of the unit; outcrop is poor, so there are probably more beds of tuff not exposed. Individual flows were not recognized; the thicknesses of lava, between the beds of tuff and argillite that were mapped, range from 50 to 300 m.

Upper part of lava unit. A proposed reference section for the upper part of the lava unit, exposing part of this sequence of flow-breccia and lava, is shown diagrammatically in Figure 16; the location is given in Figure 22. A brief description of outcrops along the section line is given in Table 18.

The flow-breccia occurs as beds or bands between lava flows, and as detached masses incorporporated in the lava. It forms outcrops along the section line (Fig. 22) at distances of 180, 670, and 1400 m from the boundary with the andesite belt. In the general area, there are also outcrops at 60, 150, 240, 440, 1600, and 2200 m from that boundary. The breccia fragments range in size from less than 1 mm to at least 25 cm. They are predominantly angular, and tend to be elongate in the direction of foliation of the rock. At some localities, the fragmental material is rounded as in a conglomerate, and ranges in size from boulders, through pebbles, to sand.

The flow-breccia is intimately associated with lava occurring above and below it, and in many places is incorporated into it. The lava is predominantly fine-grained and granular. It contains a high proportion of feldspar and is paler than the lava of the andesite belt; some thin sections have a trachytic appearance. An outcrop of porphyritic lava, highly sheared, is seen in the upper third of the reference section; at other localities porphyritic lava is found near the boundary with the andesite belt. Vesicular lava crops out along the reference section at several places between 450 to 620 m from the boundary with the andesite belt; in the general area it is associated with the lower five zones of flow-breccia.

At G.R. 370360, near where the track to Gooandra homestead crosses Gooandra Creek, some 250 m from the andesite belt, a thin bed of fine-grained cherty sediment rests on vesicular lava. The bed does not crop out along the section line.

## TABLE 18. REFERENCE SECTION OF THE UPPER PART OF THE LAVA UNIT (THE 'BRECCIA BELT')

Location: Tantangara 1:100 000 Sheet area, across the upper part of the Eucumbene River; starting in the westernmost headwater tributary of Gooandra Creek, 180 m upstream from its mouth (Fig. 22)

| Reference point | Geological description |
|---|---|
| 0. Start of section: as above; bearing 274° | Weathered andesite in bank of creek |
| 200 m W | Pale grey andesite; granular appearance |
| 300 m, turn to 200° | White, fine-grained andesite or trachyandesite; granular appearance |
| 550 m, turn to 267° | Andesite, medium-grained, granular appearance; banding dips at 85° towards 120° |
| 950 m, turn to 300° | Fine to medium-grained pale greenish grey andesite |
| 1150 Over a distance of 200 m from turn | Outcrops of greenish grey andesite; some contain sharp-edged lenticular vesicles, up to 10 mm x 3 mm |
| 1350, turn to 265° | Greenish grey andesite; granular appearance. Possible beds of tuff |
| 1550, turn to 342° | Grey and greenish grey sheared andesite; vertical banding strikes 020° |
| 1850, turn to 283° | Sericite-chlorite schist, probably sheared andesite, in bank of upper Eucumbene River |
| 2070 m | Lava and flow-breccia |
| 2130 Slight turn to 290° | Outcrop resembles highly stressed conglomerate; elongate andesite boulders in matrix of lava, or of arenite that consists of grains or andesite (possibly fine fraction in a flow-breccia) |

| Reference point | Geological description |
|---|---|
| W for 56 m to 2180 | Banded lava, or possible bedded volcanogenic arenite and siltstone (fine ?flow-breccia) |
| 2300 | The same; dip 85° towards 110° |
| 2430 End of section line | Schistose porphyritic andesite |

## ENVIRONMENT OF DEPOSITION

The tuff-siltstone-(arenite or greywacke)-slate-chert in the sedimentary and tuffaceous units of the volcanics, and in the thin sedimentary beds in the lava unit, suggests a continuation of the subaqueous environment that prevailed during the deposition of the Temperance Chert. The secondary minerals indicate post-depositional alteration of the rocks. This is most noticeable in the tuff and tuffaceous sediments; it is less obvious in the cherty tuff or tuffaceous chert where presumably the chert prevented the migration of elements, and in the lavas where large thicknesses of uniform lithology presumably acted as closed systems. In the breccia belt, the lava had started to solidify before it ceased to flow. Rounding of fragments was possibly due to wave action on a shoreline, or to abrasion in violent thermal currents in water in contact with the hot lava. The absence of limestone seems to preclude any likelihood of a littoral environment. In the discussion of the environment of the Bolton Beds, it was suggested that pyroclastics were being erupted from terrestrial volcanoes near the margin of a landmass that was rising during a geosynclinal orogeny. This concept could be extended to include major effusions of lava from volcanoes located along a zone of reverse faulting or thrusting that developed, as the orogeny progressed, on the sea-floor in front of the landmass.

The lava east of Peppercorn Hill is slightly older than that in the Nine Mile Volcanics, and lies within a sequence of interbedded tuff and chert. The chert indicates a subaqueous environment; however, angular blocky structures in the lava and a clinker-like surface suggest subaerial flows, possibly on a short-lived oceanic island.

## THICKNESS

The estimated thicknesses of the three lithological units of the Nine Mile Volcanics, assuming no repetition of beds through folding, are summarized in Table 19.

TABLE 19. ESTIMATED THICKNESS OF NINE MILE VOLCANICS

(derived from Figs. 18, 20, and 16)

| Lithological unit | Estimated thickness (m) | Remarks |
|---|---|---|
| LAVA | | |
| 'Breccia Belt' | | |
| 'Bullock Hill saddle' section | 900 | Decomposed, poorly exposed. Top faulted out on SE side of Bullock Hill |
| 'Eucumbene' section | 1100 | |
| Reference section of upper part of lava unit | 2300 | |
| Reference section of lower part of lava unit | 1700 | |
| Tuff | 1300 | Thin-bedded sequences; probable repetition by folding |
| Sediment and tuff | 350 | |
| Total | 7650 | |

The thickness exposed along the Eucumbene-Tumut tunnel-line (Plate 1) is about 2000 m. This does not include the basal unit, which is exposed along the road a few hundred metres south of the tunnel-line. Fairbridge estimated a thickness in excess of 2000 m near the junction of Nine Mile Creek and the Tumut River, where only the lower part of the lava unit is exposed. Assuming that there is no repetition by folding of the thick lava flows, it appears likely that the formation has a thickness of at least 6000 m.

RELATIONS

The Nine Mile Volcanics rest conformably on the Temperance Chert. The upper part of the Volcanics is faulted against Silurian sedimentary and volcanic rocks.

If the alternative interpretation that is suggested under 'Structure' were correct, it would be the lower part of the volcanics that is faulted against the Silurian. The Volcanics would pass up conformably into the Temperance Chert.

## AGE

Gisbornian graptolites were found (Opik, 1952) near the top of the Nine Mile Volcanics as exposed in the type area. From this, it seems likely that the base of the volcanics is in the Darriwillian.

Under the alternative interpretation of the structure of the area, assuming that the Bolton Beds can be correlated with the Eastonian Nungar Beds, most of the Nine Mile Volcanics and all of the Temperance Chert would have been deposited during the Gisbornian and part of the Eastonian." The base of the volcanics would be, presumably, at about the boundary between the Darriwillian and the Gisbornian.

## GEOCHEMISTRY (M.S.)

The silica content of the lavas from the Nine Mile Volcanics ranges from 48.8% to 51.6%, thus all the rocks are basic. The variation diagrams (Fig. 23) show that correlation of most of the oxides with silica is poor, although ferric, ferrous, and total iron as FeO show a weak inverse relation with silica. There is some correlation between silica and soda and potash, although potash shows the opposite relation to the usual trend, that is, it increases with decreasing silica. Lime, magnesia, and alumina show no relation with silica, although lime and magnesia, and to some extent, potash, correlate with each other, and are inversely correlated with soda and alumina. The $K_2O/Na_2O$ ratio varies from 0.08 (sample 71840385) to 2.06 (sample 71840490).

The reason for the lack of straight-line relations of oxides with silica is that they have undergone post-depositional alteration, as evidence by the presence of chlorite, sericite, pumpellyite, and epidote in thin section. Samples 71840498 from a sill which intrudes the flow units is the freshest, least altered rock obtained, and therefore probably is closest to the original composition of the magma. The alteration of the lavas probably occurred during burial metamorphism, when migration of elements resulted in the formation of secondary minerals. Smith (1968) describes similar Ordovician basic lavas

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from central-western New South Wales which have also undergone burial metamorphism. He suggests that glass is converted to chlorite with the release of calcium which then converts pyroxene to epidote and pumpellyite, resulting in patchy alteration and widely differing individual rock compositions, all of which occurs in the Nine Mile Volcanics. The Nine Mile Volcanics are of marine origin, shown by their close field association with chert and greywacke, and connate sea water trapped in the lavas probably aided in the transport of ions as well as contributing some elements to the alteration.

The trace element values are low to typical compared with averages for basic rocks (Hawkes & Webb, 1962). Chromium and nickel are correlated with magnesia, indicating substitution of these elements for magnesium in ferromagnesian minerals. The Nine Mile Volcanics are the most basic rocks encountered in the Tantangara Sheet area, the rest of the igneous units being acid to intermediate. This was shown by the stream-sediment geochemistry, which showed copper anomalies over the area covered by the Nine Mile Volcanics; whole-rock copper values are, however, typical of basic rocks.

The rocks are undersaturated, as quartz is absent in the norm of all samples and olivine ranges from 1.82% to 11.65%. The amount of normative orthoclase is variable, ranging from 1.94% to 23.74%, and reflects the variable potassium content of the rocks. Plagioclase in the norm ranges from approximately 45% to 60%, and its composition is fairly constant, ranging from $An_{43}$ to $An_{52}$. Normative diopside and hypersthene are both present, with diopside more abundant than hypersthene in all samples except the one which contains a low olivine value of 1.82% (sample 71840529). This is a result of calculating the norm, in that hypersthene is converted to olivine if insufficient silica is present. Magnetite comprises 2% to 4% of the norm, except in sample 71840529 where the high $Fe_2O_3$ content (5.4%) results in a high magnetite value of 8.08%. Generally the normative plagioclase composition and percentage and normative ferromagnesian mineral percentages agree fairly well with thin section estimates. Normative olivine, diopside, and hypersthene correspond to modal augite, chlorite, and clino-amphibole, which involves a slight redistribution of silica, with the excess silica in the norm probably allotted to orthoclase, albite, and anorthite.

Table 20. Analyses and CIPW norms from the Nine Mile Volcanics

| | 71840385 | 71540485 | 71840490 | 71840498 |
|---|---|---|---|---|
| Sample No. | 71840385 | 71540485 | 71840490 | 71840498 |
| Rock name | andesite | andesitic tuff | andesite dyke | diopside andesite |
| Grid reference | 370437 | 457601 | 479610 | 491624 |
| % | | | | |
| $SiO_2$ | 51.6 | 50.3 | 50.1 | 50.6 |
| $Al_2O_3$ | 16.4 | 14.9 | 13.8 | 11.9 |
| $Fe_2O_3$ | 1.80 | 2.85 | 1.90 | 1.85 |
| FeO | 5.90 | 7.80 | 8.85 | 7.15 |
| MgO | 6.95 | 6.25 | 6.85 | 9.35 |
| CaO | 9.25 | 7.85 | 8.30 | 10.7 |
| $Na_2O$ | 4.05 | 3.25 | 1.89 | 2.35 |
| $K_2O$ | 0.32 | 2.05 | 3.90 | 1.57 |
| $H_2O+$ | 1.98 | 3.05 | 2.80 | 2.70 |
| $H_2O-$ | 0.22 | 0.20 | 0.30 | 0.29 |
| $CO_2$ | 0.15 | 0.10 | 0.35 | 0.20 |
| $TiO_2$ | 0.83 | 0.81 | 0.51 | 0.53 |
| $P_2O_5$ | 0.10 | 0.32 | 0.41 | 0.24 |
| MnO | 0.14 | 0.14 | 0.18 | 0.15 |
| | 99.69 | 99.87 | 100.14 | 99.58 |
| ppm | | | | |
| Ni | | 30 | 30 | 65 |
| Co | | 35 | 35 | 35 |
| Cu | | 155 | 140 | 110 |
| Zn | | 95 | 95 | 85 |
| Pb | | 5 | 5 | 5 |
| Qz | - | - | - | - |
| Or | 1.94 | 12.54 | 23.74 | 9.60 |
| Ab | 35.14 | 28.45 | 16.47 | 20.58 |
| An | 26.29 | 20.72 | 18.19 | 17.90 |
| Di Wo | 7.99 | 7.00 | 8.01 | 14.24 |
| Di En | 5.07 | 3.95 | 4.24 | 9.05 |
| Di Fs | 2.41 | 2.76 | 3.53 | 4.28 |
| Hy En | 6.73 | 5.73 | 4.66 | 8.46 |
| Hy Fs | 3.20 | 4.01 | 3.87 | 4.00 |
| Ol Fo | 4.17 | 4.50 | 6.08 | 4.61 |
| Ol Fa | 2.19 | 3.47 | 5.57 | 2.40 |
| Mt | 2.68 | 4.28 | 2.84 | 2.78 |
| Il | 1.62 | 1.59 | 1.00 | 1.04 |
| Ap | 0.24 | 0.79 | 1.00 | 0.59 |
| Cc | 0.35 | 0.24 | 0.82 | 0.47 |

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Table 20. Analyses and CIPW norms from the Nine Mile Volcanics (cont'd)

| | | |
|---|---|---|
| Sample No. | 71840529 | 71840574 |
| Rock name | andesite tuff | basalt |
| Grid reference | 456604 | 468449 |
| % | | |
| $SiO_2$ | 49.2 | 48.8 |
| $Al_2O_3$ | 14.6 | 12.9 |
| $Fe_2O_3$ | 5.40 | 3.4 |
| FeO | 7.30 | 7.45 |
| MgO | 6.20 | 8.05 |
| CaO | 6.65 | 9.05 |
| $Na_2O$ | 2.60 | 2.65 |
| $K_2O$ | 3.05 | 2.30 |
| $H_2O+$ | 2.80 | 2.80 |
| $H_2O-$ | 0.30 | 0.36 |
| $CO_2$ | 0.20 | 0.65 |
| $TiO_2$ | 1.12 | 0.80 |
| $P_2O_5$ | 0.36 | 0.31 |
| MnO | 1.17 | 0.20 |
| | 99.95 | 99.72 |
| ppm | | |
| Ni | 30 | |
| Co | 50 | |
| Cu | 95 | |
| Zn | 120 | |
| Pb | 5 | |
| Qz | - | - |
| Or | 18.61 | 14.07 |
| Ab | 22.71 | 23.21 |
| An | 19.79 | 17.10 |
| Di Wo | 4.40 | 9.62 |
| Di En | 2.79 | 6.04 |
| Di Fs | 1.34 | 2.99 |
| Hy En | 11.45 | 5.04 |
| Hy Fs | 5.50 | 2.50 |
| Ol Fo | 1.19 | 6.78 |
| Ol Fa | 0.63 | 3.70 |
| Mt | 8.08 | 5.11 |
| Il | 2.20 | 1.57 |
| Ap | 0.88 | 0.76 |
| Cc | 0.47 | 1.53 |

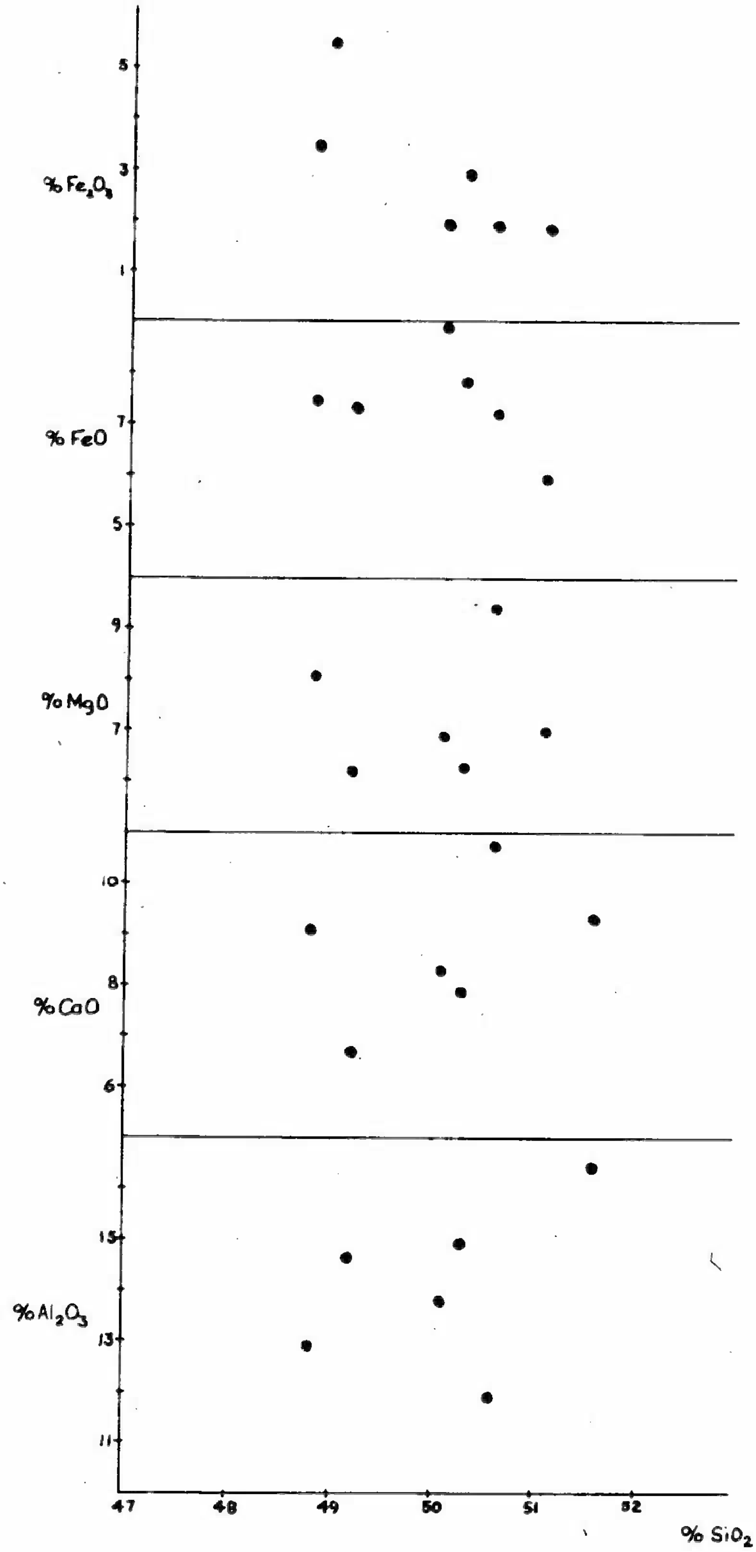


Fig. 2.3. Variation diagrams for the Nine Mile Volcanics

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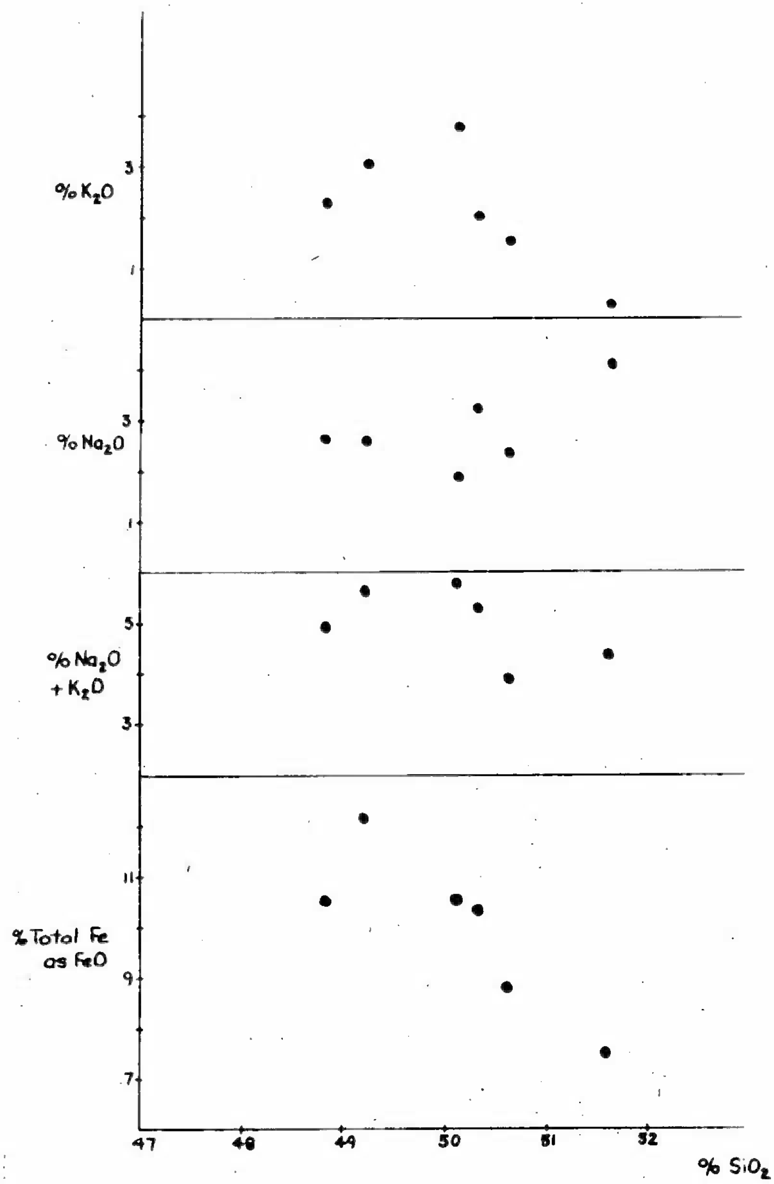


Fig. 23. (continued).

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## NUNGAR BEDS (Newberry, 1956)

(M.O.)

### NOMENCLATURE

A series of Late Ordovician slate, shale, siltstone, sandstone, and quartzite exposed in the Nungar Creek gorge was named the Nungar Beds by Newberry (1956). Stevens (1958a) described them in more detail, and mapped various lithological units within the Beds between Nungar Trig. and Providence Portal. He also described a type section on Shaft Road, in the Nungar Creek Gorge, and presented a detailed map of the section. Poorly preserved graptolites found by Stevens indicate a Late Ordovician age for the Nungar Beds.

The Nungar Beds were first referred to in published work by Stevens (1958b, p. 252) when describing the geology of the Cooleman Plain district. The beds in this area, thought to be Nungar Beds by Stevens, are now considered part of the Early Silurian Tantangara Formation (see p. 129). Walpole (1964) also referred to the Nungar Beds in a summary of the engineering geology of the Murrumbidgee-Eucumbene Tunnel. Further mention has been made in Packham (1969), where Moye, Sharpe, and Stapledon stated they are the lateral equivalent of the Adaminaby Beds, which crop out to the southeast of Adaminaby (see p. 124).

The Nungar Beds were assumed by Snowy Mountain Authority geologists (Newberry, 1956; Moye, 1957; Stevens, 1958a, and also by Crook et al., 1973) to form extensive outcrops on Nungar Range, and on the ridge between Tantangara Dam and the Pockets area. The present study has demonstrated that much of the assumed Late Ordovician in this area is Early Silurian, and this has led to the reinterpretation of the Nungar Beds given below.

The name has been retained as an informal name because of the incomplete nature of the type sections, and uncertainity about the relation of the Nungar Beds to the underlying units and also to units to the east, possibly of the same age. These are discussed more fully below.

### DERIVATION OF NAME

The unit is named from Nungar Creek, along whose gorge the type-section is situated (Newberry, 1956, p. 4).

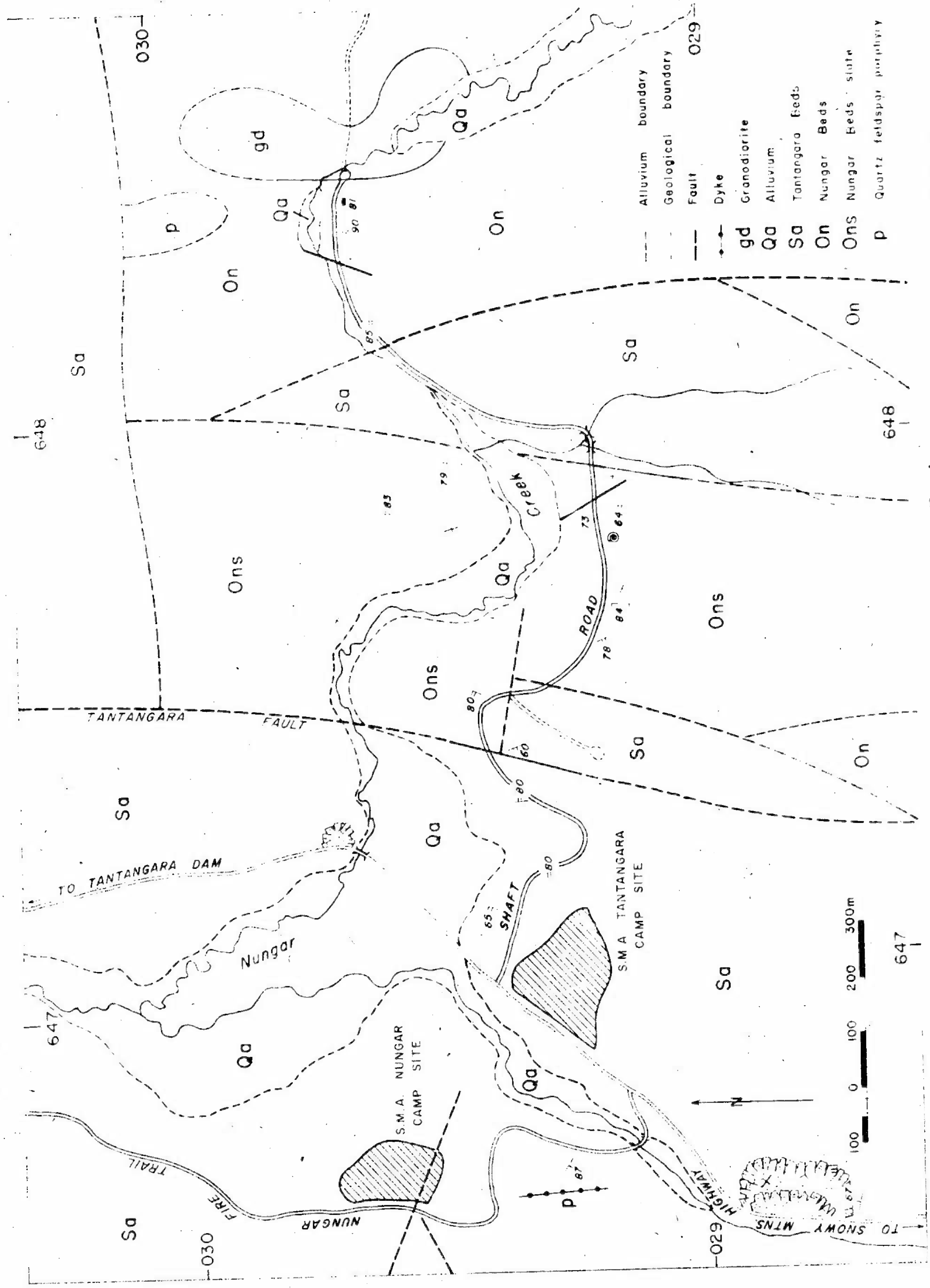


Fig. 24. Type locality of the Nungar Beds.

TYPE SECTION

The type-section is along Shaft Road, which extends from the Tantangara Road (at G.R. 469293) eastward for 2000 m through the length of the Nungar Creek Gorge to a Snowy Mountain Authority drill site at its eastern end (G.R. 484295). Stevens (1958a) thought that the rocks cropping out in this section were wholly Nungar Beds, but we consider that much of this succession should be referred to the Tantangara Beds, while the Nungar Beds are only present in two short sections at the eastern end and in the central part of the road. The present interpretation of the geology is shown in Figure 24, and an oblique aerial photograph of the type section appears in Figure 55.

Fig 55. Aerial view, from the east, of the Nungar Creek gorge, type locality of the Nungar Beds. (Neg. no. GA/8089)

Stevens (1958a, p. 2) recognized ten lithological units along Shaft Road:

10. Fine-grained buff to green sandstone

9. Interbedded slate and quartzite

8. Interbedded siltstone and shale

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7. Brown siltstone
6. Black slate
5. Grey slate or shale
4. Interbedded slate and quartzite
3. Chiefly quartzite
2. Spotted, finely bedded hornfels with some quartzite
1. Dark grey quartzite.

Granodiorite Intrusion

Only units 1, 2, 5, and 6 are considered by us to be part of the Nungar Beds; the remaining units are considered part of the Tantangara Beds. The rocks in units 3, 4, and 9, called quartzite by Stevens, are not true quartzites but strongly lithified coarse sandstone typical of much of the Tantangara Beds.

Units 1 and 2 are exposed at the eastern end of Shaft Road from the contact with a granodiorite intrusion (G.R. 484295) westward for 390 m along the road to G.R. 481292, and units 5 and 6 are exposed on the road from G.R. 479291, 810 m from the intrusion, to G.R. 477292, 950 m from the intrusion.

Between these two parts of the type section are poorly exposed Tantangara Beds, in a downfaulted block which closes to the south, giving way to interbedded quartzite and slate of the Nungar Beds lying between units 2 and 5 of the typesection. The fault on the western edge of the block of Tantangara Beds is exposed at G.R. 479291 but the eastern bounding-fault is inferred.

The type-section of the Nungar Beds is incomplete, however it is the only locality where the Beds are well exposed and so has been retained as the type section. The incompleteness of the type-section, the uncertain relations between the Nungar Beds, the underlying rocks, and the Adaminaby Beds are arguments in favour of the Nungar Beds remaining an informal unit.

## GEOGRAPHICAL DISTRIBUTION

The Nungar Beds crop out over much of the Monaro Range between the Snowy Mountains Highway and Nungar Creek. There are several rather irregular areas of outcrop farther north on Nungar Range, and also on the eastern side of Nungar Plain and on the ridge extending from north of Bulgars Hill south to the Little River and Mudhole Creek valleys. Small areas of quartzite south of Denison Hill, a black graptolitic slate at Tantangara Dam, and areas of quartzite and slate east of Paytens Creek are all considered part of the Nungar Beds. The unit is also present around the headwaters of Burgess Creek.

Outcrop of the Nungar Beds is commonly poor, but is good in some areas of the Monaro Range. The quartzite forms low tors on ridge tops as well as valley floors and sides. Float from the quartzite is generally abundant. The slate crops out more rarely: the two slate beds on the Monaro Range, depicted on the accompanying 1:100 000 geological map, are unusual in forming prominent outcrops up to 4 m high. Float from the slate beds is generally common, but where the slate is interbedded with quartzite, its debris is obscured by the quartzite float.

LITHOLOGY

The typical lithology of the Nungar Beds is interbedded quartzite and slate with a few thicker units of massive quartzite or black slate. Siltstone with abundant sedimentary structures is interbedded with quartzite in places, and thin cherts are interbedded with the slate. The only volcanic rocks found so far are the thin beds of tuffaceous sediment on the west side of Gang Gang Mountain mentioned by Stevens (1958a, p. 3).

The quartzite consists almost entirely of equigranular quartz grains about 0.1 to 0.2 mm across with interpenetrative boundaries, and a little metamorphic biotite, sericite, and chlorite. Lithic fragments are absent.

Bedding in black to dark grey slate is generally obscure or lacking but cleavage is well developed. Pyrite is common, both scattered through the rock, and in places concentrated in layers up to 0.5 mm thick, which may indicating bedding. Little can be seen in thin sections of the slate: the bulk of the rock has a black to very dark grey matrix with rare fine silt-size detrital quartz and fine, elongate sericite, aligned parallel to cleavage, scattered through the rock.

The thinly bedded siltstone with abundant sedimentary structures is strongly hornfelsed in the Shaft Road section. They are absent north of Nungar Creek, possibly owing to faulting, and disappear about 1.5 km to the south, but occur in the Burgess Creek area. The siltstone is formed of alternating layers, 0.5 to 4.0 mm thick, of fine silt grains of detrital quartz, and phyllosilicate.

The rock is strongly indurated, even where not hornfelsed, and boundaries between quartz grains are interpenetrative. Chlorite and sericite are common in the finer laminae, but biotite is rare. Where hornfelsed, the rock consists of a mosaic of unoriented grains of quartz, biotite, muscovite, feldspar, magnetite, and porphyroblastic cordierite with abundant inclusions.

Although the siltstone has been strongly hornfelsed in many places, sedimentary structures are generally clearly visible. These include contorted bedding, fine current ripple lamination, small-scale cross-stratification and graded-bedding. Transposition bedding caused by intense deformation of the Nungar Beds is also present, and necessitates care in interpretating many apparent sedimentary structures.

The rare tuffaceous sediments consist of a few deeply weathered dark greenish grey rocks present as float on the northwest slopes of Gang Gang Mountain. The rock appears to be a basic tuff, possibly waterlain, but is too weathered for firm identification.

## THICKNESS

No attempt to estimate the thickness of the Nungar Beds has been made because of their severe deformation.

## RELATIONS

The Nungar Beds may be conformable on the Nine Mile Volcanics. The evidence is circumstantial; firstly, there is little difference in age between the Nungar Beds (Eastonian) and Nine Mile Volcanics (Gisbornian), and secondly, the absence of lithic fragments and the dominance of fine-grained sediments in the Nungar Beds suggests that there had been no uplift of the earlier rocks before deposition of the Nungar Beds. The Nungar Beds therefore may conformably overlie the Nine Mile Volcanics although direct evidence is lacking.

The Tantangara Beds overlie the Nungar Beds unconformably on Nungar Range, as the Tantangara Beds have been found to rest on various horizons within the Nungar Beds. No exposures of the contact have been observed.

The relation between the Nungar Beds and the Adaminaby Beds to the east is uncertain. Although they both contain Eastonian graptolite faunas these are not sufficiently well known to be able to say whether or not one unit is younger than the other. Lithologically and structurally there are both similarities and differences, which are discussed fully in the description of the Adaminaby Beds (see p. 128).

## AGE

Stevens (1958a) noted the occurrences of poorly preserved Late Ordovician graptolites on the Monaro Range between Gang Gang Mountain and Nungar Creek. Later, during construction of Tantangara Dam, graptolites were found in a black pyritic slate cropping out in the foundations of the northern half of the Dam. The graptolites were in the collections of the Snowy Mountain Authority, Cooma, but have now been deposited in the Commonwealth Palaeontological Collection held by BMR. Preservation of most specimens is too poor for identification, but the specimens on one sample (S.M.A. sample number T6022) have been identified as Orthograptus quadrimucronatus and O.calcaratus var. tenuicornis, indicating an Eastonian (Late Ordovician) age.

The age of the Nungar Beds is therefore considered to be Eastonian.

## ADAMINABY BEDS (Adamson, 1951)

(M.O.)

## NOMENCLATURE

The name Adaminaby Beds was first published by Fairbridge (1953, p. III/3), and had been previously used by Adamson (1951). Adamson later published the name for Ordovician sediments at the site of the Eucumbene Dam (Adamson, 1956, p. 141), though in an earlier paper (Adamson, 1955) describing the regional geology of the area he failed to use the name. Later authors to refer to the Adaminaby Beds include Opik (1958) and Moye, Sharp, & Stapledon (in Packham, 1969).

None of these authors has satisfactorily described the unit and no designation of a type section has been made. The Unit is assumed to be named after the township of old Adaminaby (at the time the unit was named the old township, now flooded by Lake Eucumbene, was in existence) and, because Adamson originally used the name for beds at Eucumbene Dam, the type area is assumed to be at the Dam.

As the unit is so poorly known from previous work and the type area is well south of the Tantangara 1:100 000 Sheet area, the informal name Adaminaby Beds is retained.

DISTRIBUTION

The Adaminaby Beds crop out over a wide area in the southeast quarter of the Tantangara 1:100 000 Sheet area. The main area extends north from the southern edge of the Sheet area, in a belt 5 to 6 km wide between the Murrumbidgee Batholith to the east and the Cotter Fault to the west. Northwards this belt narrows and is interrupted by overlying Cainozoic sediments and the Stewartsfield Granodiorite intrusion near Yaouk.

From Yaouk northwards, Adaminaby Beds crop out on both sides of the Cotter Fault though on the west they are pinched out between the Gingera Granite and a north-northwest-trending fault near Blackfellows Gap. There is a further belt of Adaminaby Beds between the Goodradigbee and Bimberi Faults from Rolling Grounds Spur north to the northern edge of the Sheet area.

REFERENCE SECTION

A reference section for the Adaminaby Beds as understood in this work is situated on the south side of the Murrumbidgee at Rosedale, from G.R. 652153 to 660152. About 300 m of interbedded sandstone and shale, forming a flysch sequence, is present along a track between these two points, with beds dipping east at about 60°.

The designation of this section as a reference section is only intended to clarify the usage of the name Adaminaby Beds within the Tantangara Sheet area, and it may not necessarily be representative of the unit in its type area near Eucumbene Dam. The status of the Adaminaby Beds will remain uncertain until it is properly described and a type section formally designated in its type area.

LITHOLOGY

The lithology of the Adaminaby Beds within the Tantangara Sheet area is varied. The dominant lithology is a medium to fine-grained impure sandstone, with interbedded siltstone and shale, and minor amounts of coarse sandstone, conglomerate, black slate, and bedded chert. Limestone and tuffaceous beds are absent.

Much of the succession within the Beds represents a flysh sequence, and is similar in field appearance to the upper part of the Tantangara Beds, a feature which has led to problems in distinguishing them in the field. This is discussed more fully later (p. 128).

The dominant rock, as seen in the field, is a light to medium brown sandstone; outcrops are rare. Individual beds are up to 10 m thick, but seldom exceed 2 m; the sandstone commonly grades upwards into siltstone and shale, and a few load casts are present. The sandstone is composed of moderately rounded to angular quartz grains, generally less than 0.3 mm diameter, in a matrix of fine silt and clay; sorting is commonly poor. Rock fragments and feldspar grains are unknown. The siltstone and shale rarely crop out, though road cuttings indicate that they form an important element within the unit. They are generally light grey to brown, commonly showing small-scale laminations or cross-bedding, and a few have small slump structures.

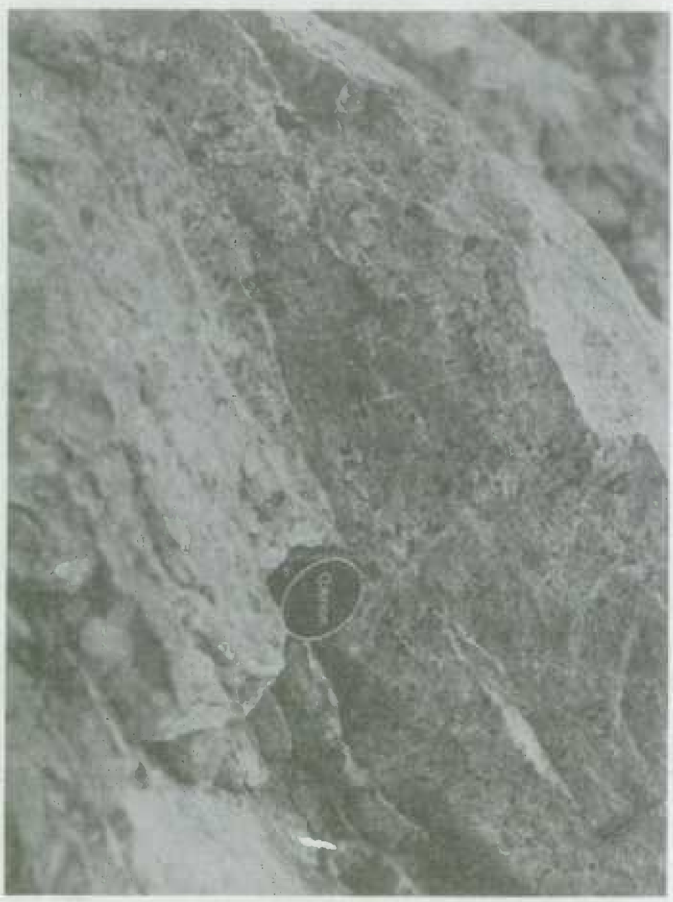

Fig. 56 Mudclasts at base of turbidite unit in Adaminaby Beds, west abutment, Corin Dam. (Neg. no. GA/8060)

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In the north, particularly in the Goodradigbee and Cotter valleys beds of coarse sandstone are an important part of the succession. The sandstone is poorly sorted, massive, generally brown, with quartz grains up to 1.5 mm in diameter, visible in hand specimen. Rock and feldspar grains are very rare, except east of the lake formed by Corin Dam, and rock clasts have only been seen immediately west of Corin Dam. At this locality elongate black mud clasts up to 50 mm long are very common at the base of thick sandstone units (Fig. 56). Other than black mudstone, there are only a few clasts composed almost entirely of a weathered sulphide, possibly pyrite with minor chalcopyrite.

In thin section the coarse sandstone formed of remarkably well rounded spherical quartz grains up to 1.5 mm diameter in a matrix of less rounded quartz grains less than .25 mm in size, and fine phyllosilicate material. The proportion of large rounded grains, ranges from more than 75% in some specimens to less than 5% in others. Rock fragments are virtually absent in samples from the south of the area, but are more common in the Cotter and Goodradigbee valleys, though they never form more than 1 or 2% of the total number of large grains. When present, the rock fragment is invariably black mudstone or very rarely chert, highly weathered volcanic rock, or quartzite. The coarse sandstone from the Adaminaby Beds is similar to that in the Tantangara Beds, particularly near Tantangara Dam, but that in the Adaminaby Beds mostly has fewer lithic fragments.

Black cleaved siltstone or mudstone is interbedded within the brown sandstone sequence at several localities in beds from 2 to several ten of metres thick. Cleavage may be sufficiently well developed to form slate. In several localities, as at G.R. 802394 southeast of Gudgenby, the black siltstone has been strongly hornfelsed by the adjacent Shannons Flat Adamellite to a quartz muscovite biotite cordierite rock, with local development of prismatic andalusite. Graptolites are fairly common at several localities, and many occur where the rock has been hornfelsed by intrusions of the Murrumbidgee Batholith, though specimens have been collected in unmetamorphosed rock, where cleavage and bedding coincide.

Bedded chert is present at one locality (G.R. 772153) on Alum Creek, 3.5 km east-southeast of Jones Plain. Dark grey to black chert, in beds from 10 to 25 cm thick, crops out over 150 m along the creek and appears to be about 30 m thick. The relation of the chert to the surrounding brown sandstone is unknown, but it is assumed to be conformable within the sandstone. The chert is similar in appearance to that in the Temperance Chert, but does not have slump-folding common in the latter.

AGE AND RELATIONS

Graptolites are known from several localities in the Adaminaby Beds, though they are poorly preserved at all localities within the Tantangara Sheet area. The best preservation was in a hornfelsed black mudstone on the ridge about 3.5 km south-southeast of Gudgenby (G.R. 804394). Among the forms present are Climacograptus bicornis, Dicranograptus cf ramosus, and D. cf hians, which indicate an Eastonian age. Subsequent work farther north, in the Brindabella Sheet area, has produced a much better preserved fauna from the Tidbinbilla Range, with upwards of ten species present. Initial work on this fauna suggests a probable late Eastonian age, but inadequate knowledge of the fauna of the type Eastonian precludes an accurate age being derived.

The base of the Adaminaby Beds is not seen, within the area examined so the relation of the Beds with the underlying rocks is unknown. The Nungar Beds are considered to be possibly the lateral equivalent of the Adaminaby Beds. Evidence for this is the similar age indicated by the graptolite faunas, though it should be noted that the graptolites from the Nungar Beds are poorly preserved and only tentatively identified. It is possible that the Adaminaby Beds could, at least in part, be slightly younger than the Nungar Beds. The two units differ lithologically, the Nungar Beds being dominantly relatively pure quartzite and black slate, while the Adaminaby Beds have a much higher proportion of micaceous or clay-rich sandstone, and little black slate. If the two units are coeval they may represent proximal (Adaminaby Beds) and distal (Nungar Beds) facies in a single flysh sequence. A problem raised by this interpretation is that the proximal facies is east of the distal facies, which would indicate a landmass eastwards, for which evidence is lacking. It would agree better with current palaeogeographic concepts to regard the proximal Adaminaby Beds as slightly younger than the Nungar Beds and to have prograded eastwards over the Nungar Beds from a landmass in the west.

The Adaminaby Beds are similar lithologically to the Early Silurian Tantangara Beds, and distinguishing the two in the field is very difficult in the absence of fossil evidence. It is possible that areas of Tantangara Beds have been shown as Adaminaby Beds on the accompanying 1:100 000 map, and vice versa. The two units differ mainly in the presence of black graptolitic shale in the Adaminaby Beds and its absence in the Tantangara Beds. In addition, sandstone (particularly coarse sandstone) from the Tantangara Beds tends to contain a higher proportion of rock fragments, though this does not apply near Corin Dam where the rocks are placed in the Adaminaby Beds on the basis of graptolite faunas found just north of the Tantangara Sheet area.

An unconformity is assumed between the Adaminaby and Tantangara Beds, as faunas of uppermost Ordovician age are unknown, and the Tantangara Beds are known to rest unconformably on the Nungar Beds, the possible lateral equivalent of the Adaminaby Beds.

## 4. SILURIAN SEDIMENTARY AND VOLCANIC ROCKS

### TANTANGARA BEDS (defined here)

(M.O.)

#### NOMENCLATURE

The name Tantangara Beds was given by Best et al. (1964) to sediments that crop out on the Nungar Range, north and south of Tantangara Dam. They were described in the map legend as 'shales, sandstones, greywackes and volcanics' and were said to be of 'undifferentiated Silurian' age, although no evidence of age was given.

Bein (1969) and Crook et al. (193) concluded from a study of graptolites found in the foundations of Tantangara Dam that the Tantangara Beds were Late Ordovician, and that there was no reason to separate them from the Nungar Beds. During the 1971-72 field season Silurian fossils were found at localities on Nungar Range, and major lithological differences were noted between the Nungar Beds and the Tantangara Beds. For these reasons the validity of the Tantangara Beds as a separate unit is upheld and a definition of the unit follows.

#### DERIVATION OF NAME

No derivation was given by Best et al. (1964), and it is assumed that the unit was named from Tantangara Dam (G.R. 502372).

#### TYPE SECTION

The road cutting above the south abutment of Tantangara Dam, from the tunnel inlet valve station (G.R. 500371) east to the bridge over the Murrumbidgee River, continued across a series of natural exposures along the hillside on the south side of The Gulf until G.R. 520369, a total distance of 2 km. The western part of the road cutting exposes a continuous section of massive, coarse dark arenite with interbedded siltstone and shale; the eastern part (Fig. 57) has discontinuous exposures of softer, brown, fine arenite. The natural exposures formed by severe soil erosion on the south side of The Gulf, are interbedded fine arenite, siltstone, and shale. Dips in the type section are generally between 70° and 80° to the west-northwest.

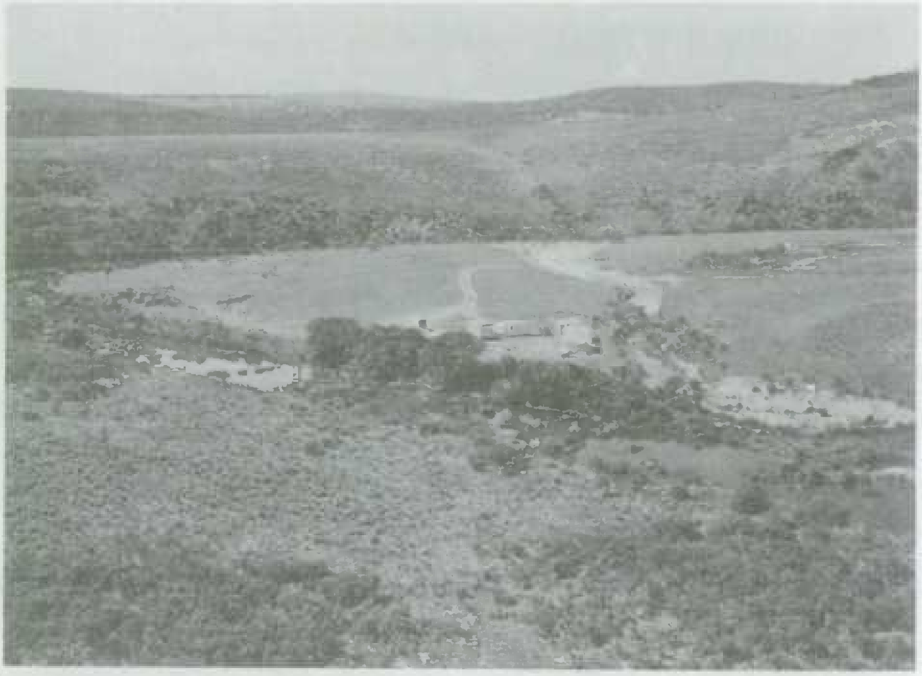

Fig. 57 Eastern end of type section of Tantangara Beds, The Gulf, Tantangara Dam. (Neg. no. GA/8066)

An additional reference section, in rocks thought to be higher in the sequence, is a roadcut on the Snowy Mountain Highway on the eastern side of the Monaro Range from G.R. 487218 to G.R. 496220. This section consists of a series of brown interbedded, fine arenite, siltstone, and cleaved shale, in beds 0.5 to 30 m thick, some of which show graded bedding. The beds dip to the southeast at 65° to 80°.

DISTRIBUTION

The Tantangara Beds crop out over a large area between the Snowy Mountains Highway and Lake Eucumbene, and extend north from there as a wide belt as far as the Murrumbidgee River east of Tantangara Dam. North of the River, the width of outcrop narrows from about 11 km east of Tantangara

Dam to disappear about 1 km east of The Pockets area.

West of Tantangara Dam the Beds crop out in a belt about 5 km wide, extending south from Nattung Trig. through the Peak Back Range and Zinc Range to Blanket Hill. Further areas of outcrop of the Tantangara Beds are northeast of Adaminaby and on the western side of the Cotter Fault.

The Tantangara Beds are generally poorly exposed, with the exception of coarse, massive arenite beds forming prominent tor-like outcrops on the Nungar Range. These beds generally crop out along ridge tops, and less commonly along the flanks of hills and in valley bottoms. Float from them has formed extensive colluvial deposits, and obscures much of the underlying geology. In a few places large scree slopes have developed, for example on the south side of Nungar Mountain.

The softer fine-grained arenite, siltstone, and shale interbedded with the coarse arenite rarely crop out, except in areas of severe soil erosion such as the area on the Murrumbidgee River known as The Gulf.

## LITHOLOGY

Two lithological associations were recognized during field work, but attempts to map them as separate units proved unsuccessful. The first association consists of dark grey, coarse-grained, massive sublitharenite, dark brown to grey siltstone, and shale in which graded bedding from coarse arenite to siltstone and shale is common. The second association consists of light to medium brown fine arenite, siltstone, and shale, with less common graded bedding.

Representative sections for the two associations are the road cutting adjacent to Tantangara Dam for the first association and the Snowy Mountain Highway cutting on the eastern slope of the Monaro Range between G.R. 487218 and 496220 for the second association.

The first association is apparently predominant in the lower part of the Tantangara Beds but is also sporadically found interbedded with the second association higher in the unit. Rocks of this association are dominant in the lower part of the Tantangara Beds in the Nungar Range where coarse arenite is widespread, apparently unconformably overlying quartzite and slate of the Nungar Beds. The distinctive rock type is a coarse to very coarse sublith-arenite or quartz arenite in beds up to 20 m thick, commonly showing graded bedding. Individual beds are lenticular, generally less than 1 km in extent;

it is uncertain whether the lensing is of tectonic or sedimentary origin. The rock is extremely resistant and forms large tor-like outcrops, showing well developed jointing and indistinct bedding.

The arenite varies from brown to very dark grey with well rounded quartz grains up to 2 mm in diameter conspicuous in hand specimen, as are brown ferruginous and, less commonly, white feldspar grains. Fossil fragments, generally of comparable size to the larger grains, are present at three localities but only reach identifiable size, up to 10 mm, at one (G.R. 492299). The bottom layers of many of the graded units contain black mudclasts, generally 5 mm to 20 mm in diameter (Fig. 58) though exceptionally clasts are up to 250 mm long by 50 mm thick. The larger clasts are elongate and commonly distorted, whereas the smaller clasts, less than 50 mm, range from elongate to nearly spherical. There are rare clasts of grey chert, which are all elongate and undeformed.

Fig. 58 Mudclasts in a turbidite unit, Tantangara Beds, Tantangara Dam. (Neg. no. GA/8041)

In thin-section the rock is trimodal. Large grains 0.5 to 2.0 mm diameter form the first size group and make up the bulk of the rock, with grains 0.05 to 0.15 mm forming the second group, and fine phyllosilicate needles fill the interstices between the larger grains. The grains of the first group are dominantly well rounded, with a high sphericity, and the fine sand grains are generally subangular and commonly have interpenetrative boundaries with adjacent grains.

Quartz forms 80% to 98% of the grains in the first and second groups with all grains showing undulose extinction, and many showing deformation lamellae. No detailed study of the type of undulose extinction and provenance of the quartz grains was made owing to lack of knowledge of the effects of subsequent strong deformation undergone by the Beds. Rare detrital grains of potassium feldspar and plagioclase form part of the second group in some samples, and there are rare flakes of muscovite, possibly of detrital origin.

Several types of rock fragments are present, the most common being black mudstone, brown in thin section, composed entirely of phyllosilicate material with no silt-size grains. Bedding is generally not visible in these fragments which are mostly elongate with length: width ratios up to 3:1. Chert is present in minor amounts and is formed of phyllosilicate and cryptocrystalline quartz. Volcanic rock fragments present in almost all samples are generally rare but are in a few places the dominant rock type. They are composed of interlocked andesine laths, averaging 0.15 mm long, set in a brown phyllosilicate matrix. They are closely comparable to the volcanic rocks in the Nine Mile Volcanics.

The matrix of the rock is composed of a pale brown network of fine phyllosilicate needles. Much is too fine-grained to be identified, though sericite and a chlorite with anomalous 'Berlin Blue' interference colours are present, and in some rocks red-brown biotite forms small clusters of fine needles.

Using the classification of Folk (1968), these rocks range from quartz arenite to sublitharenites, the dominant rock fragment being black shale, with minor chert and volcanic fragments.

Within a single turbidite unit the coarse arenite described above grades into fine arenite by a gradual elimination of the large group-one grains with little change in the ratio between the second and third groups. The fine arenite passes into siltstone by a reduction in the proportion of group-two grains, and their total elimination produces shale. The reduction in grainsize to siltstone and shale is usually accompanied by a change in colour from very dark grey to lighter grey or dark brown. The mineralogy of the finer-grained rocks is similar to the coarse arenite except that quartz grains dominate and rock fragments are rare or absent. All fine arenites would be called quartz arenites under Folk's classification.

Although the fine arenite, siltstone, and shale associated with coarse arenite commonly form the upper parts of graded-bedding units, they may also form such units without a coarse arenite at the base or may occur as individual uniform beds up to 2 m thick. The finer-grained beds are commonly much softer than the massive coarse arenite, and so rarely form natural exposures, generally being seen only in road cuttings.

The second association, typified by the section on the Snowy Mountains Highway on the east side of the Monaro Range, differs from the first by the almost complete absence of thick beds of coarse arenite. The common rock type is a medium to light brown fine arenite which may grade up into brown siltstone and grey to brown cleaved shale. Graded bedding is less prominent than in the first association, and fine arenite and shale may form thick beds showing no sign of it. Thick massive beds of coarse arenite, similar to those of the first association, are rare. Less rarely, the bottom few centimetres of a graded unit will be coarse arenite.

In outcrop the fine arenite is typically light to medium brown, or rarely grey, soft, and deeply weathered, and occurs either as the basal part of turbidite units up to 1.5 m thick, or as separate beds 0.5 to 30 m thick. Because of its soft nature it is only seen in road cuttings, a feature of all rock types of the second association. Thin sections show that it is bimodal; grains ranging in size from 0.25 to 0.05 mm form 50% to 70% of the rock, and fine silt to clay forms the matrix. Quartz grains form the bulk of the fine sand, with chert and shale fragments forming less than 5%, if present. Sparse albite and muscovite appear to be of secondary origin. The matrix is generally indeterminate, but both chlorite and sericite have been seen. The siltstones is mineralogically similar, differing only in grainsize.

The shale is brown to grey, commonly finely laminated, and invariably strongly cleaved. It either forms the upper part of a graded-bedding unit, or occurs as individual beds up to 50 m thick. In thin section the lamination is formed alternately by fine silt-grade detrital quartz and phyllosilicate material. Laminae are 0.5 to 2.0 mm thick, the coarser material forming the thicker laminae. The phyllosilicate material forming the matrix of the fine siltstone

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and shale is generally indeterminate, but includes chlorite and sericite.

Chert has been found at several places apparently within the Tantangara Beds. At one locality, 1 km south of Tantangara Dam (G.R. 498361) dark bluish grey chert in layers 20 to 60 mm thick forms a bed 5 m thick and at least 200 m long. At another locality, on both banks of Goorudee Rivulet 100 m west of the Snowy Mountains Highway (G.R. 517203), dark bluish grey chert in beds 100 to 500 mm thick is intttee bedded in roughly equal proportions with dark grey argillite. At a third locality, 6 km southeast of Tantangara Dam (G.R. 543319), cleaved and folded grey chert layers 50 to 300 mm thick, forms a bed at least 30 m thick, and extends northeast for about 1 km.

Although no formal subdivision of the Tantangara Beds on the basis of the lithological associations could be made, a coarse arenite bed within the second association proved to be a useful marker bed. This bed forms a well defined ridge extending from Little Gulf Creek at G.R. 535368 south for 4.5 km to G.R. 523318. Some coarse arenite in a structurally complex area 1 to 2 km east of the southern end of the ridge may be a continuation of the bed.

The rock forming the marker bed varies from light to dark grey. contains large (to 1.5 mm) quartz grains visible to the naked eye, and is very hard. At some localities it is recrystallized and has a spotted appearance, apparently owing to thermal metamorphism, althouth no igneous intrusions are known nearby. The rock is a coarse quartz arenite similar to the coarse arenite of the first association, except that rock fragments are uncommon. The arenite appears to be a single turbidite unit at least 25 m thick.

ENVIRONMENT OF DEPOSITION

The widespread presence of graded beds, showing many of the features described by Bouma (1962) and Walker (1967), is indicative of a turbidite or flysch environment of deposition for much of the Tantangara Beds. The predominance of coarse arenite in the lower part of the sequence, and of finer arenite in the upper part appears to indicate that the source area of the sediments either developed lower relief or became farther away. The direction in which source area of the sediments lay is unknown.

RELATIONS

The contact of the Tantangara Beds with the underlying beds is not exposed, but is considered to be an unconformity. Evidence for this is two-fold.

Firstly, there is a faunal break between the Nungar Beds (Eastonian, Late Ordovician) and the Tantangara Beds (Early Silurian), and secondly the Tantangara Beds overlap the Nungar Beds to rest on the Temperance Chert east of Nattung Trig.

The Tantangara Beds are overlain with strong unconformity by the Peppercorn Beds (Late Llandovery) and by the Kellys Plain Volcanics (Late Silurian). Eastwards the boundary of the Tantangara Beds with the Adaminaby Beds is probably always faulted, though field evidence is too poor to be certain. Faunal evidence indicates that the Tantangara Beds would rest unconformably on the Adaminaby Beds.

## THICKNESS

No accurate estimate can be made of the thickness of the Tantangara Beds because of poor outcrop and complex structure. It is considered that the section from Tantangara Dam east to Little Gulf Creek exposes at least 1000 m of sediments, and the section on the Snowy Mountains Highway, possibly at a higher stratigraphic level, exposes another 1000 m. From this the Beds would be at least 2000 m thick.

## AGE

Fossils were collected from a coarse sublitharenite at G.R. 492299 just inside the tree line on the northern edge of Nungar Plain. Although the fauna is poorly preserved and fragmentary, D.L. Strusz (BMR) has been able to confirm its Silurian age:-

'Most of the fragments of tabulate corals, and many of the smaller shell fragments cannot be identified. However a series of brachiopod fragments can be assigned with reasonable confidence to Eospirifer. This spiriferid is first known in the Llandoverian, is common throughout the Silurian, and persists into the Early Devonian in central Europe.

'In addition, two specimens of a fasciculate species of Tryplasma are present. Although this genus appears in the Upper Ordovician, it is most common in the Silurian.

'Also, one of the tabulate coral fragments can be fairly confidently assigned to Angopora, which first appears in the Silurian according to Hill & Stumm (1956, p. F464).'

It thus seems certain that a Silurian or younger age may be given to the Tantangara Beds on the basis of the fossil evidence. In addition, the strongly deformed Tantangara Beds are overlain unconformably by the more gently folded Peppercorn Beds in the Nungar Creek valley. These latter beds have been dated by conodonts from the limestone at Cooinbil homestead as late Llandovery, (see p. 143), so that the Tantangara Beds must be early Llandovery. The possibility that part of the Tantangara Beds may be of uppermost Ordovician age cannot be dismissed, but it seems unlikely that fossil evidence will be forthcoming.

Sediments of a similar age and lithology have not previously been recognized in southern New South Wales, possibly because of lithological similarity to many of the Late Ordovician rocks in the region and because of extreme scarcity of fossils.

## PEPPERCORN BEDS (defined here)

(M.O.)

### NOMENCLATURE

Peppercorn Group was the name given by Walpole (1952, p. 9) to a series of possibly ?Middle Silurian sediments exposed on The Long Plain and around the headwaters of Peppercorn Hill, a prominent hill at the north end of the Long Plain, and no type locality was designated. According to the Australian Stratigraphic Code the unit cannot be considered a Group (not being formed by two or more formations), and later workers called the unit the Peppercorn Beds.

The name Peppercorn Beds first appeared in published work in 1964 on the second edition of the Canberra 1:250 000 Geological Map (Best et al., 1964) and was mentioned briefly by Walpole (1964, p. 38). The 1:250 000 map showed a large area of Peppercorn Beds to the west of the Long Plain Fault, an area of acid volcanics which we now identify with the Goobarragandra Beds rather than the Peppercorn Beds. Walpole apparently realized this difference as he differentiated them in a sketch map (Walpole, 1964, fig. 11).

Previously Stevens (1958a) had described outcrops of chert conglomerate and sandstone in the Nungar Creek valley, and, although realizing their Silurian age, did not correlate them with the Peppercorn Beds to the north, and left them unnamed. The present work has shown that the outcrops described by Stevens are part of the Peppercorn Beds.

Legg (1968) described the Peppercorn Beds from the Peppercorn Creek area, and Bein (1969) described them in the lower Nungar Creek valley and on Dairymans Plain. Bein introduced the name 'Currango Beds' for the Nungar Creek occurrence of the Peppercorn Beds because of the then existing uncertainity about correlating between Nungar Creek and the Peppercorn area. The name 'Currango Beds', recently defined by Crook et al. (1973), is considered a junior synonym of Peppercorn Beds and is not used here.

Strusz (1971, p. 11) noted that much of the rock west of the Long Plain Fault should be included in the Goobarragandra Porphyry (Goobarragandra Beds of this Record). He also stated that 'the type area for the Peppercorn Beds is at the head of Peppercorn Creek, east of the Long Plain Fault' (Strusz, 1971, p. 13), though he failed to indicate who originally designated this area.

## DERIVATION OF NAME

The Peppercorn Beds were named by Walpole from Peppercorn Hill, a prominent hill at the head of the Long Plain, capped by Tertiary basalt.

## TYPE SECTION

The type section here chosen is in the valley of Little Peppercorn Creek, and starts about 200 m northeast of the creek crossing of an old track from Little Peppercorn Plain to Little Peppercorn Hut (Fig. 25). From this point (G.R. 482637) it extends northwestwards for about 800 m to the base of the overlying Kelly Plain Volcanics (G.R. 479643).

The contact of the Beds with the underlying Nine Mile Volcanics is not exposed, but mapping in the area has shown it to be an unconformity as the Peppercorn Beds rests on various units within the Nine Mile Volcanics as the contact is traced to the northeast. The basal unit within the Peppercorn Formation in the type section is a coarse sandstone bed about 5 m thick, which contains reworked fragments of tuffaceous material from the underlying volcanics. This unit is not exposed, being found only as float. It is followed by 65 m of poorly bedded conglomerate which, being resistant to weathering, has formed good outcrops along a ridge about 25 m high. The conglomerate is composed dominantly of well rounded chert pebbles up to 30 mm in diameter, and has interbeds of

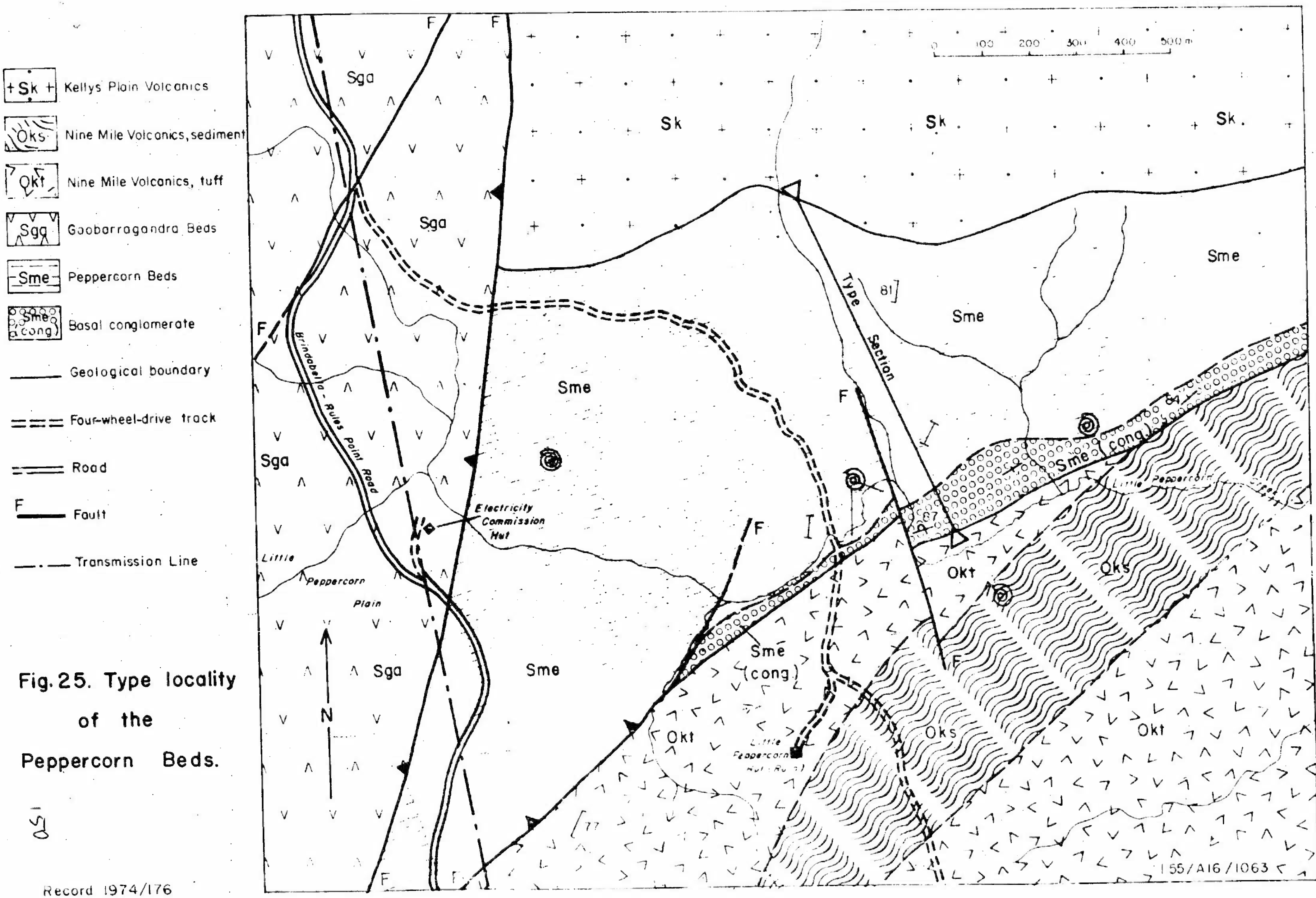


Fig. 25. Type locality of the Peppercorn Beds.

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coarse sandstone and pebbly sandstone, particularly towards the top. The beds appear to have a vertical dip, and strike 060°.

The conglomerate passes gradually up into first coarse and then finer sandstone which forms poor outcrop. This sandstone unit is about 25 m thick. It in turn passes gradually up into strongly cleaved brown siltstone which lacks obvious bedding and is very poorly exposed. This lithology continues uninterrupted up to the overlying Kellys Plain Volcanics. The thickness of the siltstone is uncertain owing to the poor exposure and lack of dip readings, but is thought to be more than 500 m.

## DISTRIBUTION

The Peppercorn Beds are widespread, extending from Nungar Creek in the south to Little Peppercorn Creek in the north. The main area is at the northern end of the Long Plain, from Cooinbil homestead north along the eastern slope of Peppercorn Hill, and Little Peppercorn Creek in a series of faulted outcrops. Southeast of Cooinbil the Peppercorn Beds are overlain by the Late Silurian Kellys Plains Volcanics, and on Currango Plain and Dairymans Plain there are only isolated inliers within the Volcanics, or small outcrops on their western boundary. Farther south, in the Nungar Creek valley, the Peppercorn Beds crop out almost continuously from the mouth of Nungar Creek to the Nungar Trail crossing, continuing from there as small isolated outliers to the eastern slopes of Blackfellows Hill. The Beds extend northeast from Little Peppercorn Creek in a narrow faulted belt for about 4 km before disappearing beneath the overlying Kellys Plain Volcanics, to reappear in the Tinpot Creek valley, and extend north into the Brindabella Sheet area.

## LITHOLOGY

The lithology of the Peppercorn Beds is constant over a wide area, and consists of a basal chert conglomerate overlain by coarse passing into fine sandstone, commonly fossiliferous immediately above the conglomerate; higher in the succession are interbedded fine sandstone, siltstone, and mudstone. Fossils are present in isolated pockets in the upper beds, and lenses of fossiliferous limestone and calcareous shale crop out near Cooinbil on the Long Plain. Locally the basal conglomerate is underlain by a medium to coarse sublitharenite up to 10 m thick, as in the type-section, and in the Nungar Creek valley.

The basal chert conglomerate is the most distinctive part of the Peppercorn Beds. Wherever it crops out it forms prominent tors and ridges, as in the lower Nungar Creek valley where outcrops are up to 10 m high. The conglomerate is mostly formed of rounded to subangular chert pebbles having a fairly high sphericity. The composition of the pebbles reflects to some extent the subjacent rock type: volcanic pebbles are present, in addition to chert, where the conglomerate overlies the Nine Mile Volcanics, and quartz arenite and sublitharenite pebbles where it overlies the Tantangara Beds. The size of the pebbles shows little variation from Little Peppercorn Creek to the lower Nungar Creek valley, averaging 1 to 5 cm in diameter, but farther south some pebbles are 20 cm across though most are no more than 10 cm in diameter.

The matrix of the conglomerate consists of well rounded sand ranging from very fine to granule size. The sand-size material also occurs as small cross-bedded lenses within the conglomerate.

The thickness of the conglomerate varies over short distances. In the Little Peppercorn Creek area it is in places up to 70 m thick although generally less than 25 m. South of Little Peppercorn Creek it is cut out completely by faulting, and when it reappears on Dairymans Plain it is about 5 m thick, though the full extent may be hidden by the overlying Kellys Plain Volcanics. In the Nungar Creek valley the thickness varies from about 3 m in the north to about 30 m in the south.

The conglomerate grades up into light brown sandstone and sandy siltstone. Fossils are present at many localities in this siltstone, almost always within a few metres of the top of the conglomerate. Rare thin beds of conglomerate, up to 0.5 m thick, are interbedded with the siltstone in the Long Plain area, and show many of the characteristics of the main conglomerate unit, although the pebbles rarely exceed 2 cm in diameter. The sandy siltstone generally shows few sedimentary structures apart from minor lamination and small-scale cross-bedding, but in the Nungar Creek valley at G.R. 473396 a bed about 80 cm thick shows well developed slump-structures (Fig. 59).

Small lenses of limestone and calcareous shale are interbedded with sandy siltstone on the Long Plain, near Cooinbil. The limestone is partly recrystallized and sheared, generally light grey with pink patches, and contains crinoids, stromatoporoids, tabulate and rugose corals, and brachiopods (Hill, 1954).

The sandy siltstone grades upwards into poorly laminated medium brown to dark grey fine siltstone or mudstone which is commonly moderately cleaved and has very poor outcrop. There are inliers of this mudstone in Kellys Plain Volcanics on Currango Plain and near Smiths Hut.

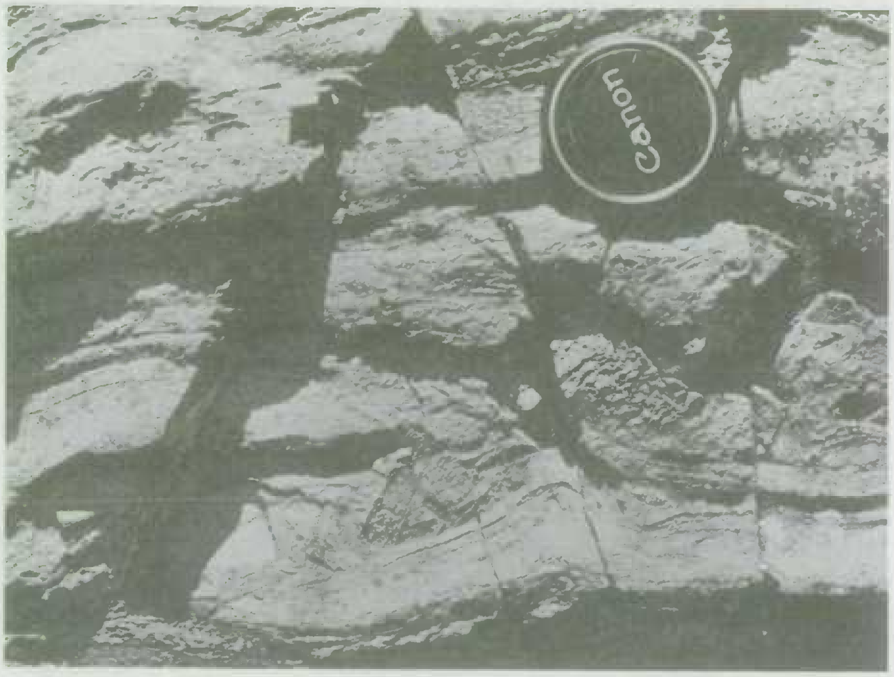


Fig. 59 Slumped siltstone bed, Peppercorn Beds, Nungar Creek (G.R. 473396). (Neg. no. GA/8107)

THICKNESS

The Peppercorn Beds in its type section is about 600 m thick. This probably represents the maximum thickness now exposed as the outcrop of the Beds elsewhere is often restricted by faulting or by the overlying Kellys Plain Volcanics.

RELATIONS

The Peppercorn Beds unconformably overlie the Nine Mile Volcanics in the Peppercorn Creek area, the Temperance Chert near Dairymans Plain, and the Tantangara Beds in the Nungar Creek valley. The top of the Peppercorn Beds is nowhere exposed, being either faulted or overlain unconformably by the Late Silurian Kellys Plain Volcanics.

The relation between the Peppercorn Beds and the younger Cooleman Plains Sequence, described on p. 168 et seq., is made uncertain as Kellys Plain

Volcanics covers the contact between tnem. The possible relation existing is fully discussed later (p. 170); it is likely that the Peppercorn Beds pass laterally into the Pocket Beds, and upwards conformably into the Cooleman Limestone.

The 'Brindabella Beds' (of Best et al., 1964) are considered the northern continuation of the Peppercorn Beds, the siltstone which forms the 'Brindabella Beds' being very similar lithologically to that in the upper part of the Peppercorn Beds.

## AGE

Macrofossils are common in the Peppercorn Beds at many localities. They are present in three differenc rock types. The most common fossils are in the sandy siltstones immediately above the basal conglomerate, particularly in the Nungar Creek and Little Peppercorn Creek valleys where they are preserved as moulds. Fossils are less abundant in the fine siltstone higher in the sequence, where they are preserved as molds, both scattered through the rock and concentrated into particular beds, the third occurrence is in the limestone lenses near Cooinbil.

Hill (1954) described corals from the limestones near Cooinbil and recognized Halysites sp. cf. australis, Coenites cf. seriatopora, H. brevicatenatus sp. nov., H. sp. indet., and Diploepora sp. cf. grayi. This fauna was stated by Hill to indicate a Wenlockian or Ludlovian age. D. Strusz (pers. comm.) came to a similar conclusion based on material collected in the Nungar Creek valley (at G.R. 471411). Significant fossils identified by Strusz were Encrinurus cf. etheridgei, Rhizophyllum sp., and ?Nucleopsira sp. More detailed work remains to be done on these faunas.

The limestone at Cooinbil has yielded a rich conodont fauna, the main elements of which have been identified by R.S. Nicoll (BMR). Significant species present are Ambalodus galerus, Apsidognathus tuberculatus, Astrognathus cf. tetractis, Neospathognathodus pennatus, Ozarkodina gaertneri, Pterospathodus amorphognathoides, and Pygodus lyra. This fauna indicates a correlation with the Telychian Stage (late Llandovery) of the Welsh Borderlands (Aldridge, 1972)

The age of the Peppercorn Beds is therefore late Llandovery.

THE COOLEMAN PLAINS SEQUENCE

(M.O.)

The term Cooleman Plains sequence is introduced to include the Middle to Late Silurian sedimentary rocks which crop out in the Cooleman Plain, Cave Creek, Goodradigbee River, and Peppercorn Creek areas. The units included are the Cooleman Limestone, Pocket Beds, and Blue Waterhole Beds. The three units are closely related, and previously have been included in the Cooleman Group. However the Australian Stratigraphic Code requires that the term group is only used if all the units within the group have the status of formations. Unfortunately it does not suggest an equivalent term to be used where the constituent units have yet to be formally defined; the term sequence is therefore used in this report for these units.

The geology of the area in which the Cooleman Plains sequence crops out was first referred to by the Rev. W.B. Clarke (1860), who reported 80 to 100 $km^2$ of cavernous limestone, apparently metamorphosed by the intrusive granites and porphyries in the Cooleman Plains area. Leigh & Etheridge (1894) reported on the caves and on several aspects of the geology, used the name Cooleman Limestone for the first time, and distinguished it from a limestone (called Cave Limestone) underlain by calcareous shale at Cooleman Falls.

No further investigations were made until Walpole (1952) mapped the area. He described the Cooleman Limestone in more detail but did not recognize the overlying siltstone and chert as a separate unit.

Snowy Mountains Authority Staff examined the area as part of a regional survey for the proposed Tantangara Reservoir, Newberry (1956) naming the Pocket Beds near Pocket Saddle and the upper Goodradigbee River valley. Stevens (1957, 1958b) presented the most detailed geological report to that date and published the first detailed geological map of the area. He recognized four units, introducing the name Wilkinson Limestone for the limestone cropping out downstream of the Cave Creek waterfall, and also recognized the existence of complex facies relations between the various units.

Walpole (1964) and Best et al. (1964) introduced a completely different nomenclature for the Silurian rocks of the area, but did not publish a written account of the units. The names introduced by them are synonymous with names introduced by Stevens (1958); the 'Marys Hill Beds' and 'Mount Murray Branch Formation' of Walpole and Best et al. being equivalent to the Blue Waterhole Beds and Pocket Beds respectively of Stevens.

Legg (1968) largely concurred with Stevens in his mapping of the area, but recognized the similarity of the Cooleman Limestone to the limestone near the top of the Pocket Beds, and further refined Stevens' ideas of lateral facies relations. He also attempted to reconstruct the palaeogeography and depositional environment of the beds.

Palmer (1972) remapped the area and added new information on the Late Silurian sediments in the Goodradigbee River valley downstream from Cave Creek. However his work was concentrated on the geochemistry of the Devonian igneous rocks of the area, and relatively little attention was paid to the sedimentary rocks.

The Cooleman area was examined by M. Owen during the 1971-2 summer and was mapped in detail by P. Jell in November 1972, with some additional mapping by D. Wyborn in the Peppercorn Creek area during March 1973. This account of the Cooleman Plains sequence was prepared by Owen using notes provided by Jell and Wyborn.

## POCKET BEDS

(Newberry, 1956)

### NOMENCLATURE

The name Pocket Beds was introduced by Newberry (1956) for a sequence of quartzite, slate, phyllite, lenticular limestone, and tuff in The Pocket area, near the Goodradigbee River and for about 5 km downstream in the Goodradigbee valley. The name was first published by Stevens (1958b). The Mount Murray Branch Formation of Walpole (1964) and Best et al. (1964) is a junior synonym of the Pocket Beds.

### DERIVATION OF NAME

The unit was named from Pocket Saddle on the divide between Pocket Creek which drains north into the Goodradigbee River, and Gurrangorambla Creek which drains south into the Murrumbidgee River.

### REFERENCE SECTION

A reference section for the Pocket Beds is designated here along the Goodradigbee River. The base of the section is taken where a dyke of

Gurrangorambla Granophyre intrudes the Pocket Beds at G.R. 553554 about 1.5 km above of the junction of Cave Creek and the Goodradigbee River. The top of the section, at the junction of the Pocket Beds and the Blue Waterhole Beds is about 0.4 km above the entry of Cave Creek at G.R. 553563. The reference section exposes about 750 m of the Pocket Beds in the bed of the Goodradigbee River and shows the typical lithology of the unit, that is, cleaved mudstone with interbeds of impure limestone, and coarser beds (some tuffaceous) near the base. Upstream of the granophyre dyke there are strata lower in the Beds, but they are strongly cleaved and poorly exposed.

The location of the reference section is shown in Fig. 26, and the succession in Table 20A.

TABLE 20A. TYPE SECTION OF THE POCKET BEDS

| Unit | Lithology | Thickness (m) |
|---|---|---|
| Blue Waterhole Beds | fine hard black chert | |
| Pocket Beds | fine-grained brown shale | 75 |
| | impure limestone | 11 |
| | fine brown shale | 115 |
| | impure grey limestone, highly fossiliferous in places, and with thin shale interbeds | 140 |
| | fine brown cleaved shale with a few coarser sandstone beds | 115 |
| | impure, highly cleaved grey limestone | 32 |
| | fine brown shale, highly cleaved with rare coarser beds | 140 |
| | coarse tuff | 15 |
| | fine brown shale | 24 |
| | medium-grained, lithic, slightly tuffaceous sandstone | 21 |
| | coarse hard tuff | 15 |
| Gurrangorambla Granophyre | intrusive granophyre sill | 18 |
| | End of section | |

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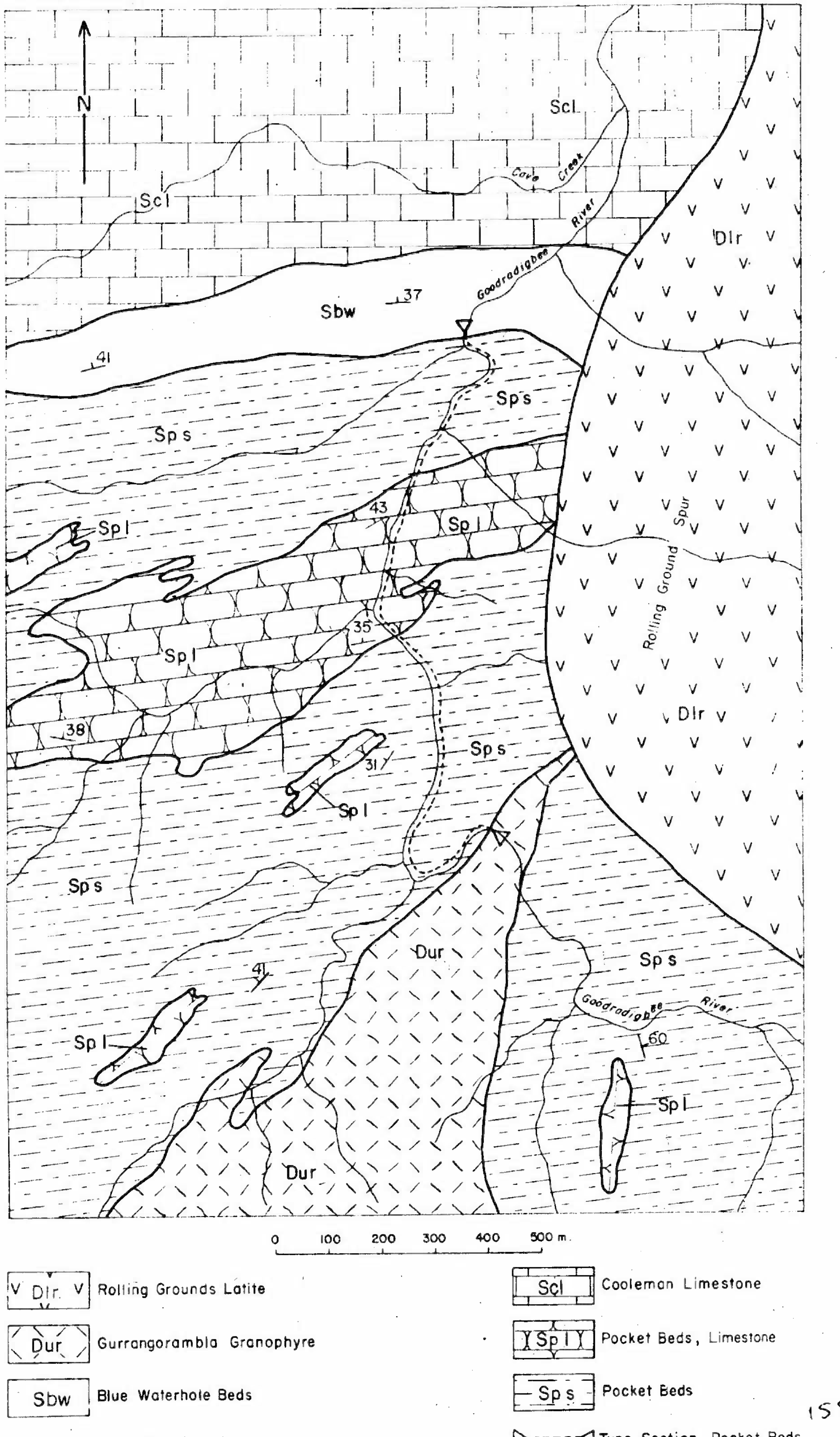


Fig.26. Type section of the Pocket Beds.

DISTRIBUTION

The Pocket Beds crop out in two areas, separated by the intrusive Gurrangorambla Granophyre and the extrusive Kelly Plains Volcanics. The northern area lies between Black Mountain to the west and Rolling Grounds Spur to the east, and is bounded in the north by a prominent ridge immediately south of Cave Creek. Southwards this area is bounded by the Granophyre, of which a narrow dyke also splits the area into two parts. The southern area in which the Pocket Beds crop out is an elongate faulted area trending north-south, about 3.5 km by 0.5 km. Its northern end occupies part of the Goodradigbee River valley and the southern part crops out in the Pocket Creek valley.

The soft, deeply weathered nature of much of the unit is reflected in the topography, both areas being the site of deeply incised tributaries of the Goodradigbee River. The limestone lenses, however, in places form ridges, as at G.R. 567537. The easily eroded nature of the Pocket Beds is emphasized by the presence of waterfalls where the Granophyre dykes cross the Goodradigbee River

LITHOLOGY

The Pocket Beds consist dominantly of cleaved mudstone with interbeds of impure limestone, and local thin sandy siltstone and tuffaceous beds. The mudstone is grey, weathering brown and massive or with indistinct bedding; it is commonly fossiliferous, and generally cleaved. The cleavage becomes stronger southward causing increasing distortion of fossils, until, with the formation of slate in the south, they are completely destroyed. Limestone lenses 1 to 3 m thick are common, and there are some up to 140 m thick.

The limestone is invariably impure, grey, often highly fossiliferous, and commonly has thin interbeds of shale. Its contacts with the mudstone may be sharp but generally is gradational; either there is an overall increase in mud content forming calcareous mudstone, and then mudstone, or the interbeds or shale or mudstone become more frequent. Stylolites are common in the limestone, and some beds have been completely recrystallized to medium-grained calcite, destroying original textures. Most of the unrecrystallized limestone has abundant fossil debris showing evidence of transportation, with a finer micrite or sparite cement. Patches of pelletal limestone also occur. Most of the limestone is biomicrite or biosparite, with rarer biopelsparite and rare dark grey dismicrite (terminology after Folk, 1968). Cleavage in the limestones becomes pronounced in the Pocket Creek area, destroying all evidence of original textures.

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PALAEONTOLOGY AND AGE

Both the mudstone and limestone of the Pocket Beds are locally richly fossiliferous, though species diversity is commonly low. The fauna from the mudstone (from Legg, 1968) includes the brachiopods Molongia elegans Mitchell, Atrypoidea angustans Mitchell & Dun, Howellella nucula Barrande, Atrypa spp., Pholidostrophia aff, nitens Williams, and the trilobite Encrinurus cf. mitchelli Foerste.

The limestone beds contain a rich coral and stromatoporoid fauna, including Heliolites daintreei Nicholson & Etheridge, Favosites gothlandicus Lamarok, Plasmopora heliolitoides Lindstrom, Phaulactis shearsbyi Sussmilch, Tryplasma lonsdalei Etheridge, and Pycnostylus dendroides Etheridge. The brachiopod Conchidium is present but rare.

No diagnostic condonts have been found in the limestone from the Pocket Beds, only simple cones of little value stratigraphically.

The fauna so far obtained from the Pocket Beds is considered to indicate a late Wenlock or early Ludlow age.

THICKNESS

The thickness of the Pocket Beds in the reference section is 750 m. This is a minimum thickness for the unit as its base is not exposed in that section.

COOLEMAN LIMESTONE (Leigh & Etheridge, 1894)

NOMENCLATURE

The name Cooleman Limestone was first published by Leigh & Etheridge (1894) and the limestone has been described by Walpole (1952), Stevens (1957; 1958b), Legg (1968), and Palmer (1972). No formal definition of the unit has been given.

Stevens (1958b) introduced the name Wilkinson Limestone for a limestone which overlies the Blue Waterhole Beds east of the Black Mountain Fault, and suggested that it was younger than the Cooleman Limestone. Recent mapping by P.A. Jell has demonstrated that the Wilkinson Limestone does not overly the Blue Waterhole Beds but is a tongue of Cooleman Limestone within the Blue Waterhole Beds; the name Wilkinson Limestone is therefore considered to be a junior synonym of the Cooleman Limestone. Walpole (1964) and Best et al. (1964) used the name Wilkinson Limestone instead of Cooleman Limestone for the main mass of limestone on Cooleman Plain, but the name Cooleman Limestone has priority.

## DERIVATION OF NAME

It is assumed that Leigh & Ethridge named the unit from Cooleman Plain.

## TYPE SECTION

Previous workers have failed to designate any type or reference sections in the Cooleman Limestone. It is therefore proposed to designate the two measured sections described below as type and reference sections.

The first, considered to be the type section, exposes 257 m in the upper part of the Limestone. It commences at the base of a steep bluff on the western side of Cave Creek, about 0.6 km upstream from the southern crossing of the Blue Waterhole track over Cave Creek (G.R. 518560), and extends east, updip, along Cave Creek for about 150 m before following a steep gully which enters Cave Creek at a point where the Creek swings sharply to the north. At the top of the gully the section continues along a bearing of 110° until the contact between the limestone and the overlying Blue Waterhole Beds is reached (G.R. 522559). Exposures are virtually continuous from the start of the section to the top of the gully, but became sparse over the 150 m before the end of the section. The location of the section is shown in Figure 27, and the succession is described in Table 21.

The second section exposes about 230 m of limestone and is considered to be stratigraphically lower in the Cooleman Limestone than the first, though the interval separating the two is unknown. It begins at the contact between the Limestone and the intrusive Gurrangorambla Granophyre (G.R. 517533) in a shallow (3 m deep) doline which receives the waters of a stream draining north from Gurrangorambla Range. The section trends at 020° from this doline over a fairly flat plain, with scattered outcrops at first, which becomes more abundant about 150 m from the doline. After 260 m, a wide (50 m) shallow gully trending due north is reached, and the section follows the west bank of this gully in abundant outcrop for about 170 m until the gully joins Cave Creek South Branch.

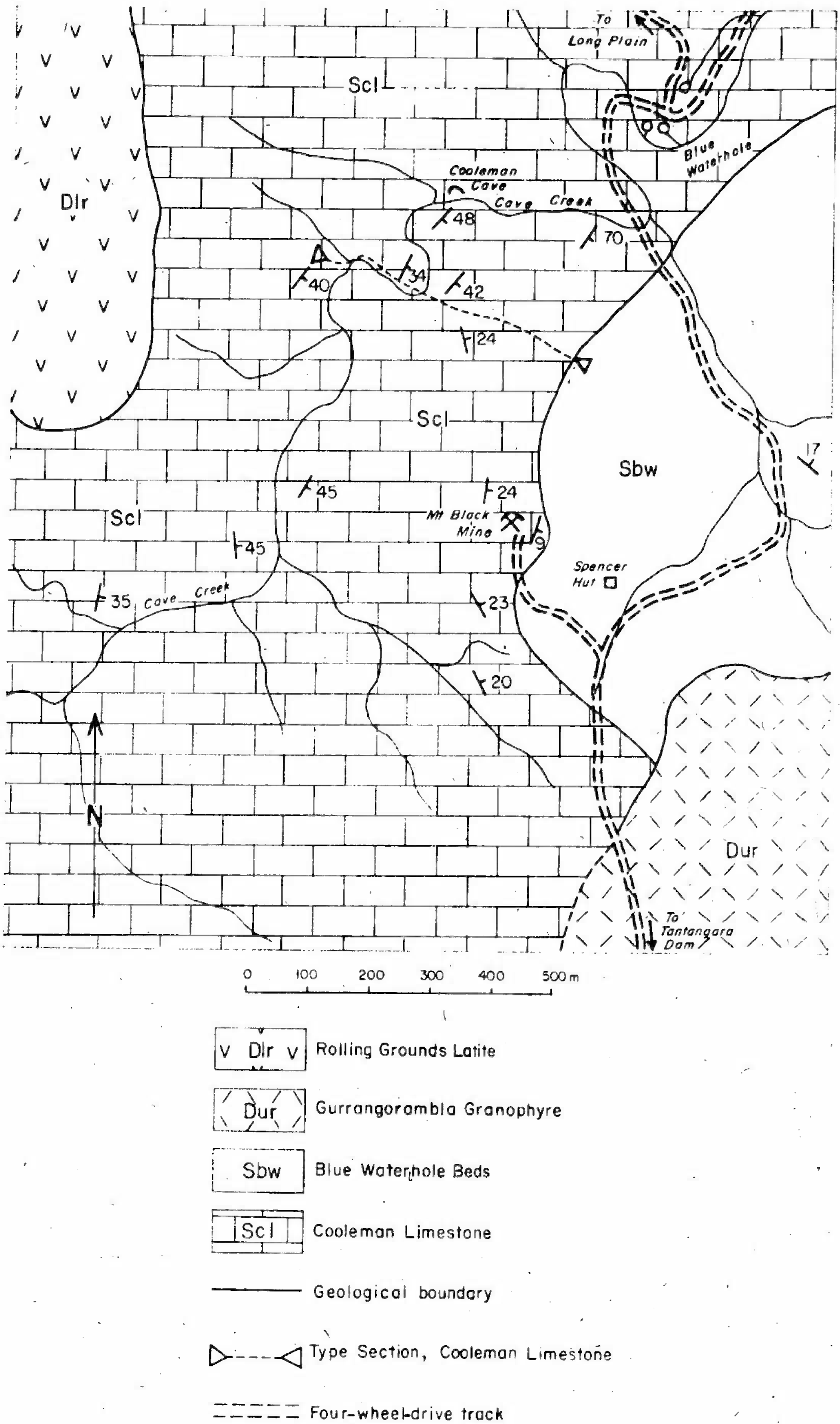


Fig. 27. Type section of Cooleman Limestone.

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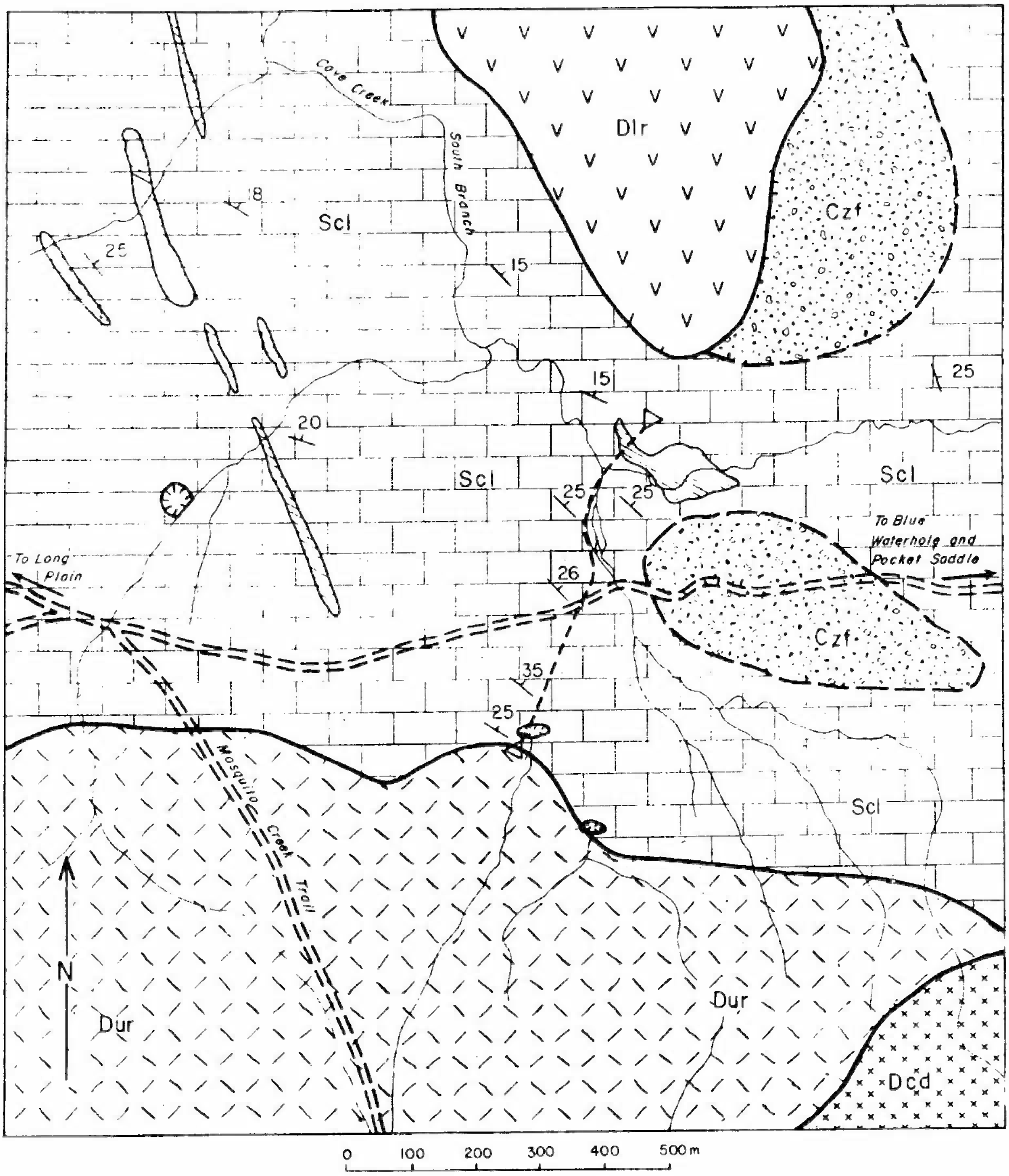


Czf Ferruginous gravels

Dcd Coolamine Diorite

Dlr Rolling Grounds Latite

Dur Gurrangorambla Granophyre

Scl Cooleman Limestone

Dolomite

Sink hole

Geological boundary

Reference section

Four-wheel-drive track

**Fig. 28. Reference section in the Cooleman Limestone.**

TABLE 21. TYPE SECTION OF THE COOLEMAN LIMESTONE

| Unit | Lithology | Thickness (m) |
|---|---|---|
| Blue Waterhole Beds | thinly bedded siltstones<br>? disconformity | |
| | poorly exposed massive limestone | 75 |
| | thinly bedded (50-150mm) dark grey limestone with irregular bedding planes passing up into thicker (100-200mm) evenly bedded limestone with stylolites | 41 |
| | well bedded light grey recrystallized sparite limestone | 5 |
| | massive to poorly bedded (2m) biomicrite limestone. Crinoids, corals, bryozoans, gasteropods, molluscs, and brachiopods. Slumped blocks of Blue Waterhole Beds (cherty siltstone) to 2m diameter, 10m above base. | 37 |
| Cooleman Limestone | Massive pale cream recrystallized limestone | 11.5 |
| | Not exposed | 7 |
| | Poorly bedded (100-500mm) cream, partly recrystallized limestone, rare brachiopods and bivalves | 23.5 |
| | Massive coarsely recrystallized limestone | 6 |
| | medium to thin-bedded (50-250mm) partly dolomitized limestone, poorly preserved fossils | 10 |
| | cream highly fossiliferous (brachiopods) limestone bed | 0.5 |
| | white partly recrystallized limestone, sparsely fossiliferous | 3.5 |
| | Poorly bedded to massive recrystallized limestone with rare large bivalves | 38.5 |
| | Start of section | |

TABLE 22. REFERENCE SECTION OF THE COOLEMAN LIMESTONE

| Unit | Lithology | Thickness (m) |
| --- | --- | --- |
| | Colluvium from overlying Rolling Grounds Latite | |
| | biosparmicrite limestone, partly replaced by dolomite | 2 |
| | sparry dolomite with small areas of micrite limestone | 5 |
| | Well bedded (150-400mm) moderate to very fossiliferous grey biomicrite (brachiopods, bivalves, stromatoporoids) | 5 |
| | Not exposed (section crosses stream alluvium) | 15 |
| Cooleman Limestone | well bedded (150-400mm) moderate to very fossiliferous grey biomicrite (brachiopods, bivalves, gasteropods, nautiloids, stromatoporoids, and rare corals). Some minor dolomitization in upper part, minor pelletal sparite | 60 |
| | gradual transition | |
| | Discontinuous outcrops of massive to thick-bedded, dark grey limestone, partly recrystallized, rare fossils, mainly brachiopods | 70 |
| | not exposed | 40 |
| | Massive grey fossiliferous limestone (brachiopods, bivalves, crinoids, corals) | 10 |
| | base of section (Gurrangorambla Granophyre) | |

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The section continues northward beyond the alluvium of Cave Creek South Branch for a short distance until the limestone is covered by solifluxion deposits derived from the Rolling Grounds Latite cropping out on the low hill to the north (end of section at G.R. 517540). The location of this section is shown in Figure 28, and the succession in Table 22.

DISTRIBUTION

The Cooleman Limestone crops out over an area of 21 km$^2$ in the Cooleman Plain, lower Cave Creek, Goodradigbee River, and Peppercorn Creek areas. About 1 km$^2$ more is thinly covered by presumed Tertiary ferruginous gravels. This is far less than the 80 to 100 km$^2$ of limestone reported by Clarke (1860).

The main area of outcrop of the Cooleman Limestone is on the southern part of Cooleman Plain, in a lunate band from Harris Hut (G.R. 483557) to north of Blue Waterhole, with a maximum width in the centre of about 3 km. It is bounded to the south and east by the intrusives of the Gurrangorambla Range and Black Mountain, and to the north by the Blue Waterhole Beds and the Rolling Grounds Latite. Outliers of Rolling Grounds Latite overlie the limestone on the Plain, and seem to be present as breccias filling depressions formed by the solution of the underlying limestone.

The second main area of Cooleman Limestone is a roughly triangular area, with a narrow extension to the southwest, in the northern part of Cooleman Plain, north and west of Coolamine homestead. It is separated from the main area to the south by the east-west ridge of Blue Waterhole Beds immediately south of Coolamine homestead.

Further areas of limestone are present in an elongate belt extending first east along the lower Cave Creek valley to its junction with the Goodradigbee River, and then in a faulted zone north along the west side of the Goodradigbee valley as far as Dunns Flat (G.R. 563635).

There are also two small outcrops of limestone in the Peppercorn Creek valley; one at G.R. 540669 occurs as a roof pendant in an intrusion of Coolamine Diorite, and the second, at G.R. 517630, is within the Blue Waterhole Beds.

The Cooleman Limestone exhibits many features typical of karst landscapes. Surface depressions, or dolines, are widespread on the southern part of Cooleman Plain, and have been formed both by solution and collapse. There are also such minor solution features as Rillenkarren. Many streams draining from the surrounding ranges flow underground as soon as the limestone is reached, and dry blind valleys are common. All the underground drainage of the area finally resurges in Blue Waterhole, a group of large risings which form the permanent source of Cave Creek. Above Blue Waterhole the creek only flows after very heavy rainfall. Almost vertically sided gorges, up to 50 m deep, have formed in several localities, for instance Clarkes Gorge, Fig. 60.

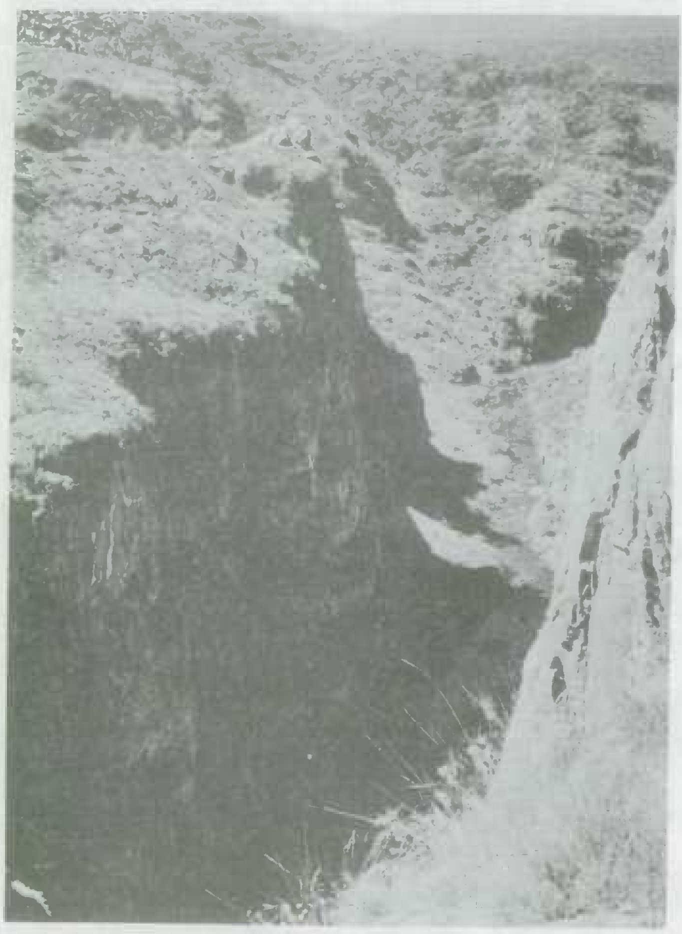

Fig. 60 Clarkes Gorge, formed in massive Cooleman Limestone, Cave Creek, 1 km downstream from Blue Waterholes. (Neg. no. GA/8110)

LITHOLOGY

Although several different rock types have been recognized within the Cooleman Limestone, the extensive recrystallization of the limestone hindered attempts to map them.

In general, the unit consists of light grey, massive to thickly bedded limestone, in places becoming moderately thin-bedded. Fossils are mostly sparse and may be completely lacking where recrystallization has reached an advanced stage. However some beds, generally of small lateral extent, are richly fossiliferous.

The bulk of the Limestone is formed by a partly recrystallized massive to thickly bedded (2m), light to medium grey limestone with few or no fossils. In thin section, two orders in size of calcite are common. The larger comprises sparry calcite crystals 2 to 4 mm across which commonly have concave boundaries, the smaller a finer sparry calcite (0.4 mm) or micrite groundmass. Variation between samples is usually limited to the degree by which the larger sparry calcite has replaced the finer calcite, and the rare occurrence of recrystallized fossil fragments.

This partly or completely recrystallized limestone in place grades both laterally and vertically into a medium grey, thickly bedded, moderately fossiliferous limestone, showing relatively few signs of recrystallization. Thin sections commonly have a very fine-grained (0.05mm) calcite groundmass with a large proportion of biogenic fragments up to several millimetres, and with rather rare complete fossils. Crinoid columnals, corals, bryozoans, gasteropods, molluscs, and brachiopods are common, with possible ostracods in some samples. Much of the lower half of the second reference section (p. 154) is formed by this moderately fossiliferous limestone.

Highly fossiliferous limestone results from an increase in the proportion of fossil fragments (not by a change in the degree of recrystallization). There is a similar range of fossils and textures to that in the less fossiliferous limestone except that biogenic fragments are dominant. Both the moderately and highly fossiliferous limestone beds show abundant evidence of bioturbation, and many fossils are worn and broken. Many limestone beds also contain pelletal material, generally formed of micritic calcite and from 0.3 mm to 4.0 mm in diameter. Stylolites are ubiquitous.

The fossiliferous limestone described above is biopelsparite or biopelmicrite, depending on the nature of the cementing matrix of the rock.

Crinoidal limestone is present in the upper part of the Cave Creek Gorge in certain zones. It is a light grey limestone, with crinoid ossicles and columns in a coarse sparry calcite matrix. Unlike the previously described fossiliferous limestone, abrasion of the crinoid fragments is minimal.

The upper part of the first measured section, in the gorge upstream of Blue Waterhole, is unusual for the Cooleman Limestone in that the dark grey limestone is well bedded. At the base of this unit the bedding surfaces are uneven and 50 to 150 mm apart, higher in the unit (which is about 40 m thick) the bedding gradually becomes more uniform, with an interval of 100 to 200 mm. Stylolites are common, and fossils rare. The limestone, from thin-section examination, is partly recrystallized, commonly about 60% being formed by sparite apparently derived from a micrite groundmass. Rare fossil fragments have been almost destroyed by the recrystallization.

Much of the limestone near Harris Hut (G.R. 483557) is formed by massive to thickly bedded, fine-grained cream intraclast sparite. The rock consists of rounded intraclasts of fossiliferous material and pelletal limestone in a medium-grained sparry calcite matrix, with coarse sparry calcite filling larger pore spaces.

Dolomitization of the limestone, in varying degrees of completion, is fairly widespread. Mostly this has taken place along major joints, and is unusual for the very sharp boundary between the dolomite and the surrounding unaltered limestone. The combination of joint-controlled dolomitization and sharp contacts with the unaltered limestone creates the superficial field appearance of dykes of dolomite intruding the limestone. Several of these dolomite 'dykes' are shown in Figure 28. Dolomitization away from joints is very patchy but appears to be controlled to some extent by lithology; however no detailed study was made of this factor.

The limestone east of Black Mountain Fault, formerly called the Wilkinson Limestone, differs from the main mass of Cooleman Limestone in that thin cherty beds are developed near its base reflecting a gradual transition from the underlying cherty Blue Waterhole Beds (Figs. 61, 62). The presence of these chert beds enables penecontemporaneous slump-structures to be recognized in the unit where it crops out near Cooleman Falls (G.R. 541563). Almost all of this unit has been highly recrystallized by the Jackson Granite, producing a sugary texture, and in parts of the Goodradigbee valley a strong cleavage is developed. Fossils are consequently rare and poorly preserved.

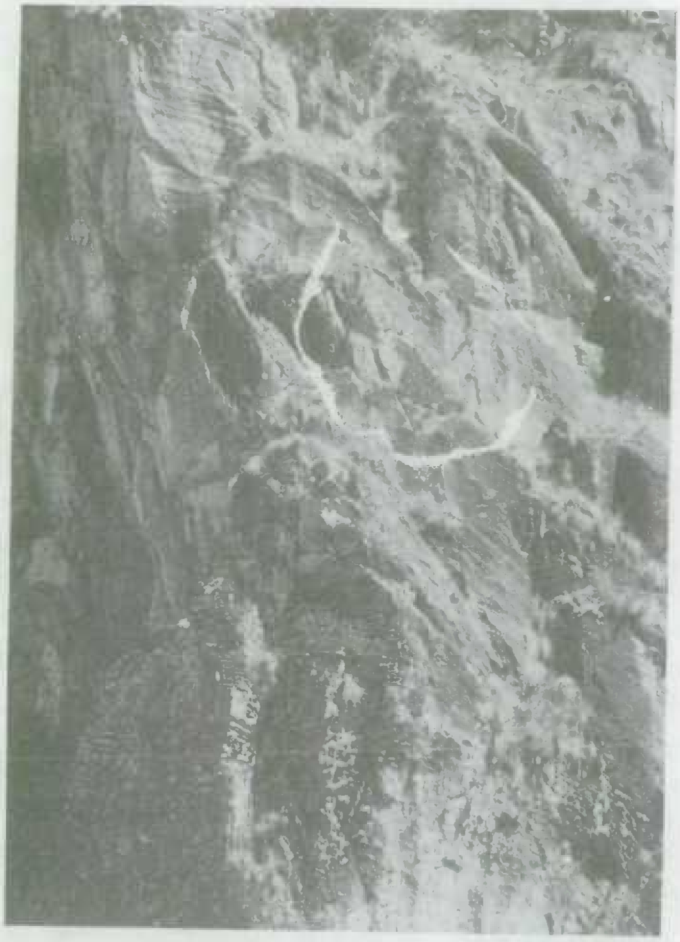

Fig. 61 Transitional contact between cherty Blue Waterhole Beds below, and Cooleman Limestone above, at Cave Creek Falls (G.R. 542564). (Neg. no. GA/8039)

Fig. 62 Cave Creek Falls, formed on the contact between the Blue Waterhole Beds and the Cooleman Limestone (Wilkinson Limestone of Stevens, 1958b). (Neg. no. GA/8033)

indicating an exposed thickness of about 70 m.

## BLUE WATERHOLE BEDS (Stevens, 1958b)

### NOMENCLATURE

The name Blue Waterhole Beds was first published by Stevens (1958b), but had previously been introduced by him in an unpublished Snowy Mountain Authority report (Stevens, 1957). Stevens also introduced the name Harris Beds in his unpublished report for a series of clastic sediments overlying the Cooleman Limestone south of Coolamine homestead, though in his later paper included this unit in the Blue Waterhole Beds.

Best et al. (1964) introduced the name Marys Hill Beds for essentially the same beds that Stevens had called Harris Beds. As we follow the prior terminology published by Stevens (1958b), the Marys Hill Beds are considered a junior synonym of the Blue Waterhole Beds.

### DERIVATION OF NAME

The Blue Waterhole Beds are named from Blue Waterhole (G R. 524563), a series of springs forming the perennial rising of Cave Creek.

### TYPE SECTION

No type or reference section was designated by Stevens for the Blue Waterhole Beds. It is therefore proposed to designate a section on Cave Creek as a type section.

The section commences at the assumed position of the contact of the Blue Waterhole Beds with the underlying Cooleman Limestone (G.R. 501557) and trends generally north along Cave Creek to a point on the hillside north of where Cave Creek swings sharply west (G.R. 500562). A map of the locality is shown in Figure 29.

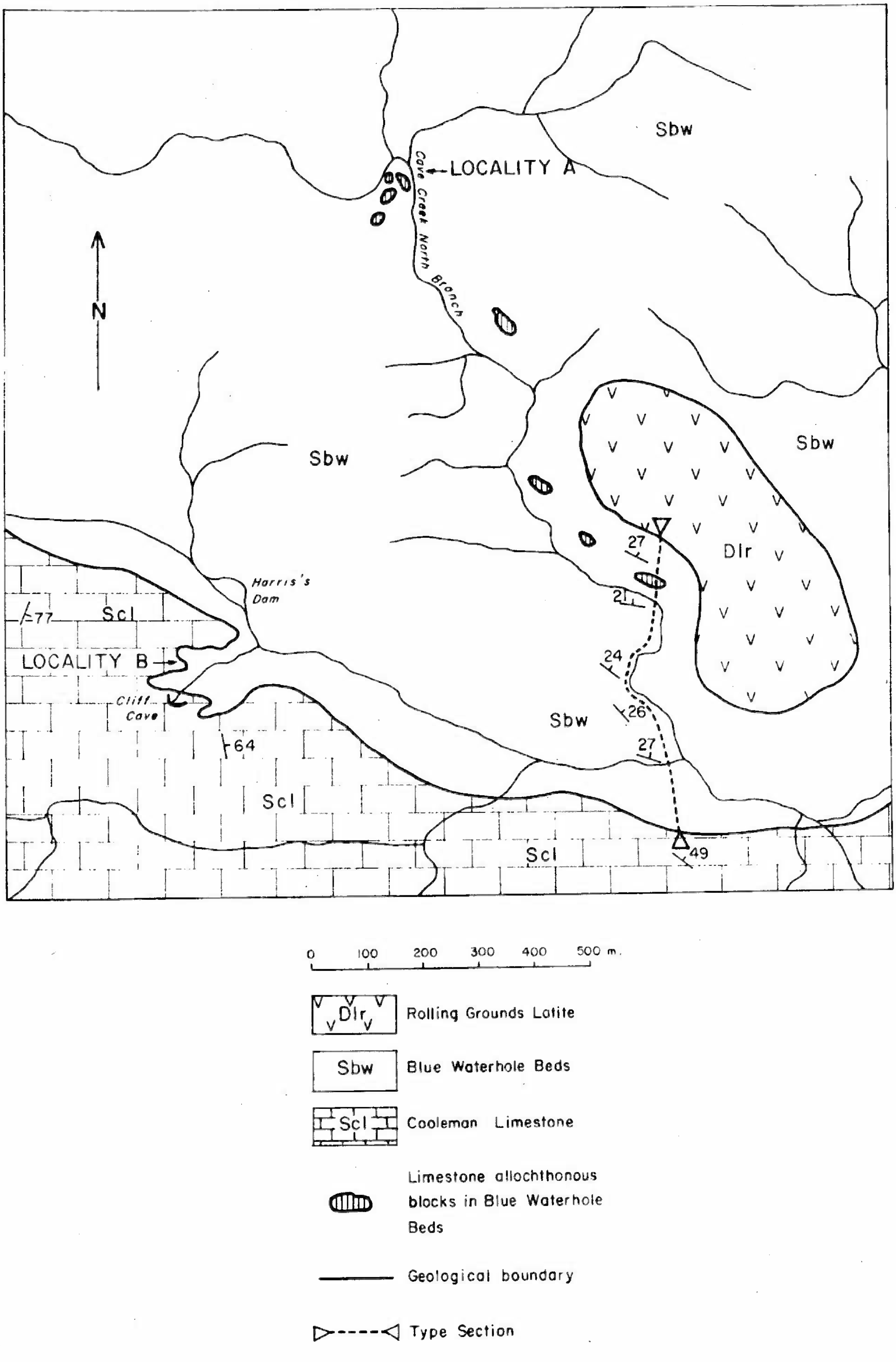


**Fig. 29 Type locality of the Blue Watherhole Beds.**

Much of the lower part of the section is not exposed, including the contact with the Cooleman Limestone, but there is almost continuous exposure in the upper part. Most of the section contains finely banded siltstone to fine sandstone beds 50 to 100 m thick, rhythmically interbedded with massive dark grey mudstone in beds 10 to 25 cm thick, showing a conchoidal fracture. Variation in the section is dominantly in the proportions of siltstone or sandstone to mudstone. Thin chert beds start to appear near the top of the section, and about 140 m above the base of the section there are some allochthonous blocks of limestone, up to 20 cm across, within a sequence showing slump structures.

The succession in the reference section is shown in Table 23.

DISTRIBUTION

The Blue Waterhole Beds crop out in four main areas in the Cooleman Plain, Goodradigbee River, and Peppercorn Creek region. These are the Coolamine/north Cooleman Plain area, the Blue Waterhole area, the lower Cave Creek/Goodradigbee valley area, and the Peppercorn Creek area. Altogether the Blue Waterhole Beds occupy an area of about 20 $km^2$.

LITHOLOGY

The lithology of the Blue Waterhole Beds shows considerable variation between different areas, being dominantly fine sandstone and mudstone in the west, and chert in the east. The characteristics of each of the main areas will therefore be considered separately.

a) Coolamine/north Cooleman Plain area. The Blue Waterhole Beds in the area south of Coolamine homestead are mainly rhythmically bedded siltstone or fine sandstone, and mudstone. The siltstone, generally in beds 50 - 100 mm thick, is composed of subangular quartz-grains, minor chlorite, epidote, and opaque minerals in a clay matrix; sorting is moderate and most of the rock is best considered a muddy siltstone. Slightly coarser-grained varieties are fine sandstone similar in composition to the siltstone except that rare rock fragments are present. The siltstone is finely laminated and small-scale cross-bedding is present.

The mudstone is generally unbedded, though an indistinct light and dark grey banding may be present. It forms beds 100 to 250 mm thick and breaks with a conchoidal fracture. Mud cracks have been observed on the upper

TABLE 23. TYPE SECTION OF BLUE WATERHOLE BEDS

| Unit | Lithology | Thickness (m) |
|---|---|---|
| | Colluvium from overlying Rolling Grounds Latite | |
| | grey mudstone thinly bedded with some siltstone and minor chert | 40 |
| | Sandstone and sandy siltstone in beds 50-150 mm thick, minor mudstone, allochthonous limestone blocks to 250 mm diameter near base | 10 |
| Blue Waterhole Beds | finely banded siltstone in beds 50-100 mm thick with interbeds of dark grey mudstone in beds 100-250mm thick and with conchoidal fracture | 10 |
| | no exposure | 7 |
| | finely banded siltstone in beds 50-100mm thick with interbeds of dark grey mudstone in beds 100-250mm thick and with conchoidal fracture | 34 |
| | no exposure | 53 |
| | weathered brown siltstone | 3 |
| | no exposure | 30 |
| | —? unconformity— | |
| Cooleman Limestone | massive limestone | |

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surface of some beds of mudstone near the base of the succession (e.g. at G.R. 478570).

The basal layers of the Blue Waterhole Beds, near Cliff Cave (G.R. 491559, locality B. in Fig. 29), are a dark brown micaceous siltstone weathering to light brown, and appear to have been deposited on an irregular surface developed on the Cooleman Limestone. They appear to be at least 40 m thick, and pass up into typical mudstone and siltstone.

Thin beds (50 - 150 mm) of dark blue-grey chert in the upper part of the sequence are interbedded with generally hard, dark grey siltstone. Above this, hard fine-grained micaceous sandstone contains small amounts of rock fragments, apparently forming the uppermost beds in the area south of Coolamine.

A distinctive zone of slump structures is present along Cave Creek, from the reference section north-northwest for 900 m as far as a sharp U-bend in the Creek (locality A in Fig. 29). This zone is about 140 m above the base of the Blue Waterhole Beds in the type section. Bedding is extremely contorted and the zone is made more distinctive by the presence of numerous allochthonous blocks of limestone ranging from less than 50 mm to several metres across. The limestone blocks become more common towards the north-northwest, and reach their greatest development at locality A of Figure 29 (G.R. 496569). The limestone is similar in appearance to the Cooleman Limestone, contains a similar conodont fauna, and appears to have been lithified before the slumping took place. The presence of allochthonous blocks of Cooleman Limestone in the Blue Waterhole Beds indicates that, even though 140 m of sediment in the Blue Waterhole Beds had been deposited, there was still Cooleman Limestone either being deposited or exposed close to the area in which the Blue Waterhole Beds now occur.

A poorly exposed sequence of Blue Waterhole Beds on the northern edge of Cooleman Plain is similar to the main part of the succession described above, except that fine sandstone appears to predominate over mudstone.

b) Blue Waterhole area. The Blue Waterhole Beds which crop out in the Blue Waterhole area appear transitional in lithology between the area of mudstone and siltstone in the west, and the area to the east where chert dominates. In the Mount Black Mine area (G.R. 522557) soft brown micaceous siltstone in beds averaging 150 to 200 mm thick forms the base of the Blue Waterhole Beds, and appears to lie unconformably on the Cooleman Limestone, though the evidence is ambiguous. The micaceous siltstone passes up into a dark to black siliceous fine siltstone in the area immediately east of Spencers Hut (G.R. 523555). The siliceous siltstone, which contains abundant fossils preserved as moulds, rests directly on Cooleman Limestone above Clarks Gorge (G.R. 529563, Fig. 63), and at this locality appears to have been deposited on an irregular surface developed on the Cooleman Limestone. Apparently the micaceous siltstone lenses out between Spencers Hut and Clarks Gorge. Towards Black Mountain from Spencers Hut the siliceous siltstone is overlain by a fine-grained quartzite which has been intruded by several sills of Gurrangorambla Granophyre.

Fig. 63 Cherty facies of Blue Waterhole Beds; above Clarks Gorge (G.R. 529563). (Neg. no. GA/8028)

c) <u>Lower Cave Creek/Goodradigbee valley area</u>. East of the Black Mountain Fault, in the lower valley of Cave Creek, and extending downstream along the Goodradigbee River as far as Dunns Flat (G.R. 563634), the Blue Waterhole Beds are formed of black bedded chert containing disseminated pyrite, and a dark siliceous fossiliferous siltstone, in places calcareous, similar to that near Spencers Hut. Limestone lenses are also present. The Blue Waterhole Beds in this area rest directly on the Pocket Beds apparently conformably, and pass upwards into a limestone unit named by Stevens the

Wilkinson Limestone, but considered by us to be part of the Cooleman Limestone. Farther downstream on the Goodradigbee River, the Blue Waterhole Beds can be seen both above and below the Cooleman Limestone which lenses out into cherts near Dunns Flat.

d) Peppercorn Creek area. The fourth main area in which the Blue Waterhole Beds crop out is an elongate belt about 1.5 km wide which starts northwest of Jackson Mountain in the Peppercorn Creek valley, and trends north-northeast into the Brindabella 1:100 000 Sheet area. At the southern end of this belt the Blue Waterhole Beds consist of well bedded siliceous siltstone, fine sandstone, and mudstone, with a few interbedded lenses of limestone at G.R. 518632. Farther north these give way to poorly bedded brown micaceous siltstone and lithic sandstone, which apparently overlie the succession o farther south. At the northern end of this belt well bedded chert and siliceous crop out, very similar in appearance to the Blue Waterhole Beds of the Goodradigbee valley, that is black siliceous siltstone in beds 10 to 30 mm thick interbedded with cream chert in beds 20 to 30 mm thick. This chert-siliceous siltstone sequence appears to be older than the succession in the central part of the belt, and contains limestone lenses. It therefore appears to be a reappearance of the succession at the southern end of the belt.

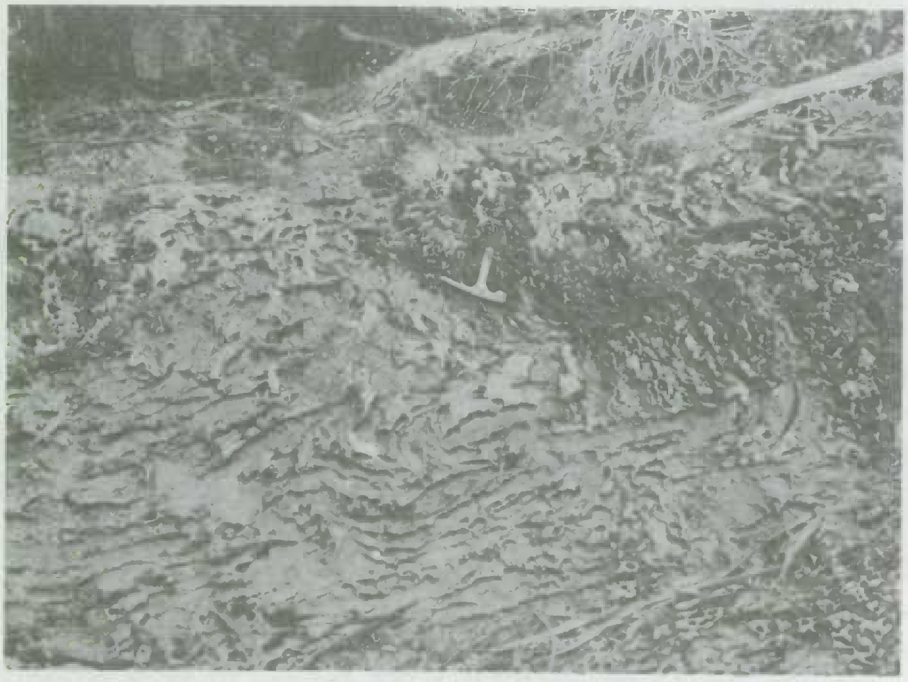

Fig. 64 Slumping in Blue Waterhole Beds, picked out by chert interbeds in siltstone; Goodradigbee River, 2 km south of Dunns Flat (G.R. 571603). (Neg. no. GA/8101)

Slumping is a feature of the cherty facies of the Blue Waterhole Beds (Figure 64) and is well exposed at many localities in the bed of the lower part of Peppercorn Creek, and parts of the Goodradigbee River about 2 km above Dunns Flat.

## PALAEONTOLOGY AND AGE

The fauna of the Blue Waterhole Beds is extensive, though mostly poorly preserved. Fossils are generally present in the siliceous siltstone, and are especially common in the lower Cave Creek Valley. Amongst the macrofossils identified by Legg (1968) are *Heliolites daintreei* Nicholson & Etheridge, *Favosites gothlandicus* Lamarck, *Plasmopora heliolitoides* Lindstrom, *Alveolites* sp., *Mucophyllum* sp., *Entelophyllum* sp., *Tryplasma lonsdalei* Etheridge, *Mazaphyllum* sp., *Rhizophyllum* sp., atryoid brachiopods, *Encrinurus* sp. cf. *mitchelli* Foerste, *Calymene* sp., and crinoid plates.

No conodonts have been obtained from the Blue Waterhole Beds, though an abundant fauna (listed on p. 160) has been obtained from the allochthonous blocks of Cooleman Limestone at locality A of Figure 29. That fauna indicates a Ludlovian age, so the Blue Waterhole Beds at this locality must be no older than Ludlow.

## THICKNESS

The Blue Waterhole Beds are estimated to be 600 m thick in the area south of Coolamine. Farther east they are about 7z00q m thick where they overlie the Pocket Beds, but thicken northwards to at least 500 m near Dunns Flat. At least 500 m of Blue Waterhole Beds is exposed in the lower Peppercorn Creek valley, though the true thickness in this area is unknown as the Beds are faulted to the west and overlain unconformably by Mountain Creek Volcanics to the east.

## RELATIONS IN THE COOLEMAN PLAINS SEQUENCE

The elucidation of the relations between the Peppercorn Beds, Pocket Beds, Cooleman Limestone, and Blue Waterhole Beds is complicated by several factors. These include the complex structure of the area, the intrusion and extrusion of igneous rocks which conceal critical areas, the lack of good palaeontological control in all except the Peppercorn Beds, and the complex facies variations thought to be present.

Before attempting a speculative statement of the possible relations between the various units (shown in Fig. 30) it is felt desirable first to summarize the reliable date from which any conclusions are to be drawn.

The Peppercorn Beds form a transgressive unit, following a mid-Llandovery orogenic episode (the Panuara episode of Packham, 1969). The Beds have a basal conglomerate which grades up through sandstone into a thick sequence of siltstone and mudstone. Macrofossils are common immediately above the conglomerate but fail to provide useful stratigraphic information. Limestone lenses are developed in the upper part of the Peppercorn Beds, near Cooinbil, and have yielded an abundant late Llandovery conodont fauna. Finally the contact between the Peppercorn Beds and the Cooleman Limestone is everywhere obscured by the younger Kellys Plain Volcanics.

The Pocket Beds have yet to be dated accurately although a broad similarity between the macrofaunas from the Pocket Beds and Cooleman Limestone indicates that the two may be close in age. The base of the Pocket Beds is not exposed, having been either faulted out or covered by younger volcanics; upwards the unit passes conformably into Blue Waterhole Beds. The siltstone and mudstone that form the bulk of the Pocket Beds are similar lithologically to those in the upper part of the Peppercorn Beds, and the limestone lenses within the Pocket Beds are similar to parts of the Cooleman Limestone.

The age of the Cooleman Limestone has been shown by conodonts to range from at least late Wenlock to probably late Ludlow, though much more work on the microfauna is needed before the limits are properly known as all of the faunas so far found are from high in the limestone. The base of the Limestone has been either destroyed by intrusions or covered by younger volcanic rocks, and the top appears to be marked by a disconformity, if not an angular unconformity. At several localities, including Cliff Cave (locality B of Fig. 29) and G.R. 508562, the basal micaceous siltstone of the Blue Waterhole Beds appears to have been deposited on an irregular surface developed on the Cooleman Limestone. At G.R. 530561, on the southern edge of Clarks Gorge, a karst surface appears to have developed on the Limestone before the basal Blue Waterhole Beds were deposited as siliceous siltstone of the Blue Waterhole Beds fills fissures up to 5 m deep and 2.5 cm wide in the limestone. However, the tongue of Cooleman Limestone east of the Black Mountain Fault (formerly the Wilkinson Limestone) is both underlain and overlain conformably by the chert facies of the Blue Waterhole Beds.

The Blue Waterhole Beds have not been directly dated by conodonts. However the unit both overlies and underlies the Cooleman Limestone east of the Black Mountain Fault, overlies limestone dated as Ludlow near Mount Black Mine, and contains slumped blocks of limestone which have yielded a Ludlovian conodont fauna on Cave Creek north of Harris Dam. It rests conformably on the Pocket Beds in the east, and possibly unconformably on the Cooleman Limestone in the west, while the tongue of Cooleman Limestone to the east is conformably within the Blue Waterhole Beds. The top of the unit is either faulted or covered by younger volcanics. In addition, evidence from the lower Peppercorn Creek area suggests that the chert facies of the Blue Waterhole Beds may be older than the siltstone-mudstone facies.

The relation between the Cooleman Limestone and Peppercorn Beds is unknown, the contact between them being covered by younger volcanics. However, it is considered that the Peppercorn Beds pass conformably upwards into the Limestone. Evidence for this is twofold. First there is relatively little difference between the upper Llandoverian age for the limestone in the Peppercorn Beds at Cooinbil and the Wenlockian age for a zone in the upper part of the Cooleman Limestone near Mount Black Mine (sample 3060/3, see p. 160). Secondly, the appearance of carbonate sedimentation in the upper part of the Peppercorn Beds, and the similarity of the upper part of this unit to the Pocket Beds suggest a gradual change from terriginous to carbonate deposition, and hence a gradual transition from Peppercorn Beds to Cooleman Limestone. This conclusion therefore implies that the Peppercorn and Pocket Beds are in part equivalent in age, but that part of the Pocket Beds represents higher zones than the Peppercorn Beds.

The Cooleman Limestone and Pocket Beds are considered to be lateral equivalents, though the lower part of the Pocket Beds may be older than the exposed Limestone. Evidence for this is that both are overlain by the Blue Waterhole Beds, the Pocket Beds conformably and the Cooleman Limestone disconformably (though probably with no great time interval), and the larger limestone lenses in the Pocket Beds resemble limestone in the Cooleman Limestone.

The Blue Waterhole Beds are in part the lateral equivalent of the upper part of the Cooleman Limestone as they both overlie and underlie conformably the limestone tongue east of the Black Mountain Fault. However the siltstone-mudstone facies in the west overlies the Cooleman Limestone disconformably or perhaps unconformably.

The probable relations between the various units under discussion, and their possible ages are shown in Figure 30. This is an idealized cross-section along an east-west line through Blue Waterhole, and illustrates the facies relations between the units.

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The history of the area from the upper Llandovery through to the Pridoli may now be summarized. After the Panuara orogenic episode in the middle Llandovery, a marine transgression represented by the basal conglomerate of the Peppercorn Beds covered the area and sedimentation rapidly changed to fine clastic and local carbonate deposition. The direction of transgression is uncertain, but was probably from west to east as it is probable that the Cotter Horst was initiated by the Panuara Orogenic Phase.

An increase in carbonate sedimentation in the west led to the deposition of the Cooleman Limestone, commencing early in the Wenlock, while farther east fine clastic sedimentation continued with the formation of sparse limestone lenses which become more numerous upwards. In the lower Ludlow, chert began to be deposited conformably on the Pocket Beds in the east, while limestone was still forming to the west. The chert sedimentation in the east was soon interrupted by the deposition of a limestone tongue extending northeastward from the main mass of Cooleman Limestone. It must have been shortly thereafter that carbonate deposition over the whole area ceased, probably late in the Ludlow. After temporary emergence of the limestone in the west, during continuous chert sedimentation in the east, a thick sequence of siltstone and mudstone, the final known marine deposits, covered the area. The age of these youngest sediments is unknown, but cannot be later than early Pridoli as the overlying Kellys Plain Volcanics are thought to be of late Pridolian age.

## GOOBARRAGANDRA BEDS

(D.W.)

### NOMENCLATURE

Joplin et al. (1953) reported that the Fiery Range consists predominantly of intrusive late Middle Devonian quartz-feldspar porphyry. They named this porphyry the Fiery Range Porphyry in the Tantangara 1:100 000 Sheet area and the Wyora Porphyry in the Brindabella 1:100 0v0 Sheet area to the north. These two intrusives were separated by a belt of Ordovician sediments in the south of the Brindabella Sheet area. To the northwest late Middle Devonian granite intruded the Fiery Range Porphyry. Farther north this granite has been called the Burrinjuck Granite by Browne (1954), but is now considered part of the Young Granodiorite (Ashley & Basden, 1973).

Adamson (1960) renamed the porphyries of the area the Goobarragandra Porphyry and stated that porphyry underlies the Late Silurian Yarrangobilly Limestone. He believed the porphyries were volcanic owing to the presence of

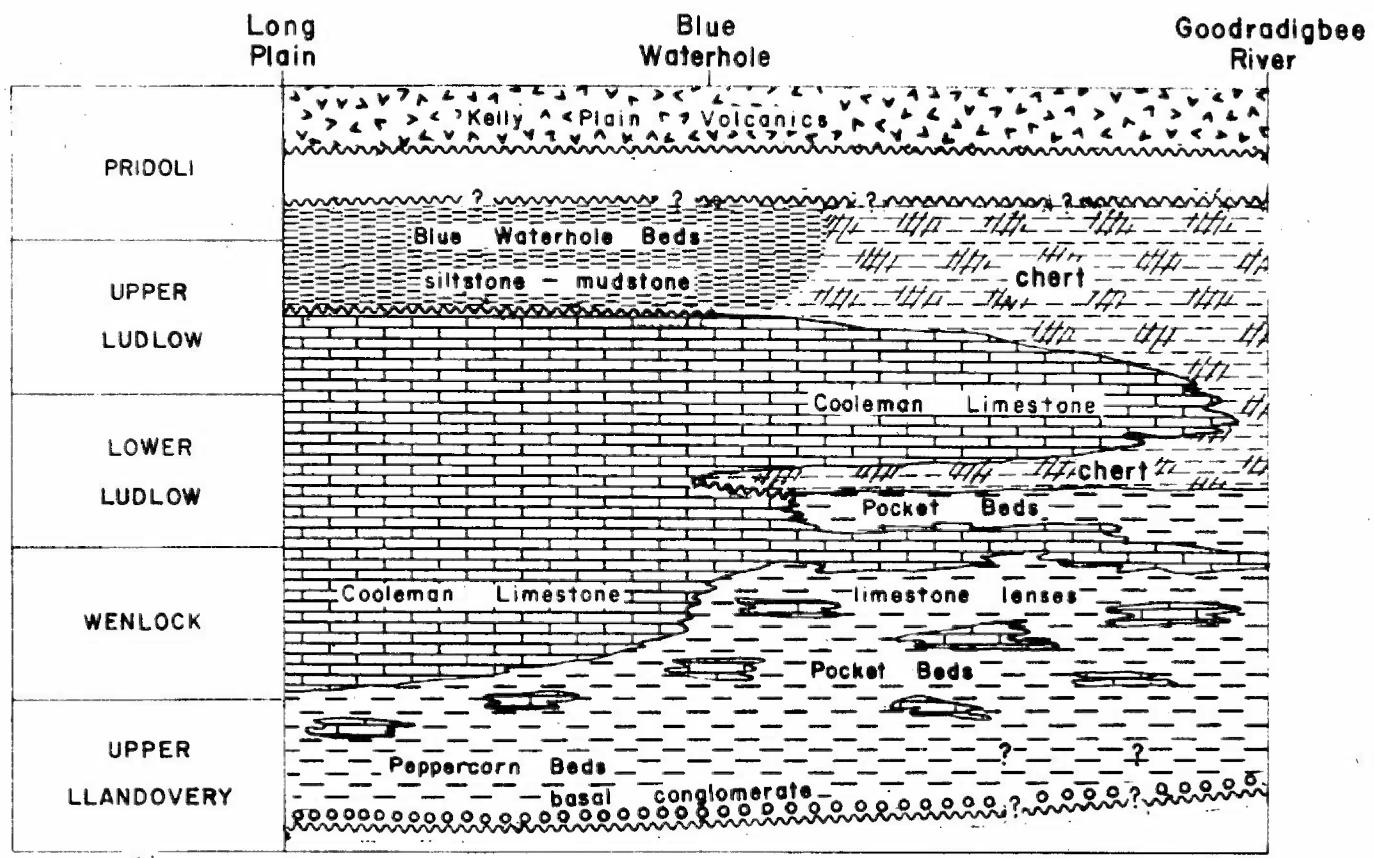


Fig. 30. Relations within the Cooleman Plains sequence.





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interbedded altered andesite south of Clifford Creek (Batlow 1" = 1 mile S.M.A. map, G.R. 28801983).

Best et al. (1964) and Strusz (1971) used the name Peppercorn Beds for a sequence of andesite, rhyolite, dacite, agglomerate, shale, sandstone, and tuffaceous sandstone near Peppercorn Hill (G.R. 458627). This name was extended to include the Fiery Range Porphyry of Joplin et al (1953). Strusz maintained that the Wyora Porphyry to the north was the final stage of intrusion of the Burrinjuck Granite.

Ashley et al. (1971) described a sequence of low-grade porphyritic metarhyodacites, metadacites, basic metavolcanics, and minor metasediments in the Goobarragandra district 21 km southeast of Tumut as the Goobarragandra Beds. These appear to be continuous with the quartz-feldspar porphyries of the Fiery Range west of the Long Plain Fault, so the terminology of Ashley et al. will be used in this Record.

## LITHOLOGY

The Goobarragandra Beds on the basis of field observations have been divided into two groups:

(1) Weakly porphyritic volcanics consisting of dacite, rhyodacite and minor andesite and chert (indicated by the letters Sga on accompanying map);

(2) Strongly porphyritic volcanics consisting of massive dacite and rhyodacite with abundant phenocrysts (Sgb on accompanying map).

(1) Weakly porphyritic volcanics. The largest belt of weakly porphyritic volcanics is immediately west of the Long Plain Fault. Near the fault, outcrop is poor and consists of highly cleaved, weathered dacite and rhyodacite. The cleavage is subvertical and strikes between 015° and 050°. In the south the bearing is closer to 015° and in the north tends to 050°. Farther west the weakly porphyritic volcanics are more massive and crop out as rounded dacite boulders commonly about 30 cm across. At a few localities larger outcrops occur and flow-banding, layering and jointing are present, e.g. at G.R. 423617, where one prominent joint set is vertical and strikes 005° and another dips southwest at 25°.

Farther west, other belts of weakly porphyritic volcanics occur along the upper Yarrangobilly River and Left Hand Branch of the Goobarragandra

River, and along the Long Flat Trail.

The major rock type in the weakly porphyritic volcanics is a dark blue-green dacite which is poorly porphyritic with phenocrysts of rounded quartz and plagioclase up to 5 mm across. Rarer phenocrysts of chlorite are also recognizable in hand specimen. Uncleaved and unjointed specimens have a pale green to white weathered skin about 5 mm thick.

Volcanic breccia is present at several localities and at G.R. 371463 consists of dark green angular fragments up to 30 mm across in a paler more siliceous matrix. Despite its brecciated appearance the rock is extremely well lithified probably owing to silicification and low-grade metamorphism.

At G.R. 405603 andesite is dark green and contains scattere plagioclase laths up to 1 mm across and a little quartz.

Chert within the sequence of volcanics mapped as unit Sga has only been found at G.R. 398497 where a strongly brecciated cherty rock, possibly a silicified rhyodacite, crops out on a fault plane, and at G.R. 350499 where a chert bed dipping 30°S and striking 095° is intercalated with porphyritic volcanics in a new road cutting on the Snowy Mountains Highway. The chert bed is white and about 30 cm thick. The chert could possibly have been deposited by subaqueous silica-rich fumaroles when volcanic activity had temporarily decreased.

The dacite and rhyodacite of the weakly porphyritic type grade (?vertically) into a much more porphyritic variety. The grading occurs over 5 to 10 m in some places but in most cases the contact is not well exposed.

(2) Strongly porphyritic volcanics. These are more massive and less jointed than the weakly porphyritic volcanics. They outcrop as rounded boulders and tors up to 4 m across and are generally better exposed than the weakly porphyritic type. The best exposure is at G.R. 395588 where an area of about 2000 $m^2$ consists of 60-70% outcrop on the side of a steep hill. Here the rock is coarsely porphyritic dacite-rhyodacite with a blue-black groundmass and phenocrysts (40%) of quartz and plagioclase up to 20 mm across. Plagioclase is slightly more common than quartz, is subhedral, pale yellow, and exhibits multiple twinning discernable in hand specimen. The average grainsize is 5 to 8 mm. Quartz (average grainsize 8 to 10 mm) is rounded and embayed. Over the whole area of outcrop no flow alignment or lithological layering is evident, and this is typical of this unit.

The uniformity of the strongly porphyritic volcanics over large areas suggests that they represent the thick welded zones of ash-flow tuff. The uniformity of these tuff sheets over large areas and distances is an important criterion for their recognition (Ross & Smith, 1961). This uniformity is not found in either ash-fall tuffs (bedded tuffs) nor flow rocks of silicic composition and is rarely found in flow rocks of intermediate composition (Ross & Smith, 1961). Ross and Smith have examined ash-flow tuffs at many localities and have found that single units are generally 100 m thick and they believe units up to 300 m thick are not unlikely. Although no individual flow units have been recognised in the Fiery Range, owing to paucity of outcrop, the lack of variance of both weakly and strongly porphyritic volcanics is indicative of an 'ash-flow field' as defined by Smith (1960). In many places, such as the locality cited above (G.R. 395588) single units must be at least 100 m thick.

From the scanty field evidence no accurate estimate of the total thickness of the Goobarragandra Beds in the Currango Sheet area can be given. Where flow-banding has been observed the dips are steeply and to the west, but there is no reason to discount repetition of the sequence in an east-west direction owing to folding or faulting on approximately north-south axes.

The base of the Goobarragandra Beds is not exposed in the Tantangara Sheet area so it is unknown what rock units they overly. Ashley et al. (1971) have reported basalt, spilite, sandstone, and siltstone from near the base of the Goobarragandra Beds, northwest of Goobarragandra. They are intruded by the Young Granodiorite and several stocks related to the Young Granodiorite. They are also intruded by gabbro and dolerite of the Micalong Swamp igneous complex and unconformably overlain by Tertiary alkali olivine basalts.

## PETROGRAPHY

Forty-five thin sections of Goobarragandra Beds dacite and rhyodacite were cut. From these sections four groups could be distinguished:

(i) Incipiently welded ash-flow tuffs still with evidence of original ignimbritic texture;

(ii) Densely welded ash-flow tuffs and /or lavas where the original texture has been obliterated by welding and devitrification of a glassy groundmass;

(iii) Lavas in which flow-alignment of microlites is preserved;

(iv) Fused rocks (reheated) due to contact metamorphism by later intrusions. There will be described later together with the intrusions involved.

Group (i) and group (ii) are by far the most widespread varieties and occur in both the weakly and strongly porphyritic rock types. Group (i) is more common in the weakly porphyritic rock type and group (ii) more common in the strongly porphyritic rock type.

(i) Incipiently welded ash-flow tuffs (e.g. samples 71840549, 71840309). These rocks contain from 0 to 35% phenocrysts of quartz, plagioclase, and very rarely orthoclase. The plagioclase ($An_{10}$ to $An_{40}$) is unzoned or only poorly zoned, euhedral to subhedral, and up to 2 mm across although 1 mm is more common. In some rocks the plagioclase has been partly sericitized and rarely epidotized to the extent that its composition could not be determined. Quartz phenocrysts are less common than plagioclase and occur evenly distributed throughout the rock. They are rounded, have strong embayments, and are up to 5 mm across. Smaller grains are bipyramidal or crescentic. All quartz grains are unaltered and free of inclusions and vacuoles and some have overgrowth rims 0.1 mm across. A few ubiquitous flakes of chlorite + epidote pseudomorphing biotite are subhedral or corroded and up to 1.5 mm across; some are aligned along layering in the groundmass. In one slide (sample 71840384) a volcanic rock fragment 8 mm across consists of mainly plagioclase laths up to 1 mm long intergrown with quartz, orthoclase, and minor chlorite. Other possible volcanic fragments, present in most sections, consist of glomeroporphyritic groups (3 to 4 mm) of plagioclase and interstitial chlorite.

The groundmass of this group of rocks is fragmental and consists of elongate and sickle-shaped devitrified shards and ash separated by chlorite and minor granular opaques. The shards average 0.5 mm across but are up to 1 mm across and virtually undeformed by welding. The coarser shards have devitrified into granophyric and axiolitic intergrowths of quartz and feldspar and the smaller shards and ash have devitrified into microcrystalline material. In most sections eutaxitic layering is preserved and is bent around phenocrysts. Chlorite is aligned along this layering. In slide 71840549 perlitic cracking is well developed and undeformed shards are well preserved.

Apatite and zircon are rare accessories and irregular patches of chlorite or epidote up to 2 mm probably indicate deuteric or later alteration.

The presence of undeformed shards in this group of rocks indicates that welding was only of minor importance and the rocks come from either the top or the bottom of ash-flow tuff cooling units (Smith, 1960).

(ii) Densely welded ash-flow tuffs and/or lavas. Most thin sections of Goobarragandra Beds from the Fiery Range belong to this group. They possess no evidence of original shards and eutaxitic layering and thus are either densely welded ash-flow tuffs from the centre of cooling units or are glassy lava flows. The phenocrysts in rocks of this group are similar to those in the first group except that overall they are larger (up to 20 mm across) and make up a greater percentage of the rock (up to 50%). Plagioclase are commonly strongly zoned with $An_{35-45}$ cores and $An_{10-25}$ rims. Others are oscillatory zoned. In two rocks (samples 71840422 and 71840423) corroded but fresh biotite occurs as phenocrysts up to 2 mm across.

The group of strongly porphyritic rocks exhibit different degrees of devitrification of the groundmass as observed experimentally by Schloemer (1964) and Lofgren (1971).

The first product of devitrification is a microcrystalline mosaic of quartz, feldspar, microspherulites, chlorite, and opaque (samples 71840316 and 71840424). Staining with $Na_2Co(NO_2)_6$ revealed that potassium feldspar is the dominant constituent, but plagioclase microlites 0.05 mm long are also present. Under plane polarised light the devitrified groundmass is colourless to pale brown.

As devitrification continued the microspherulites in the groundmass became larger and more abundant. In slides 71840378 and 71840394 the groundmass consists entirely of potash feldspar-rich spherulites up to 0.7 mm across with interstitial granules and flakes of opaques and chlorite giving a pale grey brown colour under plane polarised light.

The end product of devitrification is the granophyric or granitic stage (Lofgren, 1971, p. 122) where all traces of spherulitic fibres have been erased. This stage is evident in slides 71840392 and 71840420 where the groundmass consists of allotriomorphic equigranular quartz and orthoclase 0.1 mm across, with interstitial chlorite.

Whether the devitrification of Goobarragandra Beds dacite and rhyodacite is due only to a time factor over which thermodynamically unstable glass devitrifies without reheating or whether the devitrification observed has been accelerated by reheating is not clear. However, it is probable that low-grade regional metamorphism was imposed during folding and this would have contributed to the devitrification process if devitrification was not already complete.

Four alteration products are present in the strongly porphyritic rocks: chlorite, epidote, calcite, and prehnite.

Chlorite occurs in irregular patches up to 1 mm across, possibly filling cavities. These cavities may have been produced by a volume decrease upon devitrification. Chlorite also occurs associated with glomeroporphyritic groups of plagioclase ($An_{20-30}$) and quartz up to 10 mm across (in sample 71840527), some obviously being volcanic rock fragments. Chlorite also pseudomorphs biotite and possibly hornblende crystals up to 1 mm across.

Epidote also occurs as patches up to 1 mm across, commonly as radiating euhedral crystals probably filling cavities. It also occurs with prismatic outline, possibly pseudomorphing amphibole or pyroxene phenocrysts.

Calcite appears in amounts ranging up to 3% (in sample 71840527). It occurs as an alteration product of both plagioclase phenocrysts and groundmass material in irregular patches up to 1 mm across.

Prehnite is rarer than the other three alteration products and occurs mainly as fracture fillings, veins, and cavities. Where it occurs as veins and fracture-fillings, it appears to be much younger than the original rock as these fractures are cross-cutting features (e.g. sample 71840378). Where it fills cavities, up to 2 mm across (e.g. sample 71840407), it may be filling original vughs. In the cavities the prehnite occurs as anhedral grains up to 0.3 mm across. A few euhedral epidote crystals up to 0.2 mm across have also grown in the cavities and euhedral quartz crystals up to 0.1 mm long penetrate the cavities from the cavity walls.

Of these four alteration products chlorite and epidote are the most common, composing up to 3% of some rocks. It is unknown whether these products are due to deuteric alteration or alteration by later connate waters.

(iii) Lavas where flow-alignment of microlites is preserved. This group is apparently rare in the Fiery Range, only one sample, a plagioclase andesite, being known (sample 71840408 from G.R. 405603). This rock consists of scattered phenocrysts of plagioclase ($An_{45}$) up to 1 mm across in a groundmass of pilotaxitic plagioclase microlites up to 0.2 mm across. Orthoclase, chlorite, and granular opaques are interstitial. Quartz is rare and occurs as very widely scattered anhedral phenocrysts up to 0.3 mm across.

## GEOCHEMISTRY

Six total rock analyses and CIPW norms are presented in Table 24, together with one by Ashley et al. (1971). Harker diagrams of the volcanics plus the Young Granodiorite and related stocks are presented in Figure 31.

The rocks have a restricted range of silica content, from 67.6% to 70.8%. This shows that differentiation has only been of minor importance and the rocks are remarkably similar in composition over distances of up to 35 km. $K_2O$ is the only oxide that shows affinities for $SiO_2$. MgO and FeO total decrease with increasing $SiO_2$ and CaO and $Al_2O_3$ probably decrease slightly. $K_2O/Na_2O$ ranges from 0.6 to 1.2, so the rocks are not potash-rich. The sample with the lowest silica content has the highest concentrations of Ni, Co, and Cu. Zn is slightly enriched in the more basic samples and Pb has no distinct trend.

The Goobarragandra Beds volcanics contain between 32% and 39% normative quartz, and normative corundum is in every case greater than 1%. The anorthite content of normative plagioclase ranges from $An_{20}$ to $An_{30}$, although sample 71840527 has been altered by the introduction of $CO_2$ (the anorthite content is only $An_{0.12}$). Normative hypersthene averages 5% to 10%, with ferrosilite greater than or equal to enstatite content.

The restricted range of $SiO_2$ content of Goobarragandra Beds volcanics is markedly different to the range of the Kellys Plain Volcanics. (compare Table 24 with Table 25). This provides a strong argument against the possibility of the two units being the same sequence on opposite sides of the Long Plain Fault. Rather, the Goobarragandra Beds volcanics are chemically remarkably similar to the Young Granodiorite and differentiation of the parent magma of granodiorite-adamellite composition has been very minor. In contrast the Kellys Plain Volcanics are similar to the Gingera Granite where differentiation of the parent magma has been strong.

## AGE

The exact age of the Goobarragandra Beds is unknown. They are intruded by the Early Devonian Young Granodiorite (400 m.y.) to which they are chemically very similar. Ashley et al. (1971) have equated the Goobarragandra Beds to the Blowering Beds and Honeysuckle Beds which they give an age of ?Middle Silurian-basal Devonian. Ashley et al. have reported the Middle to Late Silurian conodonts *Triconodella inconstans* and *Ozarkadina* cf. *jaegeri* from a conglomeratic limestone in the Blowering Beds.

Rb-Sr age determination of the Goobarragandra Beds has been done by Amdel Laboratories on a suite of samples collected from the Snowy Mountains Highway 2 to 5 km northwest of Rules Point by B.M.R. An isochron fitted to 7 samples gives an age of 438 + 28 m.y. (see appendix 2). This age can be compared with the age of the Mount Painter Porphyry of 438 ± 4 m.y. reported

TABLE 24. ANALYSES AND CIPW NORMS FOR VOLCANICS FROM THE GOOBARRAGANDRA BEDS

| Sample No<br>Rock type<br>G.R. | 71840378<br>rhyodacite<br>479527 | 71840382<br>dacite<br>405535 | 71840527<br>dacite<br>15155933* | 71840528<br>dacite<br>412547 | 71840532<br>rhyodacite<br>469640 | 72840120<br>rhyodacite<br>375895≠ | 8<br>rhyodacite<br>see<br>Ashley et al<br>(1970) |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 70.1 | 69.0 | 69.7 | 67.6 | 70.8 | 69.3 | 69.82 |
| $TiO_2$ | 0.68 | 0.66 | 0.57 | 0.72 | 0.42 | 0.60 | 0.49 |
| $Al_2O_3$ | 13.6 | 14.0 | 12.8 | 14.1 | 13.8 | 14.0 | 13.94 |
| $Fe_2O_3$ | 0.79 | 0.75 | 1.50 | 1.00 | 0.65 | 0.95 | 0.69 |
| FeO | 3.15 | 3.70 | 2.65 | 4.05 | 2.85 | 3.20 | 3.03 |
| MnO | 0.12 | 0.07 | 0.09 | 0.07 | 0.10 | 0.07 | 0.07 |
| MgO | 1.45 | 2.20 | 1.08 | 2.25 | 1.26 | 1.75 | 1.49 |
| CaO | 2.25 | 1.62 | 1.57 | 2.15 | 1.86 | 2.95 | 2.53 |
| $Na_2O$ | 2.80 | 3.25 | 4.25 | 2.90 | 2.55 | 2.60 | 2.96 |
| $K_2O$ | 3.05 | 2.45 | 2.65 | 2.30 | 3.00 | 2.85 | 3.33 |
| $P_2O_5$ | 0.07 | 0.13 | 0.11 | 0.14 | 0.10 | 0.12 | 0.12 |
| $H_2O+$ | 1.18 | 1.96 | 1.52 | 2.00 | 1.52 | 1.29 | 1.02 |
| $H_2O-$ | 0.34 | 0.14 | 0.22 | 0.30 | 0.24 | 0.11 | 0.12 |
| $CO_2$ | 0.20 | 0.10 | 1.10 | 0.05 | 0.55 | 0.10 | 0.12 |
| Total | 99.78 | 99.97 | 99.81 | 99.63 | 99.70 | 99.93 | 99.73 |
| Ni | 20 | 25 | 20 | 30 | 10 | | |
| Co | 10 | 10 | 10 | 15 | 5 | | |
| Cu | 5 | 15 | 10 | 25 | 15 | | |
| Zn | 30 | 70 | 65 | 65 | 50 | | |
| Pb | 5 | 35 | 5 | 20 | 15 | | |
| Q | 34.59 | 32.93 | 32.52 | 32.87 | 39.32 | 33.55 | 31.38 |
| C | 2.27 | 3.68 | 2.96 | 3.48 | 4.59 | 1.82 | 1.45 |
| or | 18.34 | 14.78 | 15.96 | 13.96 | 18.10 | 17.10 | 19.96 |
| ab | 24.10 | 28.07 | 36.65 | 25.20 | 22.02 | 22.33 | 25.39 |
| an | 9.61 | 6.69 | 0.12 | 9.69 | 5.20 | 13.42 | 11.16 |
| Hy ( en | 3.67 | 5.59 | 2.74 | 5.76 | 3.20 | 4.42 | 3.76 |
| Hy ( fs | 4.31 | 5.32 | 2.91 | 5.70 | 4.28 | 4.30 | 4.38 |
| mt | 1.17 | 1.11 | 2.22 | 1.49 | 0.96 | 1.40 | 1.01 |
| il | 1.31 | 1.28 | 1.10 | 1.40 | 0.81 | 1.16 | 0.94 |
| ap | 0.17 | 0.31 | 0.27 | 0.34 | 0.24 | 0.29 | 0.29 |
| cc | 0.46 | 0.23 | 2.55 | 0.12 | 1.28 | 0.23 | 0.28 |

Oxides and norms in % elements in ppm

* From Wagga Wagga 1:250 000 Sheet area - grid reference not in metric units

≠ From Brindabella 1:100 000 Sheet area

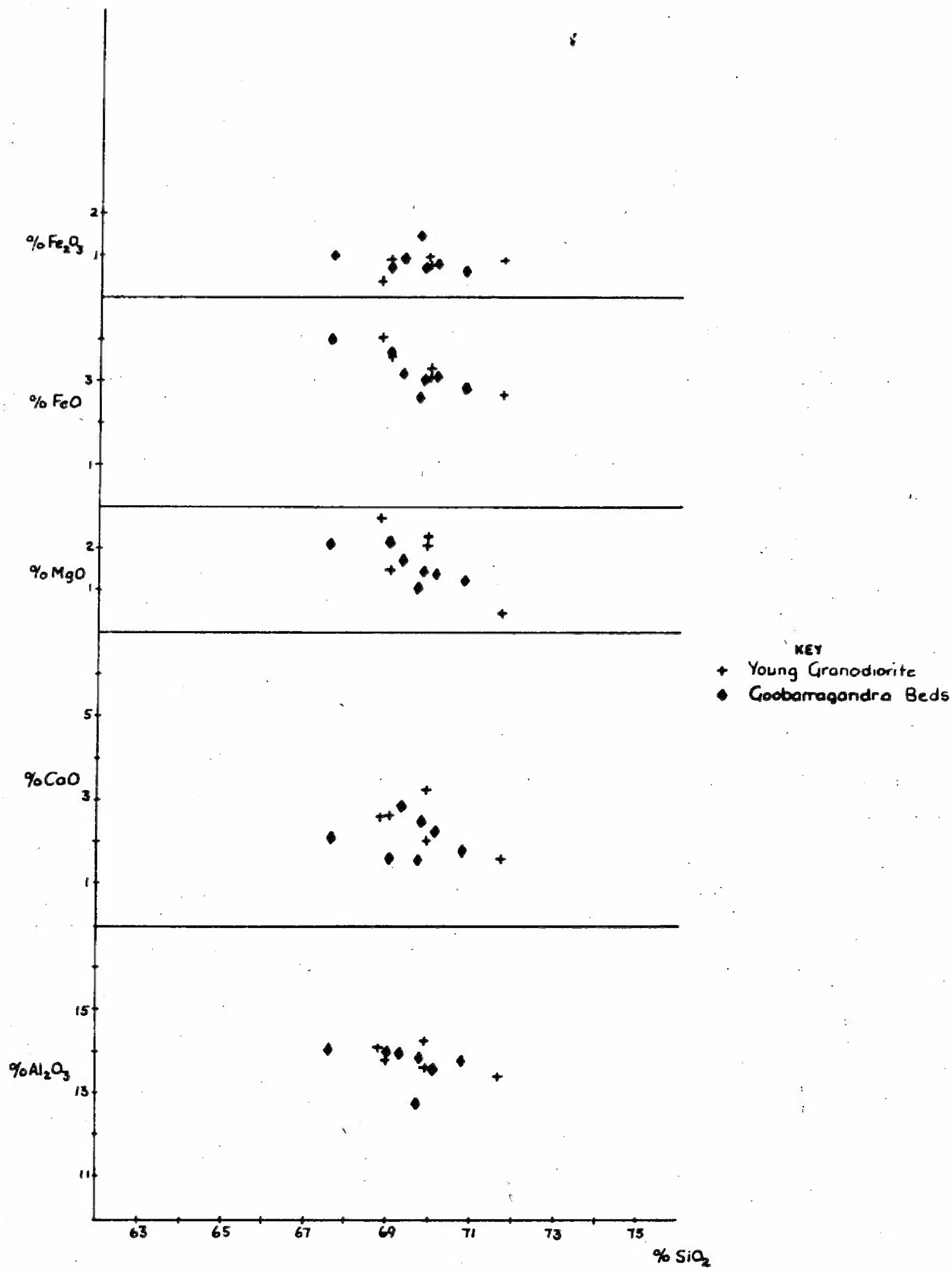


Fig. 31. Variation diagrams for the Young Granodiorite and Goobarragandra Beds.

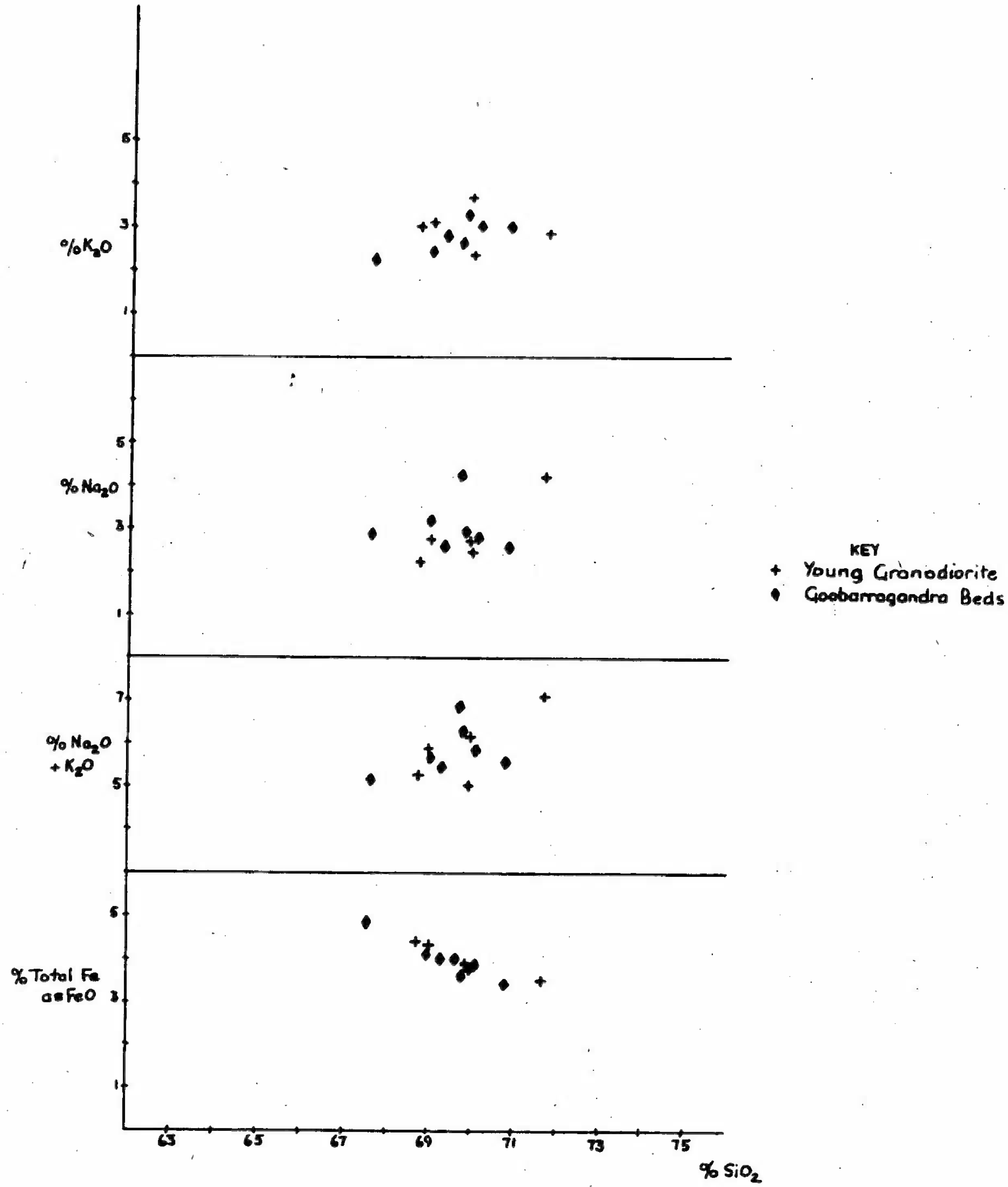


Fig. 31. (continued)

by Bofinger, Compston, & Gulson (1970). They assign a Ludlovian age for this date, but recent mapping by B.M.R. in the Brindabella 1:100 000 Sheet area (Owen & Wyborn, in prep.) indicates that the Mount Painter Porphyry near Mount Painter probably underlies the Uriarra Volcanics and is of Wenlockian age. A Wenlockian age has therefore been given to the Goobarragandra Beds, but because of their great aereal extent and probable large thickness the Goobarragandra Beds may range up into the Ludlow.

## KELLYS PLAIN VOLCANICS (Newberry, 1956)

(M.O.)

### NOMENCLATURE

The name Kellys Plain Dacite was proposed by Newberry (1956) for a quartz feldspar porphyry that crops out on Kellys Plain 1 km west of Tantangara Dam, and to the north on Smiths Range. Newberry recognized the extrusive nature of the unit, which had previously been mapped by Ivanac & Glover (1949) and Walpole (1952) as an unnamed intrusive. Stevens (1958b) first published the name and described its occurrence in the Cooleman and Currango Plain areas. The unit was called the Kellys Plain Porphyry in the 2nd edition of the Canberra 1:250 000 geological map (Best et al. 1964), and this name was retained in Packham (1969). Bein (1968) described the unit in detail between Kellys Plain and the southern edge of Currango Plain, calling it the Kellys Plain Beds.

As the unit is entirely volcanic, the name Kellys Plain Volcanics is used in this Record.

### DERIVATION OF NAME

The unit is named from Kellys Plain, about 3 km southwest of Tantangara Dam. (G.R. 480350).

### TYPE LOCALITY

No type locality has been published. It is therefore proposed that the large disused quarry at Traces Knob (G.R. 489366, 1500 m southwest of Tantangara Dam) be considered the type locality (Fig. 65). About 25 m of fresh massive dark bluish-grey quartz feldspar porphyry, typical of much of the Kellys Plain Volcanics in the southern part of the outcrop, is exposed in this quarry. It is the only artificial exposure of the Kellys Plain Volcanics, and, as such, is also one of the few localities where unweathered rock can easily be obtained.

Fig. 65 Type locality of Kellys Plain Volcanics; Traces Knob quarry, Tantangara Dam, G.R. 488368. (Neg. no. GA/8055)

DISTRIBUTION

The Kellys Plain Volcanics are widely distributed with continuous outcrop extending from the Nungar Creek valley to the lower Peppercorn Creek valley, a distance of 35 km. In the Currango Plain they have an eastwest extent of 12 km. The southernmost outcrop is in the Nungar Creek valley near Blackfellows Hill (G.R. 472313). From this locality the volcanics crop out in a belt widening gradually to the north, with an eastern boundary at the western foot of the Nungar Range, and a western boundary approximately along Nungar Creek. Extensive boulder outcrops are present on Smiths Range and Kellys Plain. North of the Murrumbidgee River the volcanics crop out over much of the floor of Tantangara Reservoir and most of Currango Plain. From Currango Plain the main outcrop trends northwest to Skains Hill, and extends as far as the eastern edge of the Long Plain. From Skains Hill the main outcrop narrows considerably and trends northeast along the Cooleman Mountain into the lower Peppercorn Creek and Tinpot Creek valleys. In addition, Kellys Plain Volcanics crop out in a faulted belt extending from the northeast edge of Currango Plain along Pocket Creek as far as Rolling Grounds Spur.

LITHOLOGY

Several different lithologies could be recognized in the field, although it was not possible to map boundaries between them. The most common variety in the south, and the one present at Traces Knob quarry is a quartz-plagioclase-potassium feldspar-biotite porphyry with a dark blue-grey groundmass. The rock crops out as abundant large tors and boulders up to 4 m across. This style of outcrop is typical of all members of the Kellys Plain Volcanics. The pale brown weathered surface is generally encrusted with rounded or bipyramidal quartz phenocrysts up to 6 mm in diameter and less common feldspar crystals to 10 mm across. The quartz phenocrysts are commonly embayed and cracked, or broken into angular fragments. Plagioclase is present as pale green phenocrysts up to 10 mm long. They are generally subhedral, little zoned, and have a composition of $An_{30-35}$. Saussuritization is extensive. Potassium feldspar is rare as phenocrysts and is strongly altered. Biotite phenocrysts are almost completely altered to chlorite and sphene. The groundmass is commonly strongly chloritized, although quartz and feldspar are present. Staining with sodium cobaltinitrite indicates that much of the feldspar present in the groundmass is potassium feldspar. Garnet was recorded by Bein (1968) at several localities, though none was observed during the present surveys.

The second variety of porphyry has a light grey groundmass, and is widely distributed from Currango Plain northwest, but is rare farther south where it is present mainly on the western margin of the Kellys Plain Volcanics. Phenocrysts are rarer and smaller than in the first variety, and are generally less than 4 mm across. Potassium feldspar (perthite) phenocrysts are more abundant, but plagioclase phenocrysts less. Biotite also is more abundant, forming subhedral to euhedral crystals up to 3 mm long, but is almost completely altered to chlorite. Rare augite phenocrysts are also present. The groundmass of this second variety is chloritized, though less so than in the first variety. Staining indicates that quartz and potassium feldspar form the bulk of the groundmass.

Varieties of porphyry with similar phenocryst mineralogy but differing groundmass colour are present locally. A pink groundmass is fairly common in porphyries on Smiths Range near Traces Hut, and also in the northern part of the area on the ridge between Tinpot and Peppercorn Creeks. Varieties with a dark green groundmass, apparently due to greater chloritization, are fairly widespread. A porphyry with a very light cream groundmass and scattered small (to 3 mm) quartz, feldspar, and biotite phenocrysts crops out to the east of 'Currango' and in the hills west of Old Currango.

At least two ash-flow tuffs are present within the Kellys Plain Volcanics. The lower forms the basal bed of the unit, at G.R. 467348 is a fine-grained light greyish-brown rock, lacking obvious phenocrysts, and forms blocky boulders up to 200 mm maximum length. It consists of small angular fragments of quartz and feldspar (to 0.5 mm) in a matrix of devitrified shards. The shards are clearly defined and indicate that little compaction or welding has taken place. Xenoliths of this rock are present in the overlying porphyry.

Farther north, ash-flow tuff also crops out on the western end of the Gurrangorambla Range, and appears to be high in the Kellys Plain Volcanics. It occurs as large massive boulders, and is light grey and mottled. The tuff consists of angular fragments of partly resorbed quartz (to 4 mm long), partially sericitized plagioclase and minor orthoclase set in a groundmass of devitrified shards and patches of chlorite. Compaction and welding of the shards is more nearly complete than in the basal tuff.

Agglomeratic porphyry is widespread along the western side of the Kellys Plain Volcanics from Currango Plain southwards. An excellent example is on the west shore of Tantangara Reservoir at G.R. 490398; (Fig. 67), where rounded to angular fragments of quartz-feldspar-biotite porphyry 10 to 500 mm across are enclosed in a porphyry with similar phenocrysts but darker matrix. Elsewhere, xenoliths of the underlying Ordovician and Silurian sediments are present in a porphyry matrix, and at G.R. 503469 angular fragments of chert, andesitic volcanics, quartzite, shale, and limestone are present in a tuffaceous matrix.

The composition of most of the Kellys Plain Volcanic porphyries appears to be in the rhyolite to rhyodacite range, although they resemble dacites in hand specimen. Although plagioclase phenocrysts are far more abundant than potassium feldspar phenocrysts, staining has demonstrated that much of the groundmass is formed of potassium feldspar, and only rarely is plagioclase present. None of the Kellys Plain Volcanics appears to represent actual lava flows, and it seems likely that the volcanics were deposited as ash-fall and ash-flow tuff or ignimbrite. The limited recognition of ash-flow tuff is thought to be due to the extensive devitrification and chloritization of the groundmass in most of the porphyries. If this interpretation is correct then some of the ignimbrite flows must have been very thick; for example the porphyry exposed in the Traces Knob quarry appears to be within one cooling unit, and is at least 25 m thick.

Depositional structures are widespread south of but very rare north of Currango Plain. Columnar jointing is common, especially in the lower Nungar Creek valley and on Currango Plain. Excellent examples are on the east bank of Nungar Creek at G.R. 477406 (Fig. 66), and on Currango Plain 600 m north of Old Currango (G.R. 504498). Columns are up to 2.5 m long and 150 mm across, with 4 to 7 sides. The direction of dip of the cooling surface indicated by the columnar jointing is generally less than 15° and almost always to the east.

Fig. 66 Columnar jointing in dacite of Kellys Plain Volcanics, Nungar Creek, G.R. 477406. (Neg. no. GA/8093)

Banding is also common, especially south of the Murrumbidgee River, and generally consists of alternating quartz-rich and feldspar-rich layers about 10 mm thick, emphasized by weathering. The banding generally dips east at 15° to 30°. A more spectacular example is at G.R. 480366 and consists of alternating colour bands 5 to 50 mm wide, formed by porphyry with alternating light and dark grey groundmass. The strike and dip of the banding varies significantly with some dips being as much as 80°, and there is also apparently slumped bedding.

Fig. 67 Agglomerate within Kellys Plain Volcanics, west shore of Tantangara Reservoir, G.R. 490398. (Neg. no. GA/8062).

## FIELD RELATIONS AND AGE

The Kellys Plain Volcanics unconformably overlie the Temperance Chert, Nine Mile Volcanics, Tantangara Beds, Peppercorn Beds, Cooleman Limestone, Blue Waterhole Beds, and Pocket Beds. The contact of the volcanics with the underlying rocks is exposed at two localities in the Nungar Creek valley. In the south, at G.R. 466341, a tuff layer about 2 m thick rests on siliceous mudstone of the Tantangara Beds, and is overlain by about 10 m of pale brown ash-flow tuff. The contact dips east at 10° with a strike of 015°.

Farther north, on the west side of Smiths Range at G.R. 476395, rhyodacite tuff rests on dark grey mudstone of the Peppercorn Formation, the contact dipping 35° due east. Small angular fragments of the underlying mudstone up to 10 mm across were caught up in the basal 30 mm of the rhyodacite.

The land surface upon which the Kellys Plain Volcanics were deposited appears to have been irregular. Inliers of Tantangara Beds and Peppercorn Beds are common, especially from Currango Plain south to the northern end of Smiths Range. In most places there appears to have been extensive silicification of the sedimentary rocks forming these inliers. A relief of at least 50 m is suggested by inliers of Peppercorn Formation in the upper Mosquito Creek valley.

The relation between the Kellys Plain Volcanics and the Rolling Grounds Latite in the Cooleman area is uncertain as direct field evidence is lacking; the two units are never found in contact. However, geochemical data suggest that the Kelly Plain Volcanics are the older. Geochemically, the Kellys Plain Volcanics are similar to the Gingera Granite and could well be its extrusive equivalents. Moreover, the Rolling Grounds Latite is closely related to the Coolamine Complex, probably being its extrusive equivalent, and the complex intrudes the Kellys Plain Volcanics. It can also be shown that the Gingera Granite is intruded by dykes apparently originating from the Coolamine Diorite. It is therefore certain that the Kellys Plain Volcanics are older than the Rolling Grounds Latite.

The Gingera Granite, discussed later (p. 223), is related to the Murrumbidgee Batholith, which has been dated at 415 m.y. (Pidgeon & Compston, 1965) and 420 m.y. by Roddick (ANU, pers. comm.).

In addition, the Rolling Grounds Latite is almost certainly of late Gedinnian (Early Devonian) age, so the Kellys Plain Volcanics must be of late Pridolian (Late Silurian) or early Gedinnian age.

It therefore appears that an isotopic age determ nation of the Kellys Plain Volcanics would provide useful information on the age of the Silurian-Devonian boundary (see Brooks & Leggo, 1972). Unfortunately alteration in samples collected so far has precluded any attempt to date the Volcanics.

## THICKNESS

In view of the irregular land surface the Kellys Plain Volcanics were deposited on, the thickness of the unit is probably quite varied. However, in the area of Skains Hill a minimum thickness of about 300 m is indicated, while in the south on Smiths Range, if a gentle dip to the east is assumed, a thickness of about 150 m is present. These are minimum thicknesses as an unknown amount has been removed by subsequent erosion.

GEOCHEMISTRY (M.S.)

Samples analysed by BMR (Table 25) were all of acid composition, with the silica content ranging from 67.7 to 79.1%. Five analyses by Palmer (1972), with a silica range from 66.85 to 71.61%, have also been plotted on the variation diagrams (Fig. 32). Correlation between the various oxides and silica is poor; in particular, no fractionation trend lines can be drawn for lime, soda, and potash. Trend lines may be drawn for the other oxides, but scatter is high. The $K_2O/Na_2O$ ratio varies from 0.05 (sample 71840258) to 7.92 (sample 71840250), so rocks from the Kellys Plain Volcanics may be either potassium-rich or sodium-rich, or may contain approximately equal amounts of potassium and sodium. This unusual alkali relation and the irregular distribution of lime values could be due to post-solidification alteration of the rocks. Devitrification, saussuritization, and chloritization probably affected the alkali and calcium distribution.

Although there is no definite evidence that the Kellys Plain Volcanics are related to the Gingera Granite and McLaughlin Flat Granodiorite there is a strong possibility that this is so, as the units are of similar age and are fairly close in geographic distribution. The three units have therefore been plotted on the same variation diagrams, where they fit on the same fractionation trend lines, providing further evidence for a close relation. The Volcanics, however, show more scatter from the trend lines because of their greater alteration.

The nickel, copper, cobalt, and zinc contents of the rocks decrease with increasing silica, and values are normal for felsic rocks (Hawkes & Webb, 1962). The lead content is very variable and ranges from high to low for felsic rock, bearing no apparent relation to silica content.

Normative quartz is high in all samples and ranges from 28% to 40%. The amount of orthoclase is controlled by the amount of potash in the analysis, and varies from 2.61 (0.36% $K_2O$) to 36.54% (6.10% $K_2O$). Normative corundum is present in all samples, indicating the amount of alumina is greater than the total of potash, soda, and lime. In unaltered holocrystalline rocks this excess alumina would crystallise as biotite or muscovite, but in the Kellys Plain Volcanics it is found in the glassy or microcrystalline groundmass, or in the chlorite formed by alteration. The low calcium content of the rocks is reflected by the absence of normative diopside and the low content of anorthite. Enstatite (Mg) and ferrosilite (Fe) are approximately equal in the hypersthene molecule, but the higher content of total iron compared to magnesium is shown by the relatively high normative magnetite and ilmenite.

TABLE 25. ANALYSES AND CIPW NORMS FROM THE KELLYS PLAIN VOLCANICS

| Sample No. | 71840247 | 71840250 | 71840257 | 71840258 | 71840440 |
|---|---|---|---|---|---|
| Rock type | rhyodacite | rhyolite | rhyodacite | dacite | rhyodacite |
| G.R. | 470354 | 474359 | 478410 | 481402 | 567545 |
| % | | | | | |
| $SiO_2$ | 74.9 | 79.2 | 70.0 | 73.7 | 70.6 |
| $Al_2O_3$ | 12.5 | 10.3 | 14.1 | 14.2 | 14.4 |
| $Fe_2O_3$ | 1.03 | 0.81 | 0.89 | 0.31 | 0.80 |
| FeO | 1.43 | 0.59 | 2.25 | 1.61 | 2.35 |
| MgO | 1.13 | 0.30 | 2.05 | 1.09 | 1.27 |
| CaO | 0.14 | 0.12 | 0.72 | 0.14 | 1.40 |
| $Na_2O$ | 3.60 | 0.77 | 4.30 | 6.55 | 1.56 |
| $K_2O$ | 3.15 | 6.10 | 3.10 | 0.36 | 5.30 |
| $H_2O+$ | 1.12 | 0.78 | 1.19 | 0.90 | 1.20 |
| $H_2O-$ | 0.44 | 0.48 | 0.61 | 0.84 | 0.20 |
| $CO_2$ | 0.18 | 0.13 | 0.22 | 0.12 | 0.25 |
| $TiO_2$ | 0.45 | 0.25 | 0.39 | 0.30 | 0.64 |
| $P_2O_5$ | 0.09 | 0.06 | 0.08 | 0.07 | 0.14 |
| MnO | 0.05 | 0.01 | 0.03 | 0.02 | 0.06 |
| | 100.21 | 99.90 | 99.83 | 100.21 | 100.17 |
| ppm | | | | | |
| Ni | 10 | 5 | 20 | 10 | 25 |
| Co | 10 | 5 | 10 | 5 | 10 |
| Cu | 5 | 5 | 5 | 5 | 25 |
| Zn | 50 | 35 | 45 | 45 | 50 |
| Pb | 30 | 10 | 110 | 65 | 15 |
| Qz | 40.72 | 51.90 | 28.38 | 32.32 | 36.66 |
| C | 3.60 | 2.69 | 2.89 | 3.28 | 4.52 |
| Or | 18.87 | 36.54 | 18.68 | 2.16 | 31.70 |
| Ab | 30.86 | 6.60 | 37.10 | 56.26 | 13.36 |
| An | - | - | 2.34 | - | 4.51 |
| Di | - | - | - | - | - |
| Hy ( En | 2.85 | 0.76 | 5.21 | 2.76 | 3.20 |
| Hy ( Fs | 1.14 | 0.02 | 2.86 | 2.28 | 2.74 |
| Mt | 1.51 | 1.19 | 1.32 | 0.46 | 1.17 |
| Il | 0.87 | 0.48 | 0.76 | 0.58 | 1.23 |
| Ap | 0.22 | 0.14 | 0.19 | 0.17 | 0.34 |
| Cc | 0.41 | 0.30 | 0.28 | 0.28 | 0.58 |

TABLE 25 (Cont'd)

| Sample No.<br>Rock type<br>G.R. | 108*<br>dacite<br>481565 | 110*<br>dacite<br>481592 | A2*<br>dacite<br>466553 | 120*<br>dacite<br>473588 |
|---|---|---|---|---|
| % | | | | |
| $SiO_2$ | 66.85 | 69.01 | 71.61 | 70.89 |
| $Al_2O_3$ | 14.29 | 14.52 | 13.31 | 13.66 |
| $Fe_2O_3$ | 0.62 | 0.88 | 1.35 | 0.83 |
| FeO | 3.89 | 3.31 | 1.98 | 2.69 |
| MgO | 2.17 | 1.78 | 1.15 | 1.35 |
| CaO | 2.94 | 2.58 | 2.06 | 2.18 |
| $Na_2O$ | 2.45 | 3.25 | 3.42 | 2.34 |
| $K_2O$ | 3.24 | 2.07 | 3.26 | 3.25 |
| $H_2O+$ | 1.57 | 1.27 | 1.10 | 1.47 |
| $H_2O-$ | 0.14 | 0.20 | 0.18 | 0.18 |
| $CO_2$ | 0.23 | 0.30 | 0.01 | 0.22 |
| $TiO_2$ | 0.68 | 0.54 | 0.49 | 0.53 |
| $P_2O_5$ | 0.18 | 0.14 | 0.13 | 0.12 |
| MnO | 0.08 | 0.05 | 0.05 | 0.05 |
| S | 0.09 | 0.01 | 0.03 | 0.01 |
| | 99.42 | 99.91 | 100.14 | 99.77 |
| ppm | | | | |
| Ni | | - | | |
| Co | | - | | |
| Cu | | 3.7 | | |
| Zn | | 63.8 | | |
| Pb | | 23.0 | | |
| Qz | 29.92 | 33.69 | 33.09 | 38.24 |
| C | 2.44 | 3.31 | 0.75 | 3.23 |
| Or | 19.62 | 12.43 | 19.49 | 19.56 |
| Ab | 21.24 | 27.93 | 29.28 | 20.16 |
| An | 12.25 | 10.15 | 9.42 | 8.80 |
| Di | - | - | - | - |
| Hy ( En | 5.54 | 4.50 | 2.90 | 3.42 |
| Hy ( Fs | 5.80 | 4.63 | 1.83 | 3.54 |
| Mt | 0.92 | 1.30 | 1.98 | 1.23 |
| Il | 1.32 | 1.04 | 0.94 | 1.03 |
| Ap | 0.44 | 0.34 | 0.31 | 0.29 |
| Cc | 0.54 | 0.69 | 0.02 | 0.51 |

* Ref: Palmer (1972)

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TABLE 25 (Cont'd)

| Sample No.<br>Rock type<br>G.R. | 71840449<br>rhyodacite tuff<br>508515 | 71840450<br>rhyodacite tuff<br>571550 | 72840086<br>dacite<br>489366 | 145*<br>dacite<br>512620 |
|---|---|---|---|---|
| % | | | | |
| $SiO_2$ | 69.3 | 72.2 | 67.7 | 67.80 |
| $Al_2O_3$ | 13.9 | 12.9 | 14.1 | 14.72 |
| $Fe_2O_3$ | 0.75 | 0.65 | 0.57 | 0.63 |
| FeO | 4.30 | 2.60 | 3.70 | 3.94 |
| MgO | 2.30 | 1.05 | 2.55 | 2.17 |
| CaO | 2.60 | 1.55 | 0.51 | 3.85 |
| $Na_2O$ | 2.85 | 2.80 | 2.65 | 1.85 |
| $K_2O$ | 1.60 | 3.55 | 4.85 | 2.44 |
| $H_2O+$ | 1.18 | 1.17 | 2.35 | 1.18 |
| $H_2O-$ | 0.16 | 0.49 | 0.14 | 0.11 |
| $CO_2$ | 0.10 | 0.10 | 0.15 | 0.24 |
| $TiO_2$ | 0.66 | 0.46 | 0.63 | 0.66 |
| $P_2O_5$ | 0.12 | 0.12 | 0.13 | 0.15 |
| MnO | 0.08 | 0.05 | 0.07 | 0.06 |
| S | - | - | 0.03 | 0.01 |
| | 99.90 | 99.69 | 100.13 | 99.81 |
| ppm | | | | |
| Ni | 25 | 15 | | |
| Co | 15 | 5 | | |
| Cu | 20 | 25 | | |
| Zn | 80 | 50 | | |
| Pb | 20 | 25 | | |
| Qz | 35.86 | 37.17 | 27.82 | 35.23 |
| C | 3.32 | 2.20 | 4.33 | 2.98 |
| Or | 9.59 | 21.40 | 29.36 | 14.64 |
| Ab | 24.46 | 24.16 | 22.96 | 15.89 |
| An | 11.65 | 6.40 | 0.75 | 16.85 |
| Di | - | - | - | - |
| Hy ( En | 5.81 | 2.67 | 6.50 | 5.49 |
| Hy ( Fs | 6.43 | 3.64 | 5.55 | 5.82 |
| Mt | 1.10 | 0.96 | 0.85 | 0.93 |
| Il | 1.27 | 0.89 | 1.23 | 1.27 |
| Ap | 0.29 | 0.29 | 0.32 | 0.36 |
| Cc | 0.23 | 0.23 | 0.35 | 0.55 |

* From Palmer (1972)

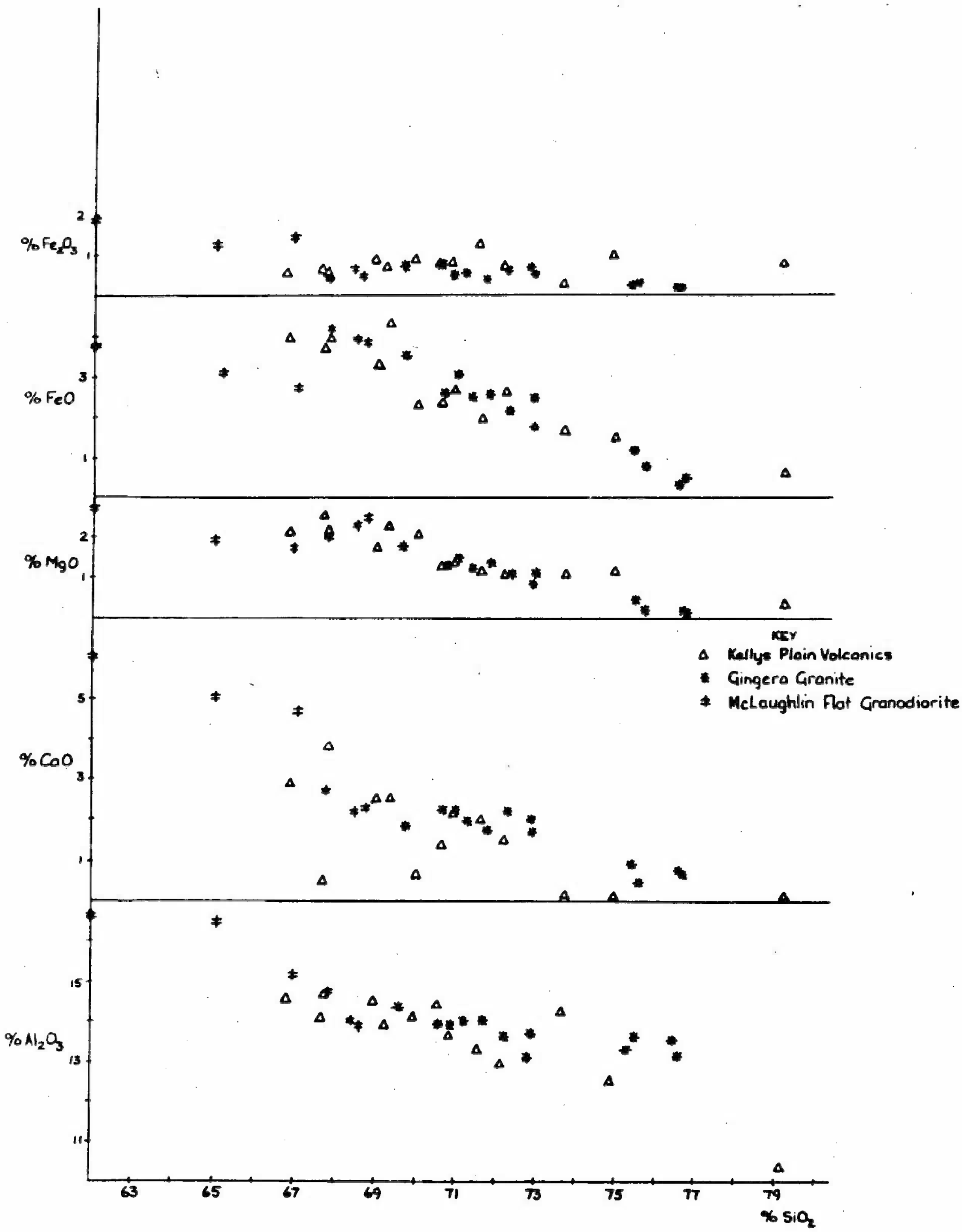


Fig. 32. Variation diagrams for the Kellys Plain Volcanics, Gingera Granite, and McLaughlin Flat Granodiorite.



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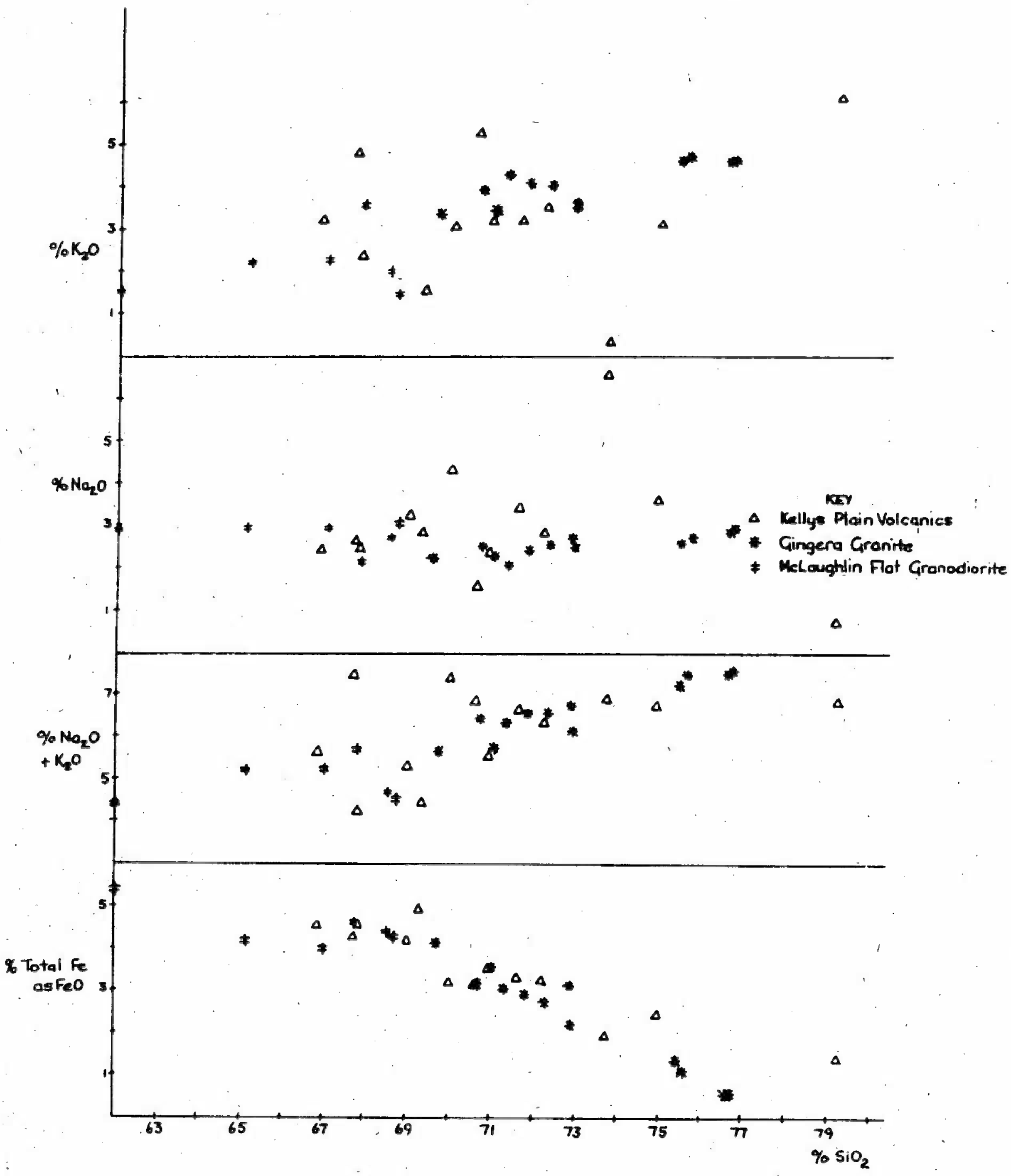


Fig. 32. (continued)

## 5. The Devonian volcanic rocks

### ROLLING GROUNDS LATITE (defined here)

(M.O. and D.W.)

#### NOMENCLATURE

The Rolling Grounds Latite was given the name Rolling Grounds Andesite by Stevens (1958, p. 254) for a series of augite-bearing latites present on Rolling Grounds Spur and Cooleman Plain. He had previously used the name in a Snowy Mountain Authority report (Stevens, 1957). Before Steven's work they had been mapped as an unnamed intrusive porphyry by Walpole (1952).

On the 2nd edition of Canberra 1:250 000 geological map (Best et al., 1964), the Rolling Grounds Latite is shown as either Kellys Plain Volcanics (the Rolling Grounds Spur outcrops) or Mountain Creek Volcanics (the Cooleman Plain outcrops). The present mapping has demonstrated that the Rolling Grounds Latite may best be considered as the basal member of the Mountain Creek Volcanics, but formal re-definition in those terms will be held over until mapping of the Mountain Creek Volcanics is completed and the Volcanics can be defined, when the Latite will be included in a complete description of the Volcanics.

#### DERIVATION OF NAME

The unit was named from Rolling Grounds Spur which rises eastwards from the junction of the Cave Creek and the Goodradigbee River (lat. 35° 38'S, long. 138° 43'E).

#### TYPE LOCALITY

Since no type locality was designated by Stevens (1958b), the area on Rolling Grounds Spur at G.R. 574560 is here designated the type locality of the Rolling Grounds Latite (Fig. 33). At this locality, lavas with poorly developed columnar jointing form low rubbly outcrops.

#### DISTRIBUTION

The main outcrop of the Rolling Grounds Latite is on Rolling Grounds Spur, but others include disconnected small outcrops on Cooleman Plain south of Coolamine, a large area trending northeast from Coolamine as far as the Black Mountain Fault, and a narrow elongate area about 7 km long by 0.5 to 0.75 km wide extending from the northwest side of Jackson Mountain north-northeast along McLeods Spur.

## LITHOLOGY

The Rolling Grounds Latite mostly consists of dark green to grey rock of latite composition. Several tuffaceous rocks of more acid composition are associate with the latite.

The latite is formed of dark green pyroxene phenocrysts up to 3 mm long, and rarer pale green feldspar phenocrysts up to 4 mm long in a very dark green or grey groundmass. A thin (2 to 4 mm) brown weathered crust having a very rough surface texture is developed on exposed surfaces.

The feldspar phenocrysts are commonly embayed and strongly altered, generally making identification impossible; however plagioclase probably of andesine composition has been identified in some specimens. Other more altered grains may be sanidine. Augite ($2V_z = 40 - 45^{o}$) occurs as common (10 - 15%) euhedral phenocrysts up to 2 mm across and embayed grains up to 3 mm across. The grains are colourless to very pale green and are completely unaltered though some contain embayments of chlorite and minor sericite. Minor exsolution lamellae parallel to (100) are common. Also present are slightly less common phenocrysts of a completely altered mineral of pyroxene habit. Chlorite and talc are the alteration productions. The reason for the alteration is unknown but it is suggested that the altered phenocrysts were originally strongly out of equilibrium with the groundmass. They were probably orthopyroxene. Quartz was reported as rare phenocrysts by Stevens (1958b) and Legg (1968). None was observed in the present study although sample 72840135 from north of Jackson Mountain (G.R. 547658) contains a few grains up to 0.3 mm across in the groundmass. These may be alteration products rather than phenocrysts. Pyrite is common in the latite north of Jackson Mountain. In sample 72840144 (G.R. 545654) pyrite forms about 5% of the rock; there are abundant irregular grains less than 0.1 mm across, and common euhedral grains up to 0.3 mm across. The euhedral grains occur in clusters of 6 or more.

The groundmass of the latite is extremely fine-grained and only very small feldspar laths, commonly roughly aligned and with flow tendency aroung phenocrysts, are visible. Staining with sodium cobaltinitrite and sodium thiocyanate indicates roughly equal amounts of both potassium feldspar and plagioclase in the groundmass.

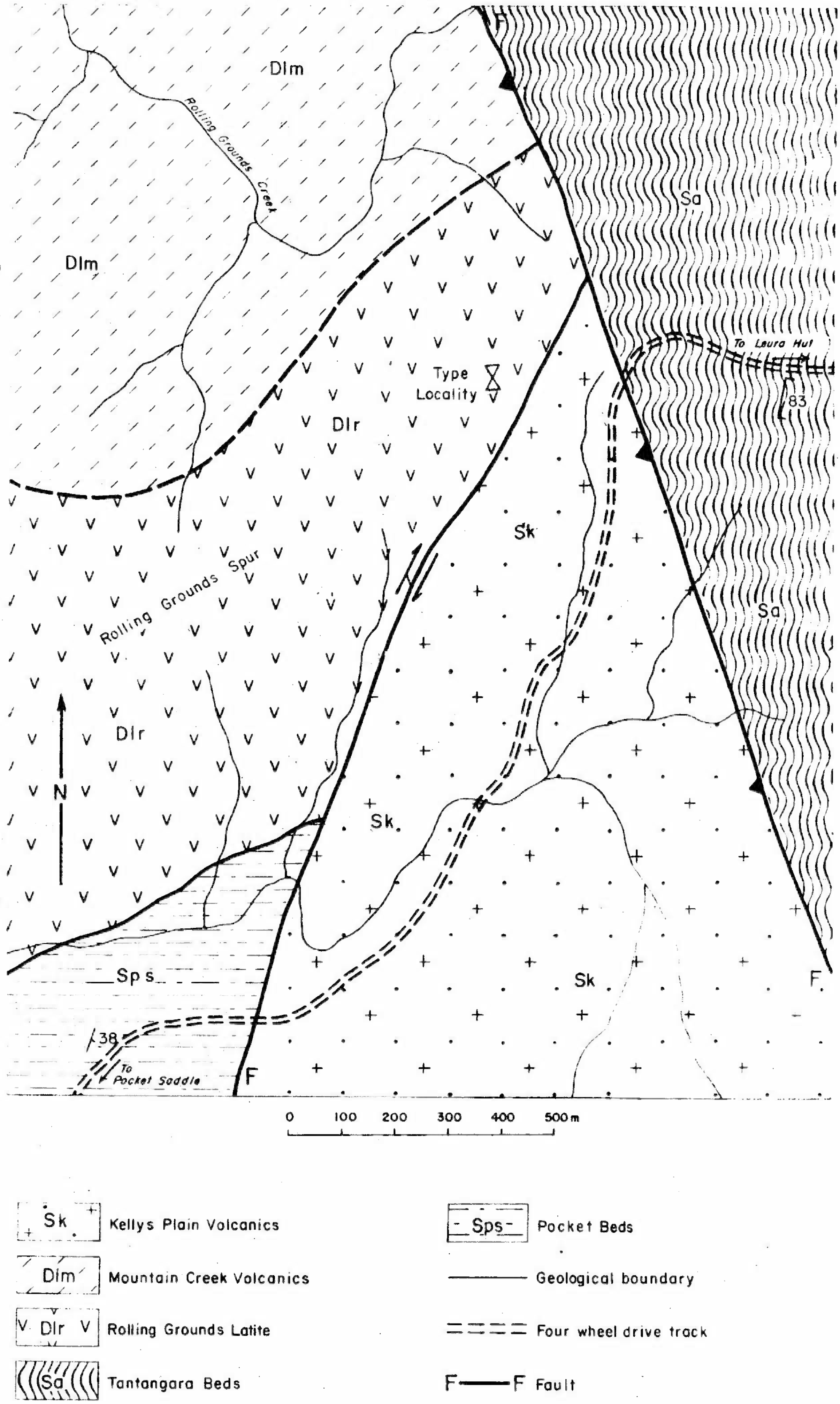


Fig. 33. Type locality of the Rolling Grounds Latite.

The rock may therefore on petrographic characters be called a latite, with roughly equal amounts of potassium and plagioclase feldspar, and with quartz minor or absent.

Sample 72840173 (G.R. 522659) is from an andesite dyke about 20 metres below the base of the Rolling Grounds Latite on McLeods Spur. The dyke may be a feeder to the overlying latite. It consists of altered and partly altered subhedral augite phenocrysts (10%) and sericitized plagioclase phenocrysts (10%), both up to 1.5 mm across, in a groundmass of euhedral plagioclase laths (70%) about 0.7 mm across separated by intergranular quartz (5%) and K-feldspar (5%). The augite is altered to actinolite, chlorite, and opaques. The plagioclase is strongly zoned with $An_{10}$ rims but cores whose composition cannot be determined because of complex and imperfect twinning.

## FIELD RELATIONS AND AGE

The Rolling Grounds Latite unconformably overlies the Late Silurian Cooleman Limestone and Blue Waterhole Beds, and is therefore no older than latest Silurian. No direct evidence for an upper age limit was found in the area. However, the Rolling Grounds Latite underlies the Mountain Creek Volcanics north of Jackson Mountain and on Rolling Grounds Spur. As the Mountain Creek Volcanics are conformably overlain by Early Devonian limestone and are unconformably underlain by Late Silurian rocks near Wee Jasper (Pedder et al., 1970, p.207) and probably by earliest Devonian strata at Bowning (Link, 1970), an Early Devonian age for the Rolling Grounds Latite is almost certain.

The relation between the Rolling Grounds Latite and the overlying Mountain Creek Volcanics is complex. North of Jackson Mountain they appear to be conformable, but in the Goodradigbee valley the Mountain Creek Volcanics directly overlies Blue Waterholes Formation, and the Rolling Grounds Latite is absent. The latite probably forms a wedge which thins towards the east.

The relation between the Rolling Grounds Latite and the Kelly Plain Volcanics is uncertain. We consider that the Rolling Grounds Latite may be younger than the Kellys Plain Volcanics. The Rolling Grounds Latite is chemically equivalent to dioritic intrusives near Cooleman which intrude the Kellys Plain Volcanics.

THICKNESS

The latite in a few places shows columnar jointing or flow structure which indicate that the lavas are mostly horizontal. There is a minimum thickness of 140 m east of Coolamine, probably slightly more on Rolling Grounds Spur. On McLeods Spur flow structure in the Mountain Creek Volcanics immediately overlying the Rolling Grounds Latite indicates dips of up to 80° to the east. Here, the Rolling Grounds Latite is probably about 250 m thick.

GEOCHEMISTRY

The geochemistry of the Rolling Grounds Latite is discussed along with that of the Mountain Creek Volcanics on p. 202.

## MOUNTAIN CREEK VOLCANICS

(D.W.)

FIELD OCCURRENCE

The Mountain Creek Volcanics are found mainly in the Brindabella 1:100 000 Sheet area, but there are also three disconnected occurrences in the Tantangara 1:100 000 Sheet area. Some notes on occurrence and lithology are given here; a fuller description will be provided after the mapping of the Brindabella Sheet area (Owen & Wyborn, in prep.).

The Mountain Creek Volcanics crop out on a hill 2 km north of Blue Waterhole, west of the Black Mountain Fault. They also occur near Rolling Grounds Creek east of Rolling Grounds Spur (where they form the core of a syncline and occupy about 3 $km^2$), while the main outcrops of Mountain Creek Volcanics in the Tantangara 1:100 000 Sheet area are north of Jackson Mountain. A belt about 3 km wide extends north from there, contracting to 1 km wide in the Goodradigbee valley. This belt continues into the Brindabella Sheet area. In all three areas of outcrop the Mountain Creek Volcanics appear to be conformable over the Rolling Grounds Latite.

LITHOLOGY

The Mountain Creek Volcanics are a sequence of dark blue, purple, and green flow-banded rhyolites. On Rolling Grounds Spur the rhyolite is purple and contains yellow-white phenocrysts of feldspar up to 5 mm across. Immediately north of Jackson Mountain the Rolling Grounds Latite is overlain by a narrow band of pale-grey rhyodacite which has been metamorphosed by the Jackson Granite. Farther north the latite is overlain by a blue to dark blue rhyolite, followed by a purple variety. In the Goodradigbee valley north west of Mount Ginini the rock is a highly sheared white to pale green rhyolite. On McLeods Spur the rhyolite has very well developed flow-banding dipping up to 80° to the east, while columnar jointing approximately perpendicular to the flow banding is common.

The rhyolite is composed of up to 30% phenocrysts averaging about 1 mm across, comprising sericitized feldspar (possibly sanidine), less common plagioclase, and rare quartz, in a groundmass of fluidal devitrified felsic glass. The glass has devitrified into rounded globules about 0.03 mm across. A few irregular phenocrysts composed of epidote, chlorite, opaques, and quartz were probably originally hornblende or augite.

Samples 71840468 and 72840172 are rhyodacites that have been recrystallized by contact metamorphism from the Jackson Granite. Sample 72840172 consists of relict phenocrysts of plagioclase up to 3 mm across with recrystallized and altered rims in a groundmass of quartz and orthoclase exhibiting a mortar texture with quartz grains up to 1 mm across. Microcline perthite occurs as uncommon ?porphyroblasts possibly altered from sanidine. One grain is 7 mm across. Brown biotite up to 0.2 mm across occurs as recrystallized groups partly altered to chlorite. Sample 71840468 consists of phenocrysts of altered feldspar up to 2 m across, and actinolite after augite up to 1 mm across, in a micrographic intergrowth of quartz and feldspar. There are some quartz porphyroblasts up to 1 mm across. Granular opaques occur both surrounding the actinolite grains and as inclusions in them.

At G.R. 536622 xenoliths of hornblende-pyroxene rock are present in slightly metamorphosed rhyodacite of the Mountain Creek Volcanics. The xenoliths range in size from single hornblende crystals a few millimetres across, to angular blocks up to 2 m across. Sample 72840215 from the largest xenolith contains about 45% hornblende, 30% augite, 15% plagioclase, and 10% orthoclase. The hornblende occurs in a great range of sizes up to 5 mm across. It is pleochroic with $\alpha$ = very pale brown, $\beta$ = greeny brown, $\gamma$ = light yellow brown, and absorption $\beta > \gamma > \alpha$. $2V_x = 80°$. The larger hornblende grains contain many unoriented inclusions of augite ($2V_z = 50°$) averaging 0.5 mm across. Augite also occurs as individual rounded grains up to 1 mm across. Plagioclase occurs as altered grains up to 0.8 mm across and orthoclase occurs as interstitial patches.

The Mountain Creek Volcanics and Rolling Grounds Latite unconformably overly the Late Silurian Cooleman Limestone and Blue Waterhole Beds. They are overlain by Lower Devonian limestone near Wee Jasper (Pedder et al., 1970, p. 207). An Early Devonian age for the Mountain Creek Volcanics may therefore be assumed.

In the Goodradigbee River valley west of Mt Ginini the Mountain Creek Volcanics are highly folded and sheared making it difficult to estimate thickness. In the Tantangara 1:100 000 Sheet area they are probably at least 300 m thick.

## MOUNTAIN CREEK VOLCANICS AND ROLLING GROUNDS LATITE GEOCHEMISTRY (M.S.)

The Mountain Creek Volcanics and Rolling Grounds Latite are discussed together because only two rocks from the Mountain Creek Volcanics have been analysed. Further examination of the geochemistry of the Mountain Creek Volcanics will be found in later work in the Brindabella 1:100 000 Sheet area. Analyses of the Rolling Grounds Latite and Mountain Creek Volcanics have been plotted on the same variation diagrams (Fig. 35) as the Coolamine Igneous Complex, Jackson Granite, Gurrangorambla Granophyre, and minor intrusions, and include three analyses of the Rolling Grounds Latite by Palmer (1972).

The samples analyses are of intermediate to acid composition, as silica ranges from 57.2 to 69.4%. (Table 26). The fractionation trend lines for lime, ferrous, ferric and total iron as FeO, potash, and total alkalis show little scatter, and line up with those of the other rock units. Lime, ferrous, and total iron as FeO are inversely correlated with silica, potash, and total alkalis show a positive correlation, whilst ferric iron is almost constant regardless of silica content. Samples 71840479, 71840361, and 71840531 fall well above the magnesia trend line but below the alumina trend line, suggesting that these three rocks may have been affected at some stage by alteration or contamination. Correlation between silica and soda is very poor. The suite is potassium-rich, the $K_2O/Na_2O$ ratio ranging from 1.02 to 2.57.

Sample 72840144 is a pyritic andesite containing 2.13% sulphur. The ferrous iron content of this sample falls on the fractionation trend for ferrous iron, suggesting that the iron in the pyrite was not introduced but came from the rock. Palmer (1972) found 0.01 to 0.02% sulphur in the three samples he analysed, so the sulphur in sample 72840144 may have been introduced.

Trace element contents have been determined for four rocks only. Nickel, cobalt, copper, and zinc show a negative correlation with silica, having lower proportions in the more acid samples, whilst lead shows an increase with increasing silica (except in sample 71840468).

Quartz is present in the norm in all samples, whilst normative corundum occurs only in the Mountain Creek Volcanics samples, and in the pyroclastic breccia analysed by Palmer (as the high carbon dioxide content of the latter results in high normative calcite, leading to a deficienty of lime relative to alumina). This excess alumina is contained in chlorite (probably originally biotite) and possibly the glassy groundmass. Normative diopside and hypersthene increase with decreasing silica, with hypersthene always more abundant than diopside. The enstatite (i.e. magnesium-rich) member of the pyroxenes is the most abundant, as much iron is taken up in the normative magnetic and ilmenite. The amount of normative orthoclase increases with increasing silica (as potash is positively correlated with silica), whilst the amount of plagioclase and its anorthite content decrease with increasing silica (as both lime and alumina are inversely correlated with silica).

## 6. SILURO-DEVONIAN IGNEOUS INTRUSIVES

### MURRUMBIDGEE BATHOLITH

(J.S.)

Rocks of the Murrumbidgee Batholith have been recorded as early as 1860 by Clarke; Mahoney & Taylor (1913) mentioned the granite near Tharwa in their report on the Federal Territory. Browne (1914, 1931, 1944) described the rocks of the southern and eastern part of the batholith, and distinguished blue, white, and pink gneiss. Joplin (1943) was the first to carry out chemical analyses of the blue and white gneiss, which she described petrographically.

Snelling (1960) divided the rocks of the batholith into three different classes: Uncontaminated Granites, Contaminated Granites, and Leucogranites. The Uncontaminated Granites were believed to represent closely the composition of the parental magma of the batholith, the Contaminated Granites were thought to have been derived from this parental magma by assimilation of country rocks, and the potassic Leucogranites were formed by differentiation of this contaminated magma. The three classes as defined by Browne do not correspond to the classification by Snelling, and will not be considered further in this Record.

Joyce (1970, 1973) used the same classification as Snelling. He concluded, mainly on chemical evidence, that all three groups were derived from partial melting of psammopelitic rocks of the Tasman Geosyncline. Uncontaminated Granites and Leucogranites were formed by fractional crystallization of

TABLE 26. ANALYSES AND CIPW NORMS OF THE MOUNTAIN CREEK VOLCANICS, INCLUDING THE ROLLING GROUNDS LATITE

| Sample No. | 71840361 | 71840468 | 71840469 | 71840479 | 71840531 |
|---|---|---|---|---|---|
| Rock type | latite | rhyolite | rhyolite | latite | latite |
| G.R. | 512549 | 531622 | 529624 | 511579 | 573560 |
| % | | | | | |
| $SiO_2$ | 62.0 | 67.3 | 69.4 | 61.7 | 61.7 |
| $Al_2O_3$ | 13.7 | 14.4 | 14.2 | 13.1 | 13.2 |
| $Fe_2O_3$ | 1.25 | 1.80 | 1.35 | 1.90 | 1.45 |
| FeO | 4.55 | 2.15 | 2.05 | 4.15 | 4.50 |
| MgO | 5.50 | 1.86 | 0.82 | 5.65 | 5.35 |
| CaO | 5.35 | 3.60 | 2.30 | 4.85 | 5.40 |
| $Na_2O$ | 2.00 | 3.25 | 2.65 | 1.99 | 1.40 |
| $K_2O$ | 2.65 | 3.30 | 5.00 | 3.05 | 3.60 |
| $H_2O^+$ | 1.99 | 1.32 | 0.90 | 2.20 | 1.85 |
| $H_2O^-$ | 0.15 | 0.14 | 0.16 | 0.22 | 0.31 |
| $CO_2$ | 0.20 | <0.05 | 0.35 | 0.05 | 0.10 |
| $TiO_2$ | 0.56 | 0.57 | 0.56 | 0.59 | 0.59 |
| $P_2O_5$ | 0.13 | 0.12 | 0.10 | 0.12 | 0.13 |
| MnO | 0.11 | 0.08 | 0.08 | 0.09 | 0.09 |
| | 98.00 | 98.48 | 98.86 | 97.24 | 97.51 |
| ppm | | | | | |
| Ni | 55 | 15 | 15 | 75 | 70 |
| Co | 15 | 10 | 5 | 25 | 20 |
| Cu | 45 | 10 | 50 | 45 | 55 |
| Zn | 38 | 50 | 45 | 60 | 60 |
| Pb | 100 | 5 | 20 | 15 | 10 |
| Cd | 3 | - | - | - | - |
| Mo | 4 | - | - | - | - |
| Qz | 19.71 | 25.79 | 29.44 | 19.39 | 19.88 |
| C | - | - | 1.31 | - | - |
| Or | 15.98 | 19.80 | 29.88 | 18.53 | 21.81 |
| Ab | 17.26 | 27.91 | 22.67 | 17.31 | 12.14 |
| An | 21.00 | 15.19 | 8.64 | 18.31 | 19.59 |
| Di Wo | 1.64 | 0.76 | - | 2.21 | 2.65 |
| Di En | 1.03 | 0.52 | - | 1.49 | 1.69 |
| Di Fs | 0.50 | 0.19 | - | 0.55 | 0.79 |
| Hy En | 12.94 | 4.19 | 2.06 | 12.98 | 11.97 |
| Hy Fs | 6.24 | 1.51 | 1.89 | 4.84 | 5.62 |
| Mt | 1.85 | 2.65 | 1.98 | 2.83 | 2.16 |
| Il | 1.09 | 1.10 | 1.08 | 1.15 | 1.15 |
| Ap | 0.31 | 0.29 | 0.24 | 0.29 | 0.32 |
| Cc | 0.46 | 0.12 | 0.81 | 0.12 | 0.23 |

TABLE 26. (cont'd)

| Sample No. | 72840144 | 62* | 114* | 101* | 136* |
|---|---|---|---|---|---|
| Rock name | pyritic andesite | andesite | andesite | pyroclastic breccia | metamorphosed |
| Grid reference | 545654 | 517550 | 518567 | 561568 | 533621 |
| % | | | | | |
| $SiO_2$ | 57.2 | 61.30 | 61.62 | 59.40 | 68.50 |
| $Al_2O_3$ | 16.1 | 13.38 | 13.10 | 12.70 | 14.07 |
| $Fe_2O_3$ | 1.18 | 1.85 | 1.46 | 1.61 | 1.03 |
| FeO | 6.0 | 3.87 | 4.30 | 3.92 | 2.29 |
| MgO | 4.80 | 5.23 | 5.78 | 5.23 | 1.60 |
| CaO | 6.50 | 5.94 | 5.48 | 4.97 | 2.55 |
| $Na_2O$ | 2.1 | 1.91 | 2.40 | 1.66 | 2.56 |
| $K_2O$ | 1.49 | 2.85 | 1.90 | 2.94 | 4.20 |
| $H_2O^+$ | 1.73 | 2.22 | 2.18 | 3.24 | 1.16 |
| $H_2O^-$ | 0.07 | 0.22 | 0.13 | 0.21 | 0.16 |
| $CO_2$ | 0.10 | 0.05 | 0.08 | 2.94 | 0.28 |
| $TiO_2$ | 0.80 | 0.57 | 0.57 | 0.56 | 0.54 |
| $P_2O_5$ | 0.12 | 0.14 | 0.14 | 0.14 | 0.15 |
| MnO | 0.12 | 0.10 | 0.12 | 0.07 | 0.10 |
| S | 2.13 | 0.02 | 0.01 | 0.01 | 0.01 |
| | 100.46 | 99.66 | 99.28 | 99.61 | 99.71 |
| ppm | | | | | |
| Cu | | 57.3 | 63.7 | | 5.7 |
| Zn | | 74.1 | 66.8 | | 56.1 |
| Pb | | 15.2 | 25.0 | | 29.3 |
| Qz | 15.45 | 19.53 | 19.92 | 27.23 | 30.32 |
| C | - | - | - | 5.10 | 1.75 |
| Or | 9.12 | 17.32 | 11.58 | 18.07 | 25.35 |
| Ab | 18.40 | 16.62 | 20.94 | 14.60 | 22.12 |
| An | 31.19 | 20.14 | 19.98 | 5.36 | 10.11 |
| Di Wo | 0.31 | 3.72 | 2.76 | - | - |
| Di En | 0.17 | 2.51 | 1.81 | - | - |
| Di Fs | 0.13 | 0.93 | 0.75 | - | - |
| Hy En | 12.21 | 10.89 | 13.04 | 13.54 | 4.07 |
| Hy Fs | 9.14 | 4.03 | 5.41 | 5.28 | 2.71 |
| Mt | 1.77 | 2.76 | 2.18 | 2.43 | 1.53 |
| Il | 1.57 | 1.11 | 1.12 | 1.11 | 1.05 |
| Ap | 0.29 | 0.34 | 0.34 | 0.35 | 0.36 |
| Cc | 0.24 | 0.12 | 0.19 | 6.95 | 0.65 |

* Palmer (1972).

this parental magma, which gave rise to the Contaminated Granites after assimilation of relict solid material (xenoliths).

## UNCONTAMINATED GRANITES

### Yaouk Leucogranite and Shannons Flat Adamellite

Snelling (1960) and Joyce (1973) have mapped and described the Yaouk Leucogranite and the Shannons Flat Adamellite as separate units belonging to different groups (Leucogranites and Uncontaminated Granites respectively). However in the field this boundary proved extremely difficult to map; the boundary shown on the Tantangara 1:100 000 map is at best doubtful. Subsequent laboratory work did not supply sufficient evidence that the two types are indeed two different intrusions, rather than just one intrusion with some lateral variation. For convenience the separate units will be retained as the matter has not been conclusively resolved.

The Shannons Flat Adamellite, regarded as a different unit from the Yaouk Leucogranite, is the biggest single intrusion of the batholith, cropping out as a lenticular body up to 15 km wide along the full length of the batholith. In the southern section of the batholith it occupies most of the northeast corner of the Yaouk 1:50 000 Sheet area, extending 5 km south of Shannons Flat as a relatively narrow tongue.

The Yaouk Leucogranite has been mapped as a south-trending intrusion west of the Shannons Flat Adamellite, 3 to 10 km wide and extending from the southern boundary of the Tantangara 100 000 Sheet area to the Cotter Hut. It covers a considerably smaller area than the Shannons Flat Adamellite.

Both rocks have a porphyritic texture. Microcline phenocrysts up to 6 cm) are set in a coarse-grained groundmass of plagioclase, microcline, quartz, biotite, and locally muscovite. A north-south foliation can be distinguished in some localities, more commonly in the Shannons Flat Adamellite than in the Yaouk Leucogranite. Both granites form large well rounded tors (up to 4 m or more).

In outcrop the Shannons Flat Adamellite is generally fresh, except for a thin veneer of weathered material. The Yaouk Leucogranite tends to be more weathered, resulting in difficulties in obtaining a fresh sample. Xenoliths are present but not common in both rock types.

In contrast to Joyce's (1973) claim that rocks of the batholith are sufficiently different to allow positive classification into one of the three groups, even in an isolated hand specimen, the writer does not think that it is possible to distinguish with any degree of certain between the Yaouk Leucogranite and the Shannons Flat Adamellite in the field.

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In thin section both rocks display a porphyritic, glomerogranular structure; feldspars and micas form clusters between clots of quartz grains.

In the Shannons Flat Adamellite quartz occurs as subhedral grains (up to 7 mm) and is interstitial. Plagioclase (up to 5 mm) forms short euhedral to subhedral prisms which are generally slightly zoned: Cores have a composition of about $An_{35}$, the margins slightly lower. The cores are commonly altered to sericite and saussurite.

Microcline forms interstitial subhedral crystals up to 5 mm lont, and also euhedral phenocrysts up to 6 cm. Crosshatch twinning is common and some microperthite has developed. Microcline has inclusions of all other minerals, and is consequently younter. Biotite up to 3 mm occurs as euhedral to subhedral short prismatic grains, and is pleochroic: A = light yellow, B = dark red brown. Muscovite occurs as an alteration product along the margins of biotite. Some samples show biotite partly to completely altered to chlorite, epidote, opaques. Opaques, zircon, sphene, and apatite occur as accessories.

In the Yaouk Leucogranite quartz occurs as subhedral to anhedral grains up to 8 mm, displaying a very undulose extinction and some marginal granulation. Plagioclase forms euhedral short prismatic grains up to 6 mm, with a composition of $An_{5-10}$. Cores are partly altered to sericite and saussurite. Microcline occurs as euhedral phenocrysts up to 6 cm and interstially up to 6 mm. It is perthitic and shows some crosshatch twinning. Biotite forms short thick euhedral flakes up to 2 mm, commonly in clots up to 6 mm. Alteration to chlorite, epidote, and opaques is common. Muscovite occurs as an alteration product along the margin of the biotite clots, and is also primary. Pleochroism ranges from very light yellow to dark reddish brown. Accessories include apatite, muscovite, zircon, and opaques.

Modal analyses of the rock types were carried out with a Swift Point-counter. Thin sections (maxim. 2 x 5 cm) proved too small for these coarse-grained granites, so slabs of 5 x 5 cm or bigger were used, stained with a solution of sodium cobaltinitrite after etching with hydrofluoric acid, according to a method described by Lyons (1971). A transparent 1/12 inch grid was laid over the stained surface and counting was done with a Nikon binoculair stereozoom microscope. Approximately 600 points were counted on each slab. Table 27 gives the results of the counts. According to these modal analyses the Shannons Flat Adamellite is a true granite rather than an adamellite, but the number of counts was too small for that conclusion to be considered significant. Percentages for the plagioclase and micas are similar in the two rocks. The Yaouk Leucogranite has an average quartz percentage of 34% and microcline of 43%. The Shannons Flat Adamellite contains an average 44% quartz and 34% microcline. The average mode of the Yaouk Leucogranite, based on three samples, is similar to the average mode, based on two samples, found by Joyce (1973), but differs considerably from Snelling's (1960) results. The average mode of the Shannons Flat Adamellite is very different from the mode acquired by Joyce based on 25 samples, and also from Snellings mode which is based on 19 samples. Snellings and Joyce's results also show considerable differences.

Summary: in the field the similar nature of the two rock types makes differentiation difficult: the Yaouk Leucogranite tends to be more weathered, less foliated, and slightly lighter than the Shannons Flat Adamellite. In thin section both rocks are also very similar; the Yaouk Leucogranite shows in general more cataclastic effects and contains a more acid plagioclase than the Shannons Flat Adamellite (resp. 5-10 An% and 35 An %).

The discrepancies in modal analyses carried out by various investigators for the Shannons Flat Adamellite and to a lesser degree the Yaouk Leucogranite prevent the use of this method at this stage to differentiate between the two rocks in the laboratory.

TABLE 27. MODAL ANALYSES OF YAOUK LEUCOGRANITE AND SHANNONS FLAT ADAMELLITE

(carried out on stained slabe. Approximately 600 points counted per analysis)

| Sample | Quartz % | Microcline % | Plagioclase% | Mafic% |
|---|---|---|---|---|
| Yaouk Leucogranite | | | | |
| 72840316 | 34.0 | 41.5 | 21.4 | 2.9 |
| 72840065 | 31.4 | 46.2 | 17.6 | 4.9 |
| 72840317 | 36.3 | 42.6 | 17.5 | 3.8 |
| Average | 33.9 | 43.4 | 18.8 | 3.8 |
| Shannons Flat Adamellite | | | | |
| 72840413 | 40.8 | 36.4 | 17.5 | 5.0 |
| 72840009 | 47.0 | 33.6 | 15.8 | 4.5 |
| Average | 43.9 | 35.0 | 16.1 | 4.7 |

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As no conclusion evidence has been found to support the published hypothesis that the two rock types represent two different intrusions, it is suggested that the Shannons Flat Adamellite and the Yaouk Leucogranite form one intrusion showing some areal variation.

## LEUCOGRANITES

### Westerly Leucogranite

The Westerly Leucogranite crops out as a south-trending dyke-like body about 1 km at the western boundary of the Yaouk Leucogranite, and also as a small wedge 1 km northeast of Long Corner. It varies in structure and in mineralogy, and so can be treated as a series of leucocratic intrusions, of which three types will be described.

The most common type is a fine-grained to medium-grained, equigranular rock with a saccharoidal texture. In hand specimen quartz, feldspar, biotite, muscovite, and sometimes garnet can be distinguished. In thin section the texture is distinctly glomerogranular: clusters of feldspars and micas set in quartz. Quartz occurs as anhedral grains up to 1 mm in clusters up to 4 mm. Plagioclase forms short prismatic euhedral grains up to 2 mm, only slightly altered to sericite and saussurite; its composition is $An_8$. Microcline occurs as slightly perthitic, anhedral grains up to 2 mm; crosshatch twinning is common. Muscovite up to 2 mm is anhedral and often associated with biotite, which forms euhedral flakes up to 1 mm partly or completely altered to opaques and muscovite. Biotite is pleochroic: = light yellow, dark brownish green. Euhedral garnet up to 1 mm, andalusite (enclosed in micas), zircon, and opaques occur as accessories. The presence of andalusite will be commented on below. (page 214).

A less common type with the same mineralogy contains phenocrysts of quartz up to 1 cm and microcline up to 2 cm.

A third type exists, but no thin section could be obtained owing to the weathered state of its outcrops. This rock has conspicuous blots of biotite and muscovite up to 1 cm and some quartz and feldspar phenocrysts set in a fine-grained groundmass of quartz, feldspar, and mica. This rock type is found mainly in the northern part of the Lecogranite. In the southern part of the intrusion a large muscovite-bearing quartz vein was found, showing a foliated structure. The foliation is north-south and vertical.

Very few xenoliths were found in these leucogranites, and the only foliation observed was in the muscovite-bearing quartz vein. The varying nature of the leucogranites leads to a variety of outcrop styles. On gentle slopes groups of small boulders up to 2 m are quite general. On steeper slopes bigger boulders and bare faces of granite occur. The outcrops are generally moderately to highly weathered.

Contacts with other rock types are intrusive except for a small section of the wedge shaped body 1 km northeast of Long-Corner, where the boundaries with the Yaouk Leucogranite and Ordovician sediments are faulted.

A dark medium-grained inclusion thought to be of the Bolairo Granodiorite would indicate that the leucogranites are younger than that Granodiorite.

### Unnamed Leucogranites

Throughout the southern part of the Murrumbidgee Batholith are dykes and bosses of fine to medium-grained leucogranite. They are very numerous in the southwestern part, mapped as Yaouk Leucogranite, and along contacts between different members of the batholith. This makes the establishment of age relations between different intrusions often very difficult. The leucogranites are very similar to the various types making up the Westerly Leucogranite. In general they are moderately to highly weathered, and outcrops appear the same as the westerly Leucogranite; they are probably related to that intrusion.

## CONTAMINATED GRANITES

### Bolairo Granodiorite

The Bolairo Granodiorite forms an irregular intrusion north of Bolairo. Outcrops commonly comprised well rounded unweathered boulders up to 3 m across. Part of the granodiorite is overlain by ferricrete. Well-assimilated discoid pelitic xenoliths are numerous, and lie parallel to the primary north-south foliation. Vertical fractures also north-south, are locally abundant. The contact of the granodiorite with the Yaouk Leucogranite is faulted. The south-west-trending fault indicated by Joyce and other observers is in fact an intrusive boundary, as is the contact with the Westerly Leucogranite.

In hand specimen this medium-grained rock appears dark because of its high biotite content. Blue quartz, plagioclase, and biotite can be distinguished. Near the margin of the intrusion the rock tends to be darker than in the centre.

The Bolairo Granodiorite in thin section is very similar to the other contaminated granites, the Callemondah Granodiorite and the Willoona Tonalite. Therefore the following description applies to the Contaminated Granites in general.

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In thin section the texture is uneven-grained, glomerogranular. Whereas in outcrop a primary foliation is obvious, particularly on weathered surfaces, in hand specimen and in thin section it is difficult to detect. Cataclastic effects are commonly seen in thin section: quartz and microcline are often granulated and biotite flakes are bent and ragged. Quartz occurs as subhedral grains up to 5 mm, with very undulose extinction. Plagioclase occurs as suhedral prisms up to 5 mm. It is slightly zoned: cores have a composition of $An_{50}$, margins are slightly more acid. It is suspected that some have an anorthite content of more than 50%. Plagioclase is partly altered to sericite and saussurite. Microcline forms anhedral, poikilitic grains up to 3 mm. Grosshatch twinning is common. Biotite occurs as subhedral flakes up to 3 mm with ragged edges; bent lamellae are common. Small secondary muscovite laths occur as alteration products. Some alteration to chlorite and epidote was also observed. Biotite is pleochroic: = light yellow, = deep reddish brown. Apatite, zircon, and opaques occur as accessories.

A sample from near the margin of the Bolairo Granodiorite showed medium-grained quartz, plagioclase and biotite set in a granulated groundmass of quartz, feldspar, and mica. Microcline is probably completely granulated, white plagiocalse grains altered to sericite and saussurite often have a thin margin of fresh plagioclase.

Willoona Tonalite

The Willoona Tonalite forms an irregular, lenticular, north-trending body east of Girraween. The northern boundary with the granite mapped as Yaouk Leucogranite is a fault. The other boundaries are intrusive. Sedimentary screens occur on both sides of the intrusion and form ridges. These sediments contain andalusite, which is probably a contact metamorphic product of one of the bordering intrusions.

In outcrop the tonalite is generally fresh, forming small boulders up to 2 m, which are angular and well jointed. A north-south foliation is obvious in outcrops and less visible in hand specimen and thin section. The general appearance of the rock is somewhat darker than the Bolairo Granodiorite and it contains more zenoliths.

Callemondah Granodiorite

The Callemondah Granodiorite forms an irregular intrusion, elongate north-south, 11 km long and 2 to 3 km wide, east and northeast of Shannons Flat. Outcrop is abundant; the generally unweathered boulders, rarely larger than 1.5 m, are elongate parallel to the strong foliation which was observed throughout the intrusion.

The granodiorite is similar to other contaminated granites in thin section.

Tremolite Porphyries

In the Ordovician sediments east of the Westerly Leucogranite and also in the sedimentary screen east of the Willoona Tonalite there are small dykes up to 3 m wide of dark porphyry. Similar dykes were also found in small numbers south of the Murrumbidgee River near Ashvale. None were found intruded in the rocks of the batholith. The dykes have a north-south trend and are vertical. In outcrop the rock is generally fresh.

In thin section plagioclase and quartz phenocrysts are set in a fine-grained groundmass. Quartz forms subhedral grains up to 5 mm and is locally myrmekitic. Plagioclase occurs as euhedral phenocrysts up to 4 mm with a composition of $An_{45}$, and in the groundmass. Grains are generally antiperthitic, with margins of albite which is not antiperthitic; they have a prismatic habit. Microcline occurs as an exsolution product and possibly in the groundmass. Biotite forms irregular flakes up to 0.3 mm, mainly in aggregates with random orientation. It encloses opaques. Pleochroic: $\alpha$ = colourless and $\beta$ = yellow brown. Tremolite is fibrous, and forms spherulitic aggregates up to 2 mm. It is colourless and partly altered to talc. Opaques, zircon, and apatite occur as accessories. The composition of this rock is probably granodioritic.

SMALL UNNAMED GRANITIC INTRUSIONS

Of six previously unmapped intrusions shown but not named on the Tantangara 1:100 000 Sheet, only one lies outside the batholith - a granodiorite at G.R. 645390, 2 km north-northeast of Yaouk, intruding Ordovician sediments. All these intrusions are less than 1.5 $km^2$ in outcrop area. Their modal analyses are shown in Table 28.

Leucogranite at 683205

This rock has intruded Ordovician sediments in a lenticular area 2 km southeast of Long Corner. As only one outcrop was found, on a poorly exposed steep north-facing slope, it is not shown on the map. In hand specimen this granite shows large up to 3 cm phenocrysts of microcline set in a medium to coarse-grained groundmass of quartz, plagioclase, microcline, and biotite. An intense north-south trending foliation is visible; the granite is moderately weathered.

In thin section also the strongly foliated structure is conspicuous: fine-grained, granulated quartz and feldspar occur as seems around augen of quartz and feldspar. The few micas present are mainly parallel to the foliation. Anhedral quartz forms grains up to 3 mm, microcline occurs as phenocrysts, often perthitic and euhedral. Plagioclase forms euhedral prisms up to 5 mm with composition $An_7$, and cores generally altered to sericite. It displays undulose extinction. Subhedral biotite forms small up to 2 mm flakes, in which bent lamellae are common. Muscovite occurs as an alteration product of biotite, as small laths with random orientation, Biotite is pleochroic: $\alpha$ = light yellow, $\beta$ = deep greenish brown. Clinozoisite and anatase occur as accessories.

TABLE 28. MODAL ANALYSES OF UNNAMED INTRUSIONS FROM THE MURRUMBIDGEE BATHOLITH
(2000 points counted per thin section)

| Rock name | G.R. | Qz. | Mic. | Plag. | Biot/Chlor. | Musc. | Amph. | Other |
|---|---|---|---|---|---|---|---|---|
| Leucogranite | 683205 | 36.0 | 36.3 | 23.1 | 2.6 | 2.0 | | |
| Adamellite | 720280 | 35.2 | 26.2 | 31.7 | 5.8 | | | 1.1 (epid) |
| Leucogranite | 692162 | 39.0 | 37.4 | 19.1 | 2.5 | 2.1 | | |
| Tonalite | 690175 | 22.4 | | 58.8 | 9.5 | | 9.3 | |
| Granodiorite | 680240 | 34.6 | 13.5 | 41.4 | 9.2 | | | 1.3 (epid) |
| Granodiorite | 645390 | 38.0 | 7.2 | 19.6 | 22.5 | 6.2 | | 6.5 (epid) opaques, garnet) |

Adamellite at 720280

This rock, the largest of the unnamed granitic intrusions, occurs at the boundary between the Shannons Flat Adamellite and the Yaouk Leucogranite, west of Bradley's Creek. As shown on the map, it probably intrudes both. Inclusions of coarse-grained leucogratic granite confirm that it is younger than the Yaouk Leucogranite. In the field no foliation was observed, and phenocrysts and xenoliths are absent. Subparallel vertical fractures are fairly evenly spaced in two sets at right angles resulting in large (up to 10 m) equidimensional unweathered boulders. This medium-grained rock is very homogenuous in structure and mineralogy.

In thin section the texture is slightly glomerogranular. Quartz (up to 2 mm) is subhedral to anhedral, myrmekite common. Microcline (up to 2 mm) is anhedral, and crosshatch twinning is general. Plagioclase (up to 2 mm) is euhedral and forms short prisms. Its composition is $An_{10}$; owing to zoning, margins are slightly more acid. Cores are generally altered to sericite and saussurite. Biotite occurs as elongated flakes up to 2 mm, completely altered to chlorite and epidote. Primary muscovite and minute apatite grains occur as accessories.

The mode of this granite (Table 28) is similar to the mode of the Shannons Flat Adamellite found by Joyce and it could be regarded as an Uncontaminated Granite.

Leucogranite at 692162

This leucogranite forms a small circular intrusion in the Yaouk Leucogranite 0.5 km west of Ashvale, and so is younger than it. The granite is intensely foliated (north-south, vertical), and crops out as small (up to 2 m) moderately to highly weathered angular blocs, trending north-south as a result of the foliation. No xenoliths were found. Little variation in the nature of the rock was observed. The grey colour of quartz, the weathered nature of the feldspar, and the low percentage of dark minerals give this medium-grained granite a leucocratic appearance.

In thin section the leucogranite has a distinctive glomerogranular texture; it is uneven-grained and at this small scale the foliation appears only slight. Quartz (up to 1 mm) occurs in clusters up to 5 mm, and is anhedral. Plagioclase forms auhedral prisms up to 3 mm and is generally slightly altered. Smaller, fresh grains of plagioclase seem to be formed at the expense of microcline. The composition of plagioclase does not exceed $An_{10}$. Plagioclase forms clusters with microcline. Microcline (up to 2 mm) is anhedral and perthitic. Biotite (up to 1 mm) is closely associated with muscovite in elongated clusters and is pleochroic: $\alpha$ = light yellow, $\beta$ = dark brown. Muscovite (up to 1 mm) is primary and also occurs as an alteration product of biotite. Andalusite is an accessory, occurring as euhedral grains up to 0.5 mm with reaction rims of chlorite. Other accessories are garnet, opaques, and zircon.

The occurrence of andalusite in rocks of the Murrumbidgee Batholith has not been reported before. Andalusite has also been found as an accessory in a sample of the Westerly Leucogranite collected 1 km west of the leucogranite

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at G.R. 692162. There is no textural evidence in either case for it being a replacement mineral. It seems to have been in equilibrium with the melt when this rock was formed. The reaction rim of chlorite is most likely a weathering product.

In both cases the andalusite is found within 0.3 km of the surrounding Ordovician sediments, so the possibility of contamination should be considered. However no other signs of contamination or any changes in the nature of the granitic rocks were detected by the writer or previous observers. Also contact metamorphic effects are few and restricted to a zone no more than 30 m wide. Therefore the likelihood of mobilization seems remote and it can be concluded that the andalusite in both samples is of primary igneous origin.

Garnet has been reported before by Joyce from the Westerly Leucogranite. For mode see Table 28.

Tonalite at 690175

About 1.5 km northwest of Ashvale is a small roughly L-shaped intrusion of tonalite in the Westerly Leucogranite, at its boundary with the Yaouk Leucogranite. It is medium-grained and contains occasional equidimentional pelitic inclusions. Foliation is absent. It crops out in general as medium to large (up to 8 m) well rounded boulders which are fresh to slightly weathered. No distinctive fracture pattern was observed.

In hand specimen the tonalite has a melanocratic appearance, owing to a high biotite and amphibole content. The quartz is grey.

In thin section the texture is distinctly poikilitic: large quartz grains enclose laths of plagioclase having a random orientation. Quartz (up to 5 mm) displays a strong undulose extinction and is anhedral. Plagioclase occurs as euhedral laths up to 1.5 mm enclosed in quartz, biotite and amphibole. Its composition is $An_{51}$, with slightly more acid rims. Some cores are altered to sericite and saussuitte. Amphibole (up to 2 mm) is subhedral. It is pleochroic: $\alpha$ = grassgreen, $\beta$ = light green, $\gamma$ = yellowish green. Rims are generally darker than the cores. Biotite (up to 5 mm) is subhedral and partly altered to chlorite and epidote. It is pleochroic: $\alpha$ = light yellowish brown and $\beta$ = dark brown. Zircon, apatite, opaques, and sphene occur as accessories. For mode see Table 28.

Granodiorite at 680240

An elongate body of granodiorite was found 1.5 km northeast of Long

Corner. The rock is medium-grained and generally equigranular, without foliation; no blue quartz and very few microcline phenocrysts were seen. A few well assimilated equidimentional pelitic xenoliths were found. Owing to its biotite and chlorite content, this rock has a mesocratic appearance. The granodiorite crops out as subangular boulders 1 to 12 m across. The intrusion is at the boundary of the Yaouk Leucogranite against Ordovician sediments; field evidence suggests that it has an intrusive relation to both.

In thin section the texture is glomerogranular and even-grained. Quartz occurs as subhedral to anhedral grains up to 6 mm and is sometimes myrmekitic. Plagioclase forms euhedral to subhedral short prisms up to 3 mm. It is zoned: rims have a composition of approximately $An_{20}$, cores of about $An_{40}$. Most cores are altered to sericite and saussurite. Microcline (up to 3 mm) occurs interstitially and is generally fresh. Biotite (up to 2 mm) forms euhedral, short prismatic crystals, generally concentrated in clusters. It is partly altered to clorite and epidote. Pleochroic: $\alpha$ = light yellow brown, $\beta$ = dark brown. Muscovite, probably primary, is present as small flakes, while opaques, apatite, and zircon occur as accessories. For mode see Table 28.

Granodiorite at 645390

A small intrusion of medium-grained melanocratic granodiorite crops out amidst Ordovician sediments about 2 km west of the western boundary of the batholith, 2 km north-northeast of Yaouk. No foliation or phenocrysts were observed. The rock contains numerous equidimentional pelitic xenoliths. The quartz is grey.

In thin section the granodiorite displays an even-grained granitic texture. Quartz (up to 4 mm) occurs mainly interstitially. Plagioclase is euhedral and forms short prismatic grains up to 4 mm. Its composition is approximately $An_{35}$. Most grains are altered to sericite and saussurite. Microcline (up to 4 mm) is subhedral, partly altered, and perthitic. Biotite (up to 5 mm) occurs as euhedral prisms, but is anhedral against plagioclase. It is completely altered to chlorite, epidote, and opaques.

The accessory minerals tourmaline, garnet, apatite, zircon, and sphene are evenly distributed through the rock.

Of the six previously unmapped granitic intrusions one (the granodiorite at G.R. 645390) was found outside the batholith and is possibly not related to it.

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The Leucogranite at G.R. 683205 is possibly a foliated offshoot of the Westerly Leucogranite, and the adamellite at G.R. 720280 can be classified as a Contaminated Granite.

The mode of the leucogronite at G.R. 692162 is comparable with the mode of the Westerly Leucogranite. However the strongly foliated nature of the rock and its more weathered appearance justify considering this rock as a separate intrusion rather than an offshoot of the Westerly Leucogranite.

The modes of the tonalite at 690175 and the granodiorite at 680240 are closest to the Contaminated Granites of the batholith. However other features typical of the Contaminated Granites are absent: the quartz is grey instead of blue, foliation is absent, and xenoliths are few or absent. The low quartz percentage of the tonalite is typical for the granitic rocks of the batholith. Therefore these two rocks do not fit in any of the three groups of the batholiths as defined by Snelling. However, the size of the intrusions hardly justifies the creation of a fourth class.

The five unnamed intrusions within the bounds of the Murrumbidgee Batholith are all regarded as younger than their host rock, as they are all fully or almost fully enclosed by those rocks.

The age relations of the main members of the batholith were based by Joyce on the shape of the intrusions. In the case of the Murrumbidgee Batholith, with numerous parallel elongate intrusions of granitic rocks where faulting is common, boundaries are often obscured by abundant leucogranite and aplite dykes, and outcrop is poor, thus this method seems of doubtful value.

The only reliable indication found during this survey is an inclusion of Bolairo Granodiorite in the Westerly Leucogranite, indicating that the former is the older.

## GEOCHEMISTRY

The geochemistry of the Batholith has been fully discussed by Joyce (1970, 1973).

## MCLAUGHLINS FLAT GRANODIORITE (defined here)

(D.W.)

### NOMENCLATURE

The name McLaughlins Flat Granodiorite has been introduced for a series of petrographically and chemically similar igneous bodies which crop out in the Tantangara 1:100 000 Sheet area between Yaouk and Adaminaby. The bodies were previously included in the Gingera Granite (Best et al., 1964).

## DERIVATION OF NAME

The name is taken from McLaughlins Flat, 4.5 km north-northwest of Adaminaby Post Office.

## TYPE LOCALITY

The type locality is 2.0 km west of Adaminaby on the Snowy Mountains Highway (G.R. 576145). On the northern side of the road many rounded boulders are up to 1.5 m across. The rock is a coarse-grained blue-grey poorly foliated biotite granodiorite. Biotite-rich pelitic xenoliths up to 10 cm across are abundant. The xenoliths are elongated parallel to the biotite foliation in the granodiorite.

## GEOGRAPHICAL DISTRIBUTION

The Granodiorite crops out as a series of irregular bodies of varied size. Its total area of outcrop in the Tantangara Sheet area is about 60 $km^2$. The main body is about 7 km wide on the southern border of the Tantangara 1:100 000 Sheet area west of Adaminaby. It narrows northward to about 3 km wide near Fontenoy, and cuts out completely about 1.5 km northwest of Yaouk. The margin of the intrusion is strongly embayed by sedimentary country rock; south of Fontenoy, one such embayment is 5 km long and 1 km wide. Two other large elongate bodies are exposed. One in the Bulgar Creek valley is about 10 km long and up to 1.5 km wide. The other, east of Big Bugtown Hill, is about 6 km long and 1.5 km wide. Smaller bodies, some only a few metres across, are common.

## FIELD OCCURRENCE

Outcrop of the Granodiorite is generally good, boulders and tors up to 4 m high being widespread both in the southern undulating grassed country and in the steeper forest country to the north. Outcrop is poorer near the margins of the bodies where foliation is more strongly developed and weathering deeper. No contacts have been observed, but the irregular shape of the bodies leaves little doubt that they are intrusive. Roof pendants are common. One northeast of the Snowy Mountains Highway near Willow Grove is 2 km long and up to 500 m wide. East of Big Bugtown Hill a sedimentary screen less than 1 km wide separates the main body from a smaller body. The screen is over 9 km long and to the north it bends around the smaller body like a fold. This indicates that the structural orientation of the sediments was an important factor in controlling intrusion.

The eastern edge of the main body is faulted off by the Cotter Fault in the Murrumbidgee valley. Near Stuartfield several landslips have occurred: granodiorite boulders have slid down the fault scarp and at G.R. 613282 are more than 50 m east of the fault line.

Hand specimens from all outcrops are very similar. Samples from small bodies only a few metres across are similar in grain-size, texture, colour, and mineral composition to samples from the centres of the largest bodies. The rock is a medium to coarse-grained equigranular granodiorite with grains up to 3 mm across. It is composed of white feldspar, pale grey quartz, and black biotite. In samples from the body cropping out in the Bulgars Creek valley hornblende and biotite are recognizable in hand specimen. Some samples, e.g. sample 71840002 (G.R. 583210), are strongly foliated as indicated by biotite alignment. The strongest foliation is near the margins of the larger bodies. In all samples there are about 20% dark minerals.

Discoid pelitic xenoliths up to 40 cm across are abundant throughout. They show a range in degree of assimilation up to granitic patches slightly richer in biotite than the granodiorite. Where foliation is observable the xenoliths are aligned parallel to it.

Contact effects on the surrounding country rock are not observable even less than 1 m away from the contacts.

PETROGRAPHY

All samples collected are biotite tonalite and granodiorite. Samples from the body in Bulgars Creek valley also contain hornblende except sample 71840018 (G.R. 545201) which comes from near the margin of the body. Modal analyses are presented in Table 29.

The rocks have a distinctive hypidiomorphic granular fabric with 25% to 50% of stumpy prismatic grains of plagioclase up to 2 mm across. Rare euhedral plagioclase phenocrysts are up to 5 mm across. The plagioclase is strongly zoned with $An_{40}$ cores, and rims as sodic as $An_5$. The cores are commonly highly sericitized. Between 30% and 40% quartz is present, as anhedral interstitial patches up to 3 mm across. In some samples secondary foliation is very strongly developed (e.g. sample 72840026, G.R. 591257) and quartz has been deformed and recrystallized into composite grains. All samples show some signs of strain, as the quartz invariably possesses undulose extinction.

Biotite occurs as subhedral to anhedral flakes up to 1.5 mm across with inclusions of apatite, zircon, and opaques. It is pleochroic with $\alpha$ = pale yellow brown, $\beta = \gamma$ = dark reddish brown, and has $2V_x \doteqdot 15°$. In the more intensely foliated samples the biotite is bent and partly recrystallized, and commonly has associated secondary muscovite. Most samples show signs of weathering with the edges of biotite flakes altered to biaxially positive pale green chlorite.

Microcline is uncommon in the McLaughlins Flat Granodiorite; in some samples, e.g. sample 72840046 (G.R. 533180), it is absent. It occurs as sporadic interstitial grains up to 2 mm across commonly moulded onto euhedral plagioclase crystals. The microcline has very poorly developed tartan twinning and no observable perthite lamellae. It generally shows undulose extinction.

Hornblende occurs only in samples taken from the outcrops in the Bulgar Creek valley. It is more abundant at the southern end of this body, where it forms up to 8% of the rock, but nowhere is it as common as biotite. The hornblende occurs as anhedral grains up to 1.5 mm across and 3 mm long. It is pleochroic with $\alpha$ = very pale yellow, $\beta$ = browny green, $\gamma$ = green with a bluish tinge, and absorption $\beta > \gamma > \alpha$; $2V_x = 70°$. The hornblende rarely shows any colour zoning, other than having cores very slightly browner than margins of grains.

The accessory minerals apatite, zircon, and opaques are commonly associated with biotite. Apatite occurs as rare euhedral prisms up to 0.1 mm long. Zircon is common as euhedral grains up to 0.2 mm across. Opaques occur as subhedral to anhedral grains up to 1 mm across; in sample 72840046 (G.R. 533180) they represent 0.5% of the rock.

## GEOCHEMISTRY

Total rock analyses for 5 samples of McLaughlins Flat Granodiorite are presented in Table 30. The mineralogy, chemistry, and xenolith content of the granodiorite indicates that it is an example of the 'contaminated granite group' of Joyce (1970, 1973).

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TABLE 29. MODAL ANALYSES OF McLAUGHLINS FLAT GRANODIORITE

(Swift Point Counter: 2000 points at 450 per $cm^2$)

| Sample No.<br>Rock type<br>G.R. | 71840001<br>Granodiorite<br>589195 | 71840002<br>Granodiorite<br>583210 | 71840018<br>Granodiorite<br>545201 | 71840024<br>Granodiorite<br>597219 | 71840034<br>Granodiorite<br>540217 | 72840046<br>Tonalite<br>533180 |
|---|---|---|---|---|---|---|
| Quartz | 40.5 | 37.5 | 46.4 | 33.6 | 33.1 | 30.1 |
| K feldspar | 10.0 | 9.3 | 7.2 | 6.3 | 6.2 | - |
| Plagioclase | 25.4 | 25.1 | 26.6 | 35.5 | 37.4 | 50.3 |
| Biotite | 22.8 | 23.7 | 13.0 | 16.7 | 18.7 | 11.2 |
| Muscovite | - | 4.2 | 6.0 | - | - | - |
| Hornblende | - | - | - | - | 4.0 | 7.7 |
| Chlorite (after biotite) | - | - | - | 7.1 | - | - |
| Accessories (epidote, apatite, zircon) | 0.4 | 0.2 | 0.8 | 0.8 | 0.6 | 0.7 |

TABLE 30. TOTAL ROCK ANALYSES AND CIPW NORMS OF McLAUGHLINS FLAT GRANODIORITE

| Sample No. | 72840024 | 72840286 | 72840026 | 72840045 | 72840044 | 72840046 | Average of 16 Samples of Clear Range Granodiorite (Joyce, 1973) |
|---|---|---|---|---|---|---|---|
| Rock type | Granodior-ite | Granodior-ite | Granodior-ite | Granodior-ite | Tonalite | Tonalite | |
| G.R. | 597219 | 576145 (Berridale 1:100 000 sheet) | 591257 | 539201 | 553236 | 533180 | |
| % | | | | | | | |
| $SiO_2$ | 68.7 | 67.8 | 68.5 | 67.0 | 65.1 | 62.0 | 67.5 |
| $TiO_2$ | 0.70 | 0.67 | 0.42 | 0.46 | 0.48 | 0.61 | 0.60 |
| $Al_2O_3$ | 13.9 | 14.7 | 14.0 | 15.2 | 16.4 | 16.6 | 14.5 |
| $Fe_2O_3$ | 0.48 | 0.45 | 0.64 | 1.43 | 1.22 | 1.86 | 0.83 |
| FeO | 3.85 | 4.2 | 3.90 | 2.70 | 3.05 | 3.65 | 3.94 |
| MnO | 0.05 | 0.07 | 0.07 | 0.09 | 0.09 | 0.11 | 0.08 |
| MgO | 2.55 | 2.1 | 2.35 | 1.76 | 1.96 | 2.65 | 2.51 |
| CaO | 3.35 | 2.75 | 3.25 | 4.65 | 5.05 | 6.00 | 3.50 |
| $Na_2O$ | 3.05 | 2.15 | 2.70 | 2.95 | 2.95 | 2.85 | 2.05 |
| $K_2O$ | 1.48 | 3.60 | 2.00 | 2.25 | 2.15 | 1.50 | 3.10 |
| $P_2O_5$ | 0.13 | 0.14 | 0.14 | 0.08 | 0.10 | 0.10 | 0.16 |
| $H_2O+$ | 1.71 | 1.03 | 1.68 | 1.01 | 0.97 | 1.52 | 1.05 |
| $H_2O-$ | 0.17 | 0.17 | 0.14 | 0.15 | 0.15 | 0.16 | 0.15 |
| $CO_2$ | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.12 |
| Total | 100.2 | 99.9 | 99.8 | 99.8 | 99.5 | 99.7 | |
| PPM | | | | | | | |
| Cu | 2 | 18 | 8 | 8 | 10 | 13 | |
| Pb | 170 | 45 | 95 | 160 | 65 | 22 | |
| Zn | 48 | 50 | 50 | 55 | 55 | 76 | |
| Co | 12 | 12 | 8 | 8 | 10 | | |
| Ni | 28 | 25 | 5 | 5 | 5 | 22 | |
| Q | 32.83 | | 33.23 | 28.10 | 24.95 | 21.89 | |
| C | 1.65 | | 1.97 | - | 0.40 | - | |
| or | 8.90 | | 12.02 | 13.48 | 12.88 | 9.10 | |
| ab | 26.26 | | 23.23 | 25.30 | 25.30 | 24.60 | |
| an | 15.73 | | 15.15 | 21.89 | 24.42 | 28.62 | |
| di wo | - | | - | 0.27 | - | 0.32 | |
| di en | - | | - | 0.15 | - | 0.18 | |
| di fs | - | | - | 0.11 | - | 0.12 | |
| hy en | 6.46 | | 5.95 | 4.29 | 4.95 | 6.55 | |
| hy fs | 5.78 | | 5.70 | 3.12 | 4.02 | 4.33 | |
| mt | 0.71 | | 0.94 | 2.10 | 1.79 | 2.75 | |
| il | 1.28 | | 1.35 | 0.89 | 0.92 | 1.18 | |
| ap | 0.31 | | 0.34 | 0.19 | 0.24 | 0.24 | |
| cc | 0.12 | | 0.12 | 0.12 | 0.12 | 0.12 | |

Harker diagrams presented in Figure 32 suggest possible affinities with the Gingera Granite and Kellys Plain Volcanics. The analyses shows an inverse relation between $SiO_2$ content and $Al_2O_3$ plus CaO content while total iron (as FeO), MgO, $Na_2O$, and $K_2O$ show no significant variation with $SiO_2$ content. The more basic samples with higher CaO contents contain hornblende while the other samples contain only biotite.

A comparison of the data with the average composition of the Clear Range Granodiorite (Joyce, 1970, 1973) shows that the McLaughlins Flat Granodiorite is significantly poorer in $K_2O$ and richer in $Na_2O$. Joyce has shown that the 'contaminated granite group' was formed by the contamination of a magma of adamellite composition by reaction with relict sedimentary material (xenoliths). The sediments into which the McLaughlins Flat Granodiorite has been emplaced (Silurian Tantangara Beds) are considerably more micaceous ($K_2O$-rich) than the sediments into which the Clear Range Granodiorite has been emplaced (Ordovician Adaminaby Beds). It is thus unlikely that the contamination of the granodiorites was from the local country rock. Rather, contamination is more likely to have occurred nearer to the source of the magma.

## GINGERA GRANITE (defined here)
(D.W.)

### NOMENCLATURE

The name Gingera Granite was first introduced by Noakes (1946) for a biotite granite that crops out on Gingera Mountain on the western border of the A.C.T. The name was later published by Joplin et al. (1953) on the first edition of the Canberra 4 mile: 1 inch geological map, and also on the second edition Canberra 1:250 000 geological map (Best et al., 1964). The name was extended to apply to a series of biotite granite bodies south of Yaouk but these are now known to be separate from the main Gingera Granite body and of a different chemical composition. These southern bodies have been named the McLaughlins Flat Granodiorite (p. 217).

### TYPE LOCALITY

The type locality is on the top of Gingera Mountain at G.R. 611614. Here exposure is extremely good, with many elongate tors of foliated adamellite up to tens of metres long. The elongation of the tors parallels the foliation in the adamellite, which dips 85°W and strikes at 345°.

The rock is a white to grey foliated biotite adamellite. The grey-brown weathering skin is less than 1 cm thick and is commonly absent on face freshly broken by frost shattering. Biotite occurs as aligned flakes about 2 mm across which partly wrap around white feldspar and pale violet quartz up to 4 mm across. Biotite occupies about 10% of the rock. Xenoliths are uncommon and consist of patches of almost pure biotite a few centimetres across elongated parallel to the foliation in the adamellite.

## GEOGRAPHICAL DISTRIBUTION

The Gingera Granite occupies the spine of the mountain range between the Cotter River to the east and the Goodradigbee River to the west. The Granite extends south to Mount Morgan and north to Ginini Creek, and into the Brindabella Sheet area. The range attains its maximum height of 1910 m at Mount Bimberi. The topography is steep and rugged with maximum relief greater than 900 m.

The total area of outcrop of the Gingera Granite is about 120 $km^2$. The Granite averages 4 km wide and is 30 km long. An outlier of Gingera Granite of about 5 $km^2$ and with roughly circular outline crops out in the Murrumbidgee River valley 5 km upstream from Yaouk. Stocks less than 500 m across occur at G.R. 656687, 595684, and 571620.

## FIELD OCCURRENCE

The Gingera Granite intrudes Late Ordovician Adaminaby Beds in the north and Early Silurian Tantangera Beds in the south. Three distinct rock types can be mapped:

(1) medium to coarse-grained biotite adamellite;

(2) fine to medium-grained leucogranite;

(3) Porphyritic granite.

(1) <u>Medium to coarse-grained biotite adamellite</u>. This rock is by far the dominant type in the Gingera Granite, occupying about 85% of its total area. Outcrop is generally good, consisting of boulders and tors in places as much as 20 m across. Boulders less than 1 m across are most common, and it is seldom more than 30 m between outcrops. The rock is a medium to coarse-grained white to grey adamellite with up to 15% biotite. Xenoliths are rare,

being more common where the adamellite is richer in biotite. The xenoliths are biotite-bearing pelites, discoid, and up to 50 mm across. The adamellite is commonly strongly foliated, especially in its central part between Leura Gap and Little Ginini. The foliation dips to the west at about 75° to 85° on the western side of the intrusion and dips east at about 75° to 85° on the eastern side of the intrusion. Biotite and xenoliths are more abundant in this central, more foliated part of the intrusion. The southern end of the intrusion around Mount Morgan is a poorly foliated coarse-grained adamellite with about 10% biotite. The northern end is a poorly foliated coarse-grained adamellite with less than 10% biotite.

It is possible that the northern part of the intrusion east of Blackfellows Gap and Ginini Flats, and extending north to Ginini Falls, is a separate intrusion of slightly more leucocratic adamellite. This northern adamellite crops out as larger more rounded tors than the central more foliated adamellite, and is much more deeply weathered. Fresh samples are only obtainable from the centre of boulders more than 500 mm across. An embayment of sediments in the adamellite near Ginini Flats may be a sedimentary screen separating the two intrusions. Within this embayment at G.R. 617677 granitic dykes up to 2 m wide intrude the sediments. At least two generations of dykes are present as younger ones cut across older ones. All the dykes are similar and are medium-grained leucocratic adamellites.

(2) Fine to medium-grained leucogranite. This rock type occurs as stocks which intrude both the medium to coarse-grained adamellite and the surrounding sediments. The stocks are up to 5 $km^2$ in area though they can be as little as a few score metres across, e.g. at G.R. 593555. The largest stock occupies most of Bimberi Peak and is almost 4 km long by 1.5 km across. Other smaller stocks about 1 km across occur at G.R. 647617, 633598, and 633648. About 1 km west of Cotter Flats a medium-grained leucogranite crops out over a length of almost 4 km; it is faulted against Tantangara Beds to both east and west.

Most of the stocks are composed of fine-grained pale pink leucocratic muscovite granite with uncommon biotite. Outcrop is fair and generally occurs as rather angular blocks and float less than 1 m across. Weathering is commonly up to 50 cm deep and produces a pale yellow saccharoidal rock. There is a very sharp transition between weathered and unweathered rock.

In the two larger stocks the rock is medium-grained, especially at the northern end of the Bimberi Peak stock where the average grain-size is 2 to 3 mm and muscovite flakes are up to 10 mm long. At the southern end of the Bimberi Peak stock the grainsize is about 1 mm. This medium-grained leucogranite crops out as deeply weathered (up to 1 m) rounded boulders mostly less than 2 m across.

(3) Porphyritic granite. This rock type occurs as a single stock of about 7 km$^2$ in area which crops out on Mount Murray and extends to the north across Murray Gap, to the southwest slopes of Mount Bimberi. The granite intrudes the medium to coarse-grained adamellite. Xenoliths of the adamellite up to 30 cm across occur in the granite at G.R. 611502 and dykes of the granite cut across the adamellite at G.R. 625485. The granite is probably intruded by the Bimberi Peak leucogranite stock as the leucogranite is very fine-grained near the contact between them at G.R. 626605. Outcrop of the granite is fair and consists of sub-angular boulders generally less than 2 m across although tors over 10 m across occur near the top of Mount Murray. Several hundred metres southeast of Mount Murray sub-horizontal slabs of continuous outcrop are up to 50 m across. Jointing in the granite is uncommon, horizontal unloading joints being the most common. The rock is highly weathered, and fresh samples are only obtainable from the cores of boulders over 1 m across.

The rock is a fine to medium-grained yellow-white granite with scattered euhedral phenocrysts of K-feldspar up to 10 mm across and abundant smaller phenocrysts of biotite, quartz, and plagioclase all up to 5 mm across. Biotite phenocrysts are the most common and compose up to 15% of the rock.

As well as these three main rock types, the other igneous rocks are associated with the Gingera Granite: these are acid and basic dykes.

Aplite dykes, similar to the fine-grained leucogranite, cut the medium to coarse-grained adamellite, e.g. at G.R. 615433. Acid dykes of adamellite composition intrude the sediments surrounding the Gingera Granite. Dykes occur at G.R. 649559 and on the western bank of Corin Dam at G.R. 657632. At G.R. 657632 the dyke is about 10 wide and consists of a dark bluish purple aphanitic rock with about 25% phenocrysts of quartz and lesser feldspar.

Basic dykes intrude the Gingera Granite at G.R. 626647, G.R. 601553, and G.R. 607642. The three dykes are very similar, containing rare phenocrysts of feldspar up to 5 mm across, and subrounded amygdules up to 20 mm across filled with calcite. The groundmass is green and very fine-grained. The rock weathers to rounded boulders up to 50 cm across with a grey-green weathering skin less than 10 mm deep.

Petrography

Modal analyses of Gingera Granite adamellites and leucogranites are shown in Table 31.

## TABLE 31. MODAL ANALYSES OF THE GINGERA GRANITE

(Swift Point Counter: 2000 points at 450 per $cm^2$)

| Sample No.<br>Rock type<br>G.R. | 72840019<br>Adamellite<br>602407 | 72840087<br>Adamellite<br>611614 | 72840093<br>Leuco-adamellite<br>624617 | 72840095<br>Adamellite<br>612579 | 72840096<br>Adamellite<br>605553 | 72840088<br>Leucogranite<br>630651 | 72840094<br>Leucogranite<br>620522 |
|---|---|---|---|---|---|---|---|
| Quartz | 22.0 | 34.8 | 40.0 | 36.8 | 34.5 | 36.6 | 35.8 |
| Microcline perthite | 29.0 | 19.3 | 29.1 | 20.5 | 21.8 | 40.9 | 32.3 |
| Plagioclase | 34.2 | 29.4 | 21.1 | 26.8 | 24.8 | 13.8 | 21.1 |
| Biotite | 9.0 | 9.9 | 5.6 | 11.4 | 16.2 | 0.4 | 2.2 |
| Muscovite | 4.9 | 6.0 | 3.8 | 3.8 | 2.1 | 8.0 | 8.4 |
| Chlorite | 0.4 | 0.2 | - | - | 0.3 | 0.2 | - |
| Apatite + Zircon | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | - | 0.1 |
| Opaques | - | 0.1 | - | 0.4 | 0.2 | - | 0.1 |
| Epidote | 0.2 | 0.1 | 0.3 | 0.2 | - | - | - |
| Sphene | - | - | - | - | - | 0.1 | - |

(1) Medium to coarse-grained biotite adamellites. All samples have a hypidiomorphic granular texture with 20 to 30% subhedral plagioclase, 25 to 40% quartz, 20 to 30% microcline and 10 to 15% biotite. All the major phases show signs of strain indicating post-consolidation deformation.

Quartz occurs as anhedral grains up to 7 mm across, most grains being 3 to 4 mm. The quartz is partly recrystallized and shows strong undulose extinction. In sample 72840092 (G.R. 618653) the quartz has recrystallized in a mass of xenomorphic grains less than 0.5 mm across.

Plagioclase occurs as subhedral stumpy prisms up to 4 mm across with partly rounded and corroded edges. Some of the grains are bent or broken. Cores are oscillatorily zoned up to $An_{40}$ and are commonly sericitized. Most grains have a narrow rim of $An_{5-10}$.

Microcline occurs as anhedral grains averaging 3 to 4 mm across. Most are perthitic with vein and film perthite up to 20 $\mu$m. Grains are commonly broken into several pieces with slightly different optical orientation and have recrystallized around the edges. Subgraphic intergrowths of quartz and K-feldspar are rare and only occur in the more leucocratic samples such as 7280093 (G.R. 624617).

Biotite occurs as discrete bent and partly recrystallized flakes 1 to 2 mm across. They are pleochroic from very pale brown to dark red-brown, though some recrystallized grains are brownish green. Apatite, zircon, opaques, and secondary muscovite and chlorite are associated with the biotite. Zircon inclusions have dark brown pleochroic haloes. These accessories are less than 0.3 mm across. Samples 72840092, 72840093, and 72840103 (G.R. 628692) are all leucocratic samples from the northern part of the intrusion. They contain about 5% biotite and possess rare subgraphic quartz-feldspar intergrowths. These data support the field evidence that this northern part is a separate more leucocratic intrusion.

Muscovite occurs as secondary flakes up to 0.8 mm across but most commonly 0.1 mm across. It cross-cuts or surrounds associated biotite. Muscovite also occurs as very fine-grained intergrowths up to 3 mm across, with individual grains rarely exceeding 0.01 mm. Most samples contain less than 5% muscovite.

(2) Fine to medium-grained leucogranites. These rocks have an allotriomorphic equigranular texture with average grainsize up to 2 mm. They contain quartz 35 to 45%, microcline 30 to 40%, plagioclase 10 to 20%, muscovite 5 to 10%, and biotite 0 to 3%.

Quartz is up to 2 mm across and possesses undulose extinction. Most grains show minor recrystallization. Microcline is up to 2 mm across but is mostly about 0.5 mm. It has well developed vein perthite (20 microns) and cross-hatched twinning and is commonly intergrown with quartz. Plagioclase averages 1 mm across and is poorly zoned from $An_{10}$ to $An_{20}$. It is rarely subhedral.

Muscovite occurs as common primary flakes up to 1 mm across, and as radiating masses up to 2 mm by 5 mm. It also occurs as irregular inclusions in microcline grains. Biotite occurs as rare red-brown flakes up to 0.5 mm across, commonly partly altered to muscovite.

Accessories include zircon, apatite, anhedral blue tourmaline, and opaques. In sample 72840088 (G.R. 630651) sphene surrounded by chlorite, and epidote are minor constituents.

Sample 72840098 (G.R. 645546) is extremely deformed as it comes from near the Cotter Fault. All minerals are broken and partly recrystallized. Sample 72840104 (G.R. 623515) contains rare phenocrysts 2 mm across of strongly zoned stumpy prisms of plagioclase ($An_{40-10}$) in a groundmass of less than 1 mm grainsize. These phenocrysts are morphologically very similar to the plagioclase grains in the medium to coarse-grained adamellite.

DYKES

(1) Acid dykes Sample 72840049 (G.R. 615433) is an aplite dyke intruding the medium to coarse-grained adamellite. It is allotriomorphic equigranular with an average grainsize of 0.3 mm. Quartz and microcline perthite are abundant, with lesser albite and muscovite; biotite occurs as rare groups up to 0.8 mm across, associated with muscovite. A few grains of anhedral blue tourmaline up to 0.3 mm across are also present. The aplite is almost identical in texture and composition to the fine to medium-grained leucogranite.

Sample 72840101 (G.R. 607642) is a foliated porphyry dyke of granodiorite composition, which intrudes the medium to coarse-grained adamellite 1 km north of Little Ginini. It contains phenocrysts of strongly zoned ($An_{40-10}$) plagioclase up to 4 mm across. The groundmass averages 0.5 mm and contains zoned plagioclase, quartz, biotite (15%), and rare microcline. It also contains a few subhedral grains of blue-green to pale green hornblende less than 0.2 mm arcoss. The dyke has a similar composition to the McLaughlin Flat Granodiorite which occurs 25 km to the south.

Samples 72840090 (G.R. 649559) and 72840100 (G.R. 657632) are porphyry dykes of adamellite composition which intrude the Adaminaby Beds west of Corin Dam. Sample 72840090 contains phenocrysts of plagioclase and quartz up to 4 mm across in a groundmass with average grainsize of 0.5 mm. The groundmass is composed of quartz (40%), plagioclase (25%), microcline (25%), and biotite (10%). Sample 72840100 contains phenocrysts of quartz (20%), plagioclase (5%), and orthoclase (5%) in a foliated groundmass of sericite, chlorite, and devitrified felsic fragments. Some of the glass fragments are up to 1 mm across and are rimmed by a fine dusting of leucoxene.

(2) Basic Dykes. These dykes intrude the Gingera Granite. They contain uncommon phenocrysts of plagioclase up to 2 x 5 mm and xenocrysts of apatite up to 1 x 2 mm in a groundmass with an average grainsize of 0.1 mm. The groundmass consists of about 60% plagioclase, 25% intergrown biotite, chlorite, and actinolite, 5% opaques, 5% calcite, 3% brown green hornblende, 2% quartz, and 1% epidote. The quartz occurs as subrounded xenocrysts up to 0.5 mm across surrounded by reaction rims of biotite and chlorite. Calcite occurs in amygdules up to 2 mm across. It is present as single crystals and as many smaller grains within the amygdule.

Analyses of samples 72840091 (G.R. 607642) and 72840097 (G.R. 601553) are shown in Table 32. They are basaltic rocks with high $K_2O$ and relatively low $TiO_2$. Using the nomenclature of Mackenzie & Chappell (1972) sample 72840091 is an absarokite and sample 72840097 is a shoshonite. These names are based on the $K_2O$ and $SiO_2$ contents of the samples. It is possible that $K_2$ has been introduced by contamination from the granite into which the dykes intrude. If this was so then the parent magma for the dykes would have been a high-alumina basalt.

## CONTACT EFFECTS

Only 3 samples of contact metamorphosed rocks were taken from the sediments surrounding the Gingera Granite, all from within 2 m of the contact.

Sample 71840494 (G.R. 590605) is from the western contact of the medium to coarse-grained adamellite near Blackfellows Creek. It consists of anhedral grains up to 0.3 mm of quartz (60%), potash feldspar (5%), and albite (5%), with interstitial flakes of muscovite (15%), chlorite 10%), and brown biotite (5%). Biotite is more abundant adjacent to a 1 mm-wide quartz vein. The rock belongs to the albite-epidote-hornfels facies of Winkler (1965).

Sample 72840102 (G.R. 617680) is from the sedimentary screen separating the adamellite from the northern leucoadamellite suggested to be a separate intrusion. It contains quartz (35%) up to 0.5 mm, muscovite (20%) up to 0.3 mm, biotite (8%) up to 0.1 mm, and opaques (2%) up to 0.1 mm in a xenoblastic network of pinnite (35%). The presence of pinnite retrogressed from cordierite indicates that Winkler's hornblende-hornfels facies was reached.

Sample 72840106 (G.R. 625536) from a roof pendant in the leucogranite around Bimberi Peak contains pinnite spots up to 1 mm across and subhedral muscovite porphyroblasts up to 0.5 mm, in a matrix of brown biotite and chlorite both up to 0.05 mm, quartz (0.2 mm), sericite, and opaques. The rock has been metamorphosed to the hornblende-hornfels facies.

From the above evidence the medium to coarse-grained adamellite has metamorphosed the surrounding sediments to the albite-epidote-hornfels facies. The more leucocratic intrusives have metamorphosed the sediments to a slightly higher grade.

## AGE AND RELATIONS

The Gingera Granite and McLaughlins Flat Granodiorite intrude Late Ordovician Adaminaby Beds and Early Silurian Tantangara Beds; no younger rocks overlie them. No isotopic age determinations are available for these intrusions, but they show almost identical differentiation behaviour to the adjacent Murrumbidgee Batholith (Joyce, 1973). The three distinct groups of the Murrumbidgee Batholith (1, contaminated granodiorite; 2, uncontaminated adamellite; 3, leucogranite) are also present in the McLaughlins Flat Granodiorite (group 1) and the Gingera Granite (groups 2 and 3). It is probable that they are derived from the same parent magma and are of similar age. The Gingera Granite and McLaughlins Flat Granodiorite are thus best considered as part of the Murrumbidgee Batholith, which has been dated by K/Ar and Rb/Sr at about 420 m.y. (Roddick, pers. comm., 1973). In the Murrumbidgee Batholith the contaminated granodiorites are the oldest intrusions, so it is probable that the McLaughlins Flat Granodiorite is older than the uncontaminated Gingera Granite.

TABLE 32. ANALYSES AND CIPW NORMS FOR THE GINGERA GRANITE

| Sample No. | | 71840319 | 72840090 | 72840096 | 72840095 | 72840087 | 72840048 |
|---|---|---|---|---|---|---|---|
| Rock type | | adamellite | porphyry | adamellite | adamellite | adamellite | adamellite |
| G.R. | | 591385 | 641559 | 606553 | 612579 | 611614 | 615433 |
| % | | | | | | | |
| $SiO_2$ | | 69.7 | 70.7 | 71.0 | 71.3 | 71.8 | 72.3 |
| $TiO_2$ | | 0.68 | 0.53 | 0.53 | 0.53 | 0.42 | 0.40 |
| $Al_2O_3$ | | 14.4 | 13.9 | 13.9 | 14.0 | 14.0 | 13.6 |
| $Fe_2O_3$ | | 0.67 | 0.67 | 0.56 | 0.56 | 0.41 | 0.62 |
| FeO | | 3.55 | 2.60 | 3.05 | 2.55 | 2.60 | 2.15 |
| MnO | | 0.07 | 0.04 | 0.06 | 0.06 | 0.06 | 0.05 |
| MgO | | 1.79 | 1.27 | 1.50 | 1.28 | 1.38 | 1.08 |
| CaO | | 1.89 | 2.30 | 2.30 | 2.00 | 1.75 | 2.25 |
| $Na_2O$ | | 2.25 | 2.50 | 2.30 | 2.05 | 2.45 | 2.55 |
| $K_2O$ | | 3.40 | 3.95 | 3.45 | 4.30 | 4.10 | 4.05 |
| $P_2O_5$ | | 0.14 | 0.11 | 0.12 | 0.12 | 0.12 | 0.11 |
| $H_2O+$ | | 0.69 | 0.91 | 0.96 | 0.90 | 0.83 | 0.77 |
| $H_2O-$ | | 0.33 | 0.05 | 0.06 | 0.08 | 0.03 | 0.16 |
| $CO_2$ | | 0.15 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Total | | 99.7 | 99.6 | 99.8 | 99.8 | 100.0 | 100.1 |
| Q | | 35.91 | 33.59 | 36.18 | 36.07 | 35.09 | 34.97 |
| C | | 4.32 | 1.74 | 2.64 | 2.78 | 2.78 | 1.32 |
| or | | 20.35 | 23.66 | 20.63 | 25.71 | 24.43 | 24.12 |
| ab | | 19.28 | 21.44 | 19.68 | 17.55 | 20.90 | 21.74 |
| an | | 7.61 | 10.52 | 10.43 | 8.93 | 7.65 | 10.21 |
| hy | en | 4.52 | 3.21 | 3.78 | 3.23 | 3.47 | 2.71 |
| | fs | 5.04 | 3.47 | 4.43 | 3.50 | 3.89 | 2.89 |
| mt | | 0.98 | 0.99 | 0.82 | 0.82 | 0.60 | 0.91 |
| il | | 1.31 | 1.02 | 1.02 | 1.02 | 0.80 | 0.77 |
| ap | | 0.34 | 0.26 | 0.29 | 0.29 | 0.29 | 0.26 |
| cc | | 0.35 | 0.12 | 0.12 | 0.12 | 0.11 | 0.11 |

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TABLE 32 Cont'd

| Sample No. Rock type G.R. | 72840050 adamellite 618446 | 72840093 leuco-adamellite 624617 | 72840092 leuco-adamellite 618653 | 72840094 leucogranite 620522 | 72840089 leucogranite 645542 | 72840088 leucogranite 630651 |
|---|---|---|---|---|---|---|
| % | | | | | | |
| $SiO_2$ | 72.9 | 72.9 | 75.4 | 75.6 | 76.6 | 76.7 |
| $TiO_2$ | 0.42 | 0.29 | 0.16 | 0.13 | 0.06 | 0.06 |
| $Al_2O_3$ | 13.1 | 13.7 | 13.3 | 13.6 | 13.5 | 13.1 |
| $Fe_2O_3$ | 0.71 | 0.54 | 0.23 | 0.32 | 0.21 | 0.17 |
| FeO | 2.50 | 1.75 | 1.15 | 0.79 | 0.36 | 0.50 |
| MnO | 0.05 | 0.05 | 0.05 | 0.06 | 0.01 | 0.02 |
| MgO | 1.16 | 0.85 | 0.47 | 0.19 | 0.13 | 0.17 |
| CaO | 2.05 | 1.68 | 0.95 | 0.50 | 0.82 | 0.68 |
| $Na_2O$ | 2.50 | 2.70 | 2.60 | 2.75 | 2.90 | 2.95 |
| $K_2O$ | 3.65 | 4.05 | 4.65 | 4.75 | 4.65 | 4.65 |
| $P_2O_5$ | 0.12 | 0.12 | 0.11 | 0.13 | 0.12 | 0.12 |
| $H_2O+$ | 0.61 | 0.96 | 0.85 | 0.65 | 0.23 | 0.71 |
| $H_2O-$ | 0.17 | 0.02 | 0.09 | 0.09 | 0.05 | 0.05 |
| $CO_2$ | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.10 |
| Total | 100.0 | 99.7 | 100.1 | 99.6 | 99.7 | 100.0 |
| Q | 37.50 | 36.72 | 39.76 | 40.55 | 40.53 | 40.65 |
| C | 1.73 | 2.26 | 2.67 | 3.49 | 2.63 | 2.52 |
| or | 21.74 | 24.25 | 27.72 | 28.33 | 27.64 | 27.69 |
| ab | 21.31 | 23.14 | 22.19 | 23.52 | 24.67 | 25.15 |
| an | 9.14 | 7.33 | 3.71 | 1.33 | 2.99 | 1.97 |
| hy en | 2.91 | 2.14 | 1.18 | 0.48 | 0.33 | 0.43 |
| hy fs | 3.43 | 2.41 | 1.77 | 1.10 | 0.41 | 0.72 |
| mt | 1.04 | 0.79 | 0.34 | 0.47 | 0.31 | 0.25 |
| il | 0.80 | 0.56 | 0.31 | 0.25 | 0.11 | 0.11 |
| ap | 0.29 | 0.29 | 0.26 | 0.31 | 0.29 | 0.29 |
| cc | 0.11 | 0.12 | 0.11 | 0.12 | 0.11 | 0.23 |

TABLE 32 (cont'd)

| Sample No. Rock type G.R. | | 72840091 absarokite 607641 | 72840097 shoshonite 601553 |
|---|---|---|---|
| $SiO_2$ | | 48.80 | 51.20 |
| $TiO_2$ | | 1.83 | 1.68 |
| $Al_2O_3$ | | 15.80 | 16.30 |
| $Fe_2O_3$ | | 2.45 | 1.85 |
| FeO | | 6.55 | 6.45 |
| MnO | | 0.16 | 0.17 |
| MgO | | 6.30 | 5.55 |
| CaO | | 7.55 | 7.00 |
| $Na_2O$ | | 2.40 | 2.95 |
| $K_2O$ | | 2.10 | 2.60 |
| $P_2O_5$ | | 0.56 | 0.57 |
| $H_2O+$ | | 3.40 | 2.70 |
| $H_2O-$ | | 0.07 | 0.06 |
| $CO_2$ | | 1.80 | 0.50 |
| Total | | 99.77 | 99.58 |
| Q | | 4.60 | 1.20 |
| C | | 1.42 | - |
| or | | 12.88 | 15.87 |
| ab | | 21.08 | 25.77 |
| an | | 23.28 | 24.33 |
| di | Wo | - | 1.85 |
| | en | - | 1.11 |
| | fs | - | 0.63 |
| hy | en | 16.29 | 13.16 |
| | fs | 7.56 | 7.48 |
| mt | | 3.69 | 2.77 |
| il | | 3.61 | 3.30 |
| ap | | 1.38 | 1.40 |
| cc | | 4.25 | 1.17 |

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## GEOCHEMISTRY

Total-rock analyses and C.I.P.W. norms for samples of the Gingera Granite are given in Table 32. Harker Diagrams are shown in Figure 32 together with the McLaughlins Flat Granodiorite and Kellys Plain Volcanics.

All Harker Diagrams show relatively good trends which are aligned with the McLaughlins Flat Granodiorite at lower $SiO_2$ values. $K_2O$ shows a strong positive correlation with $SiO_2$; FeO, total iron as FeO, MgO, CaO, and $Al_2O_3$ show inverse correlation with $SiO_2$; $Na_2O$ and $Fe_2O_3$ do not vary with varying $SiO_2$. The diagrams suggest that the McLaughlins Flat Granodiorite and Gingera Granite constitute a differentiation series. The Kellys Plain Volcanics show a similar pattern on the Harker Diagrams with a relatively similar spread of $SiO_2$ values. We consider that the Kellys Plain Volcanics are extrusive equivalents of the Gingera Granite and McLaughlins Flat Granodiorite.

Variations in normative content of the possible differentiation series granodiorite-adamellite-leucoadamellite-leucogranite are shown in Table 33.

TABLE 33

NORMATIVE VARIATION IN THE GINGERA GRANITE AND MCLAUGHLINS FLAT GRANODIORITE

| Norm/Rock type | Granodiorite | Adamellite | Leucoadamellite | Leucogranite |
|---|---|---|---|---|
| Quartz % range | 20-33 | 33-37 | 37-40 | 40-41 |
| Corundum % range | 1.5 | 1.5-4 | 2.5 | 2.5-3.5 |
| Hypersthene % range | 10-12 | 5-10 | 3-4 | 0.5-2 |
| Hypersthene- Proportion of en and fs | en>fs | en≤fs | en<fs | en<fs |
| Plagioclase An content | 40-50 | 35-25 | 15-25 | 5-10 |
| Orthoclase % range | 9-14 | 20-25 | 25-28 | 27-28 |
| Ilmenite % range | 0.9-1.4 | 0.8-1.3 | 0.3-0.6 | 0.1-0.3 |

The table shows that from granodiorite to leucogranite there is a gradual, even increase in normative quartz, corundum, and orthoclase; and a gradual, even decrease in normative hypersthene, anorthite, ilmenite, and the enstatite - ferrosilite ratio. Except for orthoclase, there are no breaks or sudden jumps in the range of norm values. This is strong evidence that the rocks constitute a continuous differentiation series. Normative orthoclase is relatively low in the granodiorites (9-14%) and there is a sudden jump to 20-25% in the adamellites. This could be explained by contamination of the granodiorites by potash-poor material near the source region.

## LUCUS CREEK GRANITE (defined here)

(M.O.)

### NOMENCLATURE

The name Lucas Creek Granite is used in this Record for an elongate granite body trending south from Gang Gang Mountain to the Hughes Creek valley on the southern border of the Sheet area. Within the Sheet area this granite crops out over a length of 10 km and may be up to 2 km wide. The Bega 1:250 000 geological map (Hall, Rose, & Pogson, 1967) shows the intrusion extending a further 2 km to the south. The name was first used without definition by Stevens (1958a) and was later mentioned in Walpole (1964; appendix, p. 41).

### DERIVATION OF NAME

The granite is named rom Lucas Creek, which drains its northern end.

### TYPE LOCALITY

The type locality is along a power transmission line 500 m north-northeast of the Providence Portal turnoff from the Snowy Mountains Highway (G.R. 470217).

### LITHOLOGY

The Lucas Creek Granite is a biotite-muscovite leucogranite, grading into biotite-muscovite adamellite south of Lake Eucumbene. The leucogranite is formed by medium-grained (4-5 mm) equigranular grey quartz and white feldspar crystals, with scattered black biotite crystals. The adamellite variety is similar, except that biotite crystals are more abundant, and the rock is coarser-grained (crystals 6-8 mm across).

Biotite forms anhedral to subhedral crystals, is strongly pleochroic ($\alpha$ = pale yellow brown, $\beta$ = $\gamma$ = dark brown), and rarely is partly altered to chlorite. Muscovite is rare, forms small anhedral crystals, and in part appears to be an alteration product of biotite. Potassium feldspar is present commonly as perthite, and forms anhedral crystals. It is generally little altered. Plagioclase forms anhedral to subhedral crystals which are occasionally zoned. The composition ranges from about $An_{15}$ in the leucogranite to about $An_{25}$ in the adamellite. Alteration is minor. Quartz occurs as anhedral crystals commonly showing strain under cross-nicols. Evidence of pressure-induced recrystallization and minor shearing along grain boundaries is very common.

The modal composition of three rocks from the Lucas Creek Granite is shown below in Table 34.

TABLE 34. MODAL ANALYSES OF THE LUCAS CREEK GRANITE

| Sample No. | 71840087 | 71840202 | 71840235 |
|---|---|---|---|
| G.R. | 467220 | 468217 | 457175 |
| Rock type | Leucogranite | Leucogranite | Adamellite |
| Quartz | 35.3% | 47.3% | 34.7% |
| K-Feldspar | 41.2% | 35.7 | 29.3 |
| Plagioclase | 18.4% | 10.4 | 23.1 |
| Biotite | 3.1% | 2.8 | 10.9 |
| Muscovite | 1.7% | 3.1 | 1.3 |
| Accessory | 0.3% | 0.7 | 0.7 |

RELATIONS

The Lucas Creek Granite intrudes both Nungar Beds and Tantangara Beds. The granite/sediment contact was not observed in outcrop, apparently because the granite has been more affected by weathering near its margin. However, quartzite close to the contact is penetrated by numerous small quartz veins. The eastern contact of the granite, where intersected by the

Murrumbidgee-Eucumbene tunnel, was faulted, and this contact on the surface is marked by an abundance of vein quartz.

Preliminary geochemical evidence suggests that the Lucas Creek Granite is related to the Happy Jacks Granite, except that the former appears to have been subjected to considerable strain after solidification of the magma. In this respect it is similar to parts of the McLaughlins Flat Granite, near Adaminaby, from which it differs in the lack of xenoliths.

Two samples were analysed, and the results shown in Table 35. Both samples are potash-rich with $K_2O/Na_2O$ ratios of 1.61 and 1.62. Corundum is present in the norm of both samples.

## AGE

In the absence of any definite evidence the Lucas Creek Granite is assumed to be of similar age to the Happy Jacks Granite (Late Silurian).

## HAPPY JACKS GRANITE (Hall, 1949)

(D.W.)

## NOMENCLATURE

As a result of a preliminary reconnaissance of the Eucumbene-Tumut tunnel line, Hall gave the name Happy Jacks Granite to granitic rocks cropping out on Happy Jacks Plain (south of the Tantangara 1:100 000 Sheet area) and extending north at least as far as the Eucumbene River and Alpine Hill (Hall, 1949, reproduced in 1951 as part of BMR Record 1951/63). Later in the same year Ivanac & Glover (1949) mapped granitic intrusions north of the Snowy Mountains Highway and called them the Boggy Plain Granite.

Present field mapping, petrography, and geochemistry indicate that the Boggy Plain Granite is younger and distinct from the Happy Jacks Granite and will be discussed later. The name Happy Jacks Granite appears in published work by Kolbe & Taylor (1966), Kennedy & Rose (1966) and Hall, Rose, & Pogson (1967).

TABLE 35. ANALYSES AND CIPW NORMS FROM THE LUCAS GRANITE

| Sample No. | 71840202 | 71840235 |
|---|---|---|
| Rock type | granite | biotite adamellite |
| G.R. | 468217 | 457175 |
| % | | |
| $SiO_2$ | 74.0 | 71.4 |
| $Al_2O_3$ | 13.9 | 14.0 |
| $Fe_2O_3$ | 0.55 | 0.36 |
| FeO | 1.39 | 2.80 |
| MgO | 0.64 | 1.17 |
| CaO | 0.98 | 1.76 |
| $Na_2O$ | 2.90 | 2.45 |
| $K_2O$ | 4.70 | 3.95 |
| $H_2O+$ | 0.46 | 0.82 |
| $H_2O-$ | 0.22 | 0.28 |
| $CO_2$ | 0.10 | 0.05 |
| $TiO_2$ | 0.19 | 0.48 |
| $P_2O_5$ | 0.11 | 0.12 |
| MnO | 0.05 | 0.05 |
| | 100.19 | 99.69 |
| ppm | | |
| Ni | 5 | 20 |
| Co | <5 | 10 |
| Cu | 5 | 15 |
| Zn | 35 | 50 |
| Pb | 40 | 25 |
| Qz | 36.01 | 35.62 |
| C | 2.77 | 2.94 |
| Or | 27.91 | 23.67 |
| Ab | 24.65 | 21.02 |
| An | 3.53 | 7.74 |
| Di | - | - |
| Hy (En | 1.60 | 2.95 |
| Hy (Fs | 1.89 | 4.20 |
| Mt | 0.80 | 0.53 |
| Il | 0.36 | 0.92 |
| Ap | 0.26 | 0.29 |
| Cc | 0.23 | 0.12 |

A formal description of the Happy Jacks Granite has not been published, and as the type area on Happy Jacks Plain is outside the region under consideration in the present survey the name is here used in an informal sense.

FIELD OCCURRENCE

The Happy Jacks Granite is a large granitic body forming the northern end of the Kosciusko Batholith. In the Tantangara Sheet area it consists of muscovite and biotite-bearing leucogranite and sodic leucogranite. Farther south on Happy Jacks Plain (Kosciusko 1:100 000 Sheet area) the body is composite and consists predominantly of foliated biotite granodiorite, the leucogranite being subordinate. In the Tantangara sheet area the leucogranite crops out in two areas separated by the Boggy Plain Fault. The northern area is bounded to the west by the Boggy Plain Fault approximately along the line of Alpine Creek and extends to the east to Gang Gang Creek and to the north to the southern end of Boggy Plain, an area of about 14 $km^2$. The southern area extends from north of Alpine Hill to south of the Tantangara Sheet area. This body is elongated along a south-southwest axis and is about 5 km wide, narrowing to 2 km south of Tabletop Mountain. The total area of the southern section is about 30 $km^2$. The topography developed over the granite is hilly to undulating; some areas are deeply dissected. Maximum relief within the granite is from Alpine Hill to the Eucumbene River, about 450 m.

The granite is reasonably well exposed, occurring as tors mostly less than 2 m across and float less than 1 m across. In some areas along the Eucumbene River bluffs and low cliffs occur, and east of Tabletop Mountain flat rocky terraces 10 to 20 m across.

In hand specimen two varieties of the leucogranite can be distinguished. Biotite-poor leucogranite crops out near the eastern and western margins of the granite. This is a fine to medium-grained white to yellow-white rock with about 1% biotite. Muscovite is rare in some samples and common in others. Near Tabletop Mountain biotite poor leucogranite contains about 8% muscovite in groups and rosettes up to 10 mm across. The biotite-poor leucogranite is commonly sodic but this is not distinguishable in hand specimen.

Farther from the margins the biotite-poor leucogranite grades into a biotite-rich leucogranite with about 5% biotite. This is commonly white and medium-grained but in a few places it is pinkish. Biotite and lesser muscovite are scattered throughout.

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At the northern end of the granite, where it is intruded by the Boggy Plain Granite, the Happy Jacks Granite has been recrystallized. In hand specimen it is finer-grained than normal with phenocrysts of quartz about 3 mm across.

## FIELD RELATIONS

The Happy Jacks Granite intrudes Ordovician and Early Silurian sedimentary rocks. Contacts with the surrounding sediments are generally poorly exposed but at G.R. 394237 and 461245 sharp contacts can be seen between the granite and micaceous quartzite. North of Alpine Hill and south of Boggy Plain the granite is intruded by the Boggy Plains Granite and has been contact metamorphosed by it. Several small basic and intermediate stocks related to the Boggy Plains Granite intrude the Happy Jacks Granite at G.R. 416182, G.R. 382205, and G.R. 385211. At several other localities the white leucogranite has been altered (?metasomatized) to a pink granite (G.R. 380186, G.R. 424240, and G.R. 449223). This alteration may be also related to the later intrusion of the Boggy Plains Granite and related stocks.

## PETROGRAPHY

The Happy Jacks Granite can be divided into three distinct rocktypes on their petrographic character: (1) sodic leucogranite (2) perthitic leuco-adamellite and (3) metamorphosed perthitic leuco-adamellite.

(1) Sodic leucogranite. Rocks of this type come from two areas, one along Alpine Creek and the Snowy Mountains Highway east of Alpine Hill and another smaller area south east of Tabletop Mountain. It is not known whether other outcrops occur as the rock is only distinguishable from perthitic leuco-adamellite in thin section. Sodic leucogranite is allotriomorphic with an average grain-size of about 2 to 3 mm. Quartz (40 - 50%) occurs as anhedral grains up to 4 mm across. Plagioclase ($An_{5-10}$) occurs as slightly zoned albite twinned grains up to 2 mm across (25 - 30%). Sodic alkali feldspar (25 - 35%) occurs as anhedral grains up to 4 mm across. The alkal feldspar has no recognizable antiperthite lamellae but aligned flecks of sericite throughout the grains may be alteration products of antiperthite lamellae. The alignment of the sericite is best seen on (010) faces. On these faces the alignment intersects (001) cleavage at a high angle. This orientation of the sericite flecks is similar to the orientation of perthite and antiperthite lamellae in alkali feldspars. Calsbad, Manebach and very fine discontinuous albite twinning are common in

the sodic alkali feldspar grains. Biotite occurs as rare chloritized flakes less than 1 mm across (less than 2%) and muscovite (1%) occurs as rare sub-parallel groups, individual flakes being less than 0.5 mm across. Opaques are commonly associated with muscovite and accessory apatite and zircon are very rare.

Sample 73840151 (G.R. 361165) contains perthite (20%) as well as sodic alkali feldspar (10%). Perthite is common in some areas of the thin section and sodic alkali feldspar is common in others. The rock also contains about 30% slightly zoned plagioclase ($An_{5-15}$), 35% quartz, and 5% muscovite. It is a leuco-adamellite.

(2) <u>Perthitic leuco-adamellite</u>. This is the most common rock type in the Happy Jacks Granite in the Tantangara Sheet area. Near the eastern and western margins of the granite it contains virtually no biotite but towards the centre the biotite content increases to over 5%. The rock is composed of anhedral quartz (35-40%) up to 4 mm across, microcline (30-40%) also up to 4 mm across, zoned plagioclase ($An_{5-20}$) from 1 to 2 mm across (20-30%), and about 6-8% mica. The microcline contains film,vein, and patch perthite lamellae and is commonly twinned on the albite, pericline, and Manebach laws and less commonly on the Calsbad and Baveno laws. Rarely the albite component of the perthite occupies up to 50% of a particular perthite grain, the albite patches then exhibit albite twinning. Muscovite and brown biotite both range between zero and about 6% of the rock. When biotite is rare muscovite is common, and vice versa. Muscovite commonly occurs as groups, individual flakes in the groups being up to 0.5 mm across. Biotite up to 1 mm across is pleochroic from pale brown yellow to dark brown and is commonly chloritized. Zircon and opaques are commonly associated with the biotite and many biotite flakes have pleochroic haloes around zircon inclusions. In a few samples biotite has been partly recrystallized into a mosaic of smaller grains.

(3) <u>Metamorphosed perthitic leuco-adamellite</u>. This rock type probably originally belonged to the perthitic leuco-adamellite rock type but has been contact metamorphosed by the later Boggy Plain Granite. It occurs on the northern slopes of Alpine Hill and along the ridge which forms the divide between Boggy Plain Creek and Alpine Creek. The rock has a fairly similar modal composition to the perthitic leuco-adamellite type but a number of distinctive changes have taken place.

Grain boundaries of most of the minerals present are very irregular and quartz has commonly recrystallized into composite grains, some showing triple point boundaries. The average grainsize is less than 1 mm but some perthite and quartz grains are up to 3 mm. The potassium feldspar phase of the alkali feldspar does not exhibit well developed tartan twinning and is probably more disordered than the potassium feldspar in the unmetamorphosed rocks. Perthite lamellae are predominantly patch perthite with interconnecting veins, whereas film and vein perthite are predominant in the unmetamorphosed rocks. Biotite has a distinctive pale yellow-brown to green pleochroism.

Plagioclase is less common in the metamorphosed rocks (10 - 20%) than in the unmetamorphosed rocks (20-30%) and it is more calcic ($An_{20}$). Also where the perthite lamellae of alkali feldspar are twinned they are more calcic ($An_{15}$ or possibly $An_{20}$) than the albite lamellae in the alkali feldspars of the unmetamorphosed rocks.

Muscovite is more abundant (up to 10%) in the metamorphosed rocks than the unmetamorphosed ones. As well as occurring as interstitial flakes and groups (probably pre-metamorphic muscovite) it occurs as xenomorphic grains within perthite and as flakes up to 0.5 mm across within plagioclase. Probably the plagioclase cores were sericitized before metamorphism and the sericite flakes coalesced into muscovite flakes during metamorphism. Andalusite is common in most samples, ranging up to 5% in sample 71840195 (G.R. 44327). It occurs as subhedral to euhedral prisms up to 1 x 2 mm commonly associated with micas, particularly muscovite, and plagioclase. If it is not embedded in muscovite it has a very narrow rim of muscovite. Its association with plagioclase is probably due to the association of muscovite with plagioclase. Andalusite and potassium feldspar are separated by muscovite, indicating that the high temperature assemblage andalusite plus K feldspar is not in equilibrium in the rock.

Several samples of the metamorphic perthitic leuco-adamellite contain rare grains of garnet up to 1 mm across. It is not known whether these are of metamorphic origin or not, but they have not been observed in the unmetamorphosed rocks.

## AGE

The age of the Happy Jacks Granite has yet to be determined by isotopic methods. The stratigraphic control indicates that it is younger than the early Llandovery Tantangara Beds and older than the probable Early Devonian Boggy Plain Granite. It is probably of similar age to the Kosciusko and Murrumbidgee Batholiths and so is placed at about the Silurian-Devonian boundary.

## GEOCHEMISTRY

Only one sample of the Happy Jacks Granite has been analysed (sample 71840175, G.R. 468215). This sample is a sodic leucogranite and contains 78.2% $SiO_2$, 5.80% $Na_2O$, 0.83% $K_2O$, and 0.18% CaO. The very high $Na_2O$ content and low K/Na ratio with corresponding low CaO content is very unusual for a granite that has crystallized directly from a magma. It is most likely that the granite has been metasomatized by soda-rich solution after crystallization from a magma. It is suggested that the origin of these sodic solutions is the metamorphosed perthitic leuco-adamellite. That rock-type appears to be depleted in soda compared to the unmetamorphosed perthitic leuco-adamellite as it contains less plagioclase and the plagioclase present is more calcic.

## YOUNG GRANODIORITE (Ashley and Basden)

(M.O.)

The nomenclature of the large batholith stretching from north of Young to the Fiery Range has been confused for some time. That part of it in the Canberra 1:250 000 Sheet area was called the Burrinjuck Granite by Best et al. (1964), even though the granite at Burrinjuck is a pink alkali granite of limited extent and the bulk of the batholith is a foliated biotite granodiorite. Recently, Ashley & Basden (1973) have revised the nomenclature of the batholith, and have introduced the name Young Granodiorite for the bulk of the body. Their nomenclature is followed here.

Very little of the Young Granodiorite is present in the Tantangara Sheet area, there being about 4 $km^2$ in two areas in the northwest corner. The Granodiorite crops out much more extensively in the Brindabella 1:100 000 Sheet area and a fuller description will be given later (Owen & Wyborn, in prep.a).

Within the Tantangara Sheet area the Young Granodiorite is a grey weakly foliated biotite granodiorite with abundant biotite-rich xenoliths, becoming porphyritic close to contacts with country rock.

The geochemistry of the Granodiorite will be discussed in detail by Owen & Wyborn (in prep. a), but is mentioned briefly later in reference to granitic intrusions in the Fiery Range (p. 248).

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# STARVATION POINT ADAMELLITE (new name)

(D.W.)

## FIELD OCCURRENCE

The Starvation Point Adamellite is approximately 3.3 km southwest of Starvation Point (Parish of The Peaks) from which the name is derived; its centre is near G.R. 389531 (see Parish map for place names). It crops out as tors up to 1 m across over an area of 1.5 $km^2$ in a relatively flat valley to the west of the Fiery Range. Together with the Spicers Creek Granodiorite it is surrounded by higher hills, except to the west where a valley 300 m wide drains the area.

## TYPE LOCALITY

At the type locality 7.5 km due north of Rules Point (G.R. 391532) the rock is pink, fine to medium-grained and contains about 10% of greenish black hornblende. Plagioclase phenocrysts up to 5 mm across are widely scattered through the rock.

The adamellite intrudes the Goobarragandra Beds and near its edges evidence of contamination is present. There it becomes more porphyritic with both quartz and plagioclase phenocrysts up to 5 mm across (sample 71840383). Hornblende also gradually gives way to biotite towards the edges, probably owing to an original increase in volatiles.

Metamorphic effects on the country rock were not observed as exposures are poor near the contact. It is likely that only a narrow contact zone exists, perhaps only 1 m wide.

## PETROGRAPHY

A rock from the type locality (sample 71840318) consists predominantly of subgraphic anhedral quartz-potassium feldspar intergrowths averaging 1.5 mm across, quartz being the dominant partner. These growths are moulded around subhedral albite and perthite up to 2 mm across and subhedral to euhedral greenish brown hornblende up to 0.8 mm across ($2V_x$ = 30°, $\alpha$ = pale brown, $\beta$ = dark brown, $\gamma$ = green). Also present are a few larger subhedral plagioclase laths (2.5 mm across) which have been strongly altered and are almost black under plane-polarized light. These are probably richer in calcium than the other plagioclases. Epidote and chlorite occur as late-crystallizing phases and also as alteration products of hornblende. The modal composition of sample 71840318 is given in Table 2.

Sample 71840381 from nearer the edge of the intrusion (G.R. 385532) contains more biotite (mostly altered to chlorite) than hornblende and the hornblende has $2V_x \simeq 50°$, $\alpha$ = light brown, $\beta$ = olive brown and $\gamma$ = dark greenish brown. Strongly altered phenocrysts of plagioclase similar to those present in sample 71840318 are also present in this sample, but they are larger (up to 3 mm). Modal composition is given in Table 36.

A sample from near the edge of the intrusion (sample 71840383 from G.R. 389524) appears to be recrystallized quartz-feldspar porphyry from the Goobarragandra Beds. It contains rounded embayed quartz phenocrysts up to 4 mm across and highly sericitized plagioclase up to 5 mm across in a recrystallized allotriomorplic groundmass of quartz and K feldspar. Biotite occurs as glomeroporphyritic groups up to 2 mm across and epidote-chlorite groups up to 2 mm across are also present. The modal composition is shown in Table 36.

The geochemistry of the intrusion is discussed later (p.248).

## SPICERS CREEK GRANODIORITE (new name)

(D.W.)

### FIELD OCCURRENCE

The Spicers Creek Granodiorite crops out over an area of 1200 by 500 m about 3 km west of Spicers Creek, from which the name is derived. It lies to the west of the Starvation Point Adamellite from which it is separated by a band of unaltered but strongly jointed Goobarragandra Beds about 200 m wide. Intrusive contacts between the granodiorite and Goobarragandra Beds have not been observed in the field.

The granodiorite crops out as partly buried tors up to 2 m across, and generally provides a greater percentage of outcrop than the Starvation Point Adamellite. The rock is extremely weathered from iron-stained by breakdown of biotite. Fresh specimens are only obtainable from the cors of boulders nearly 1 m across.

TABLE 36. MODAL COMPOSITION OF ACID INTRUSIVES IN THE FIERY RANGE

| Igneous body | Starvation Point Adamellite | Starvation Point Adamellite | Starvation Point Adamellite | Spicers Creek Granodiorite | Kennedy Range Granite | Aplite near Kennedy Range Granite |
|---|---|---|---|---|---|---|
| Sample No. | 71840318 | 71840381 | 71840383 | 71840380 | 71840410 | 71840409 |
| G.R. | 391532 | 385532 | 389524 | 382527 | 402638 | 398632 |
| Rock type | hornblende adamellite | hornblende bearing biotite adamellite | porphyritic biotite micro-adamellite | biotite granodiorite | biotite bearing hornblende granite | aplite |
| quartz | 30.7 | 35.7 | 34.0 | 38.4 | 27.9 | 31.8 |
| K feldspar | 24.8 | 27.2 | 26.9 | 16.0 | 34.7 | 36.9 |
| plagioclase | 29.1 | 24.3 | 28.9 | 26.0 | 29.9 | 26.8 |
| hornblende | 8.6 | 3.5 | 0.3 | 0.6 | 4.2 | 1.3 |
| biotite | - | 0.4 | 9.1 | 1.5 | 2.5 | 4.0 |
| chlorite | 0.6 | 8.0 | 0.3 | 14.1 | - | - |
| pyroxene | - | 0.4 | - | - | - | - |
| epidote | 0.4 | 0.2 | 0.2 | 0.1 | - | - |
| apatite | - | - | - | 0.1 | - | - |
| opaque | 0.5 | 0.3 | 0.3 | 0.2 | 0.8 | 0.3 |

## TYPE LOCALITY

The intrusion is similar in composition and texture throughout. At the type locality approximately 7.5 km north of Rules Point (G.R. 382527) fresh specimens are medium-grained, white, and have pale yellow-green phenocrysts of plagioclase up to 10 mm across. Greenish black biotite is abundant.

## PETROGRAPHY

The modal composition of a sample from the type locality is shown in Table 36 (sample 71840380). Under the microscope the rock is allotrimorphic and contains rounded strongly sericitized phenocrysts of plagioclase up to 3 mm across. These phenocrysts are embedded in a medium-grained groundmass of quartz (1 mm), perthite (up to 1.5 mm across), albite (1 mm), and biotite flakes almost completely altered to chlorite. Minor hornblende occurs as prisms up to 0.2 mm across. Opaques, epidote, and apatite are rare accessories. Graphic quartz-potassium feldspar intergrowths are uncommon.

The geochemistry of the Granodiorite is discussed on page 248.

## KENNEDY RANGE GRANITE (new name)

(D.W.)

## FIELD OCCURRENCE

The Kennedy Range Granite crops out at the northern end of the Kennedy Range over an area of about 2 $km^2$. At its centre it occupies a proiment hill at the head of the Right Hand Branch of the Goobarrabandra River (G.R. 405642). The intrusion has been considerably disturbed by faulting and by the later intrusion of the Pigeon Square Gabbro. The type location is 6 km west of Peppercorn Hill (G.R. 402638).

The granite intrudes the Goobarragandra Beds and has associated widespread aplitic dykes which have been found up to 2 km southwest of the nearest granite outcrop.

The granite is extremely well jointed and in places brecciated, and is strongly weathered. Outcrop is poor and consists mainly of float and joint blocks about 20 to 30 cm across. The rock is pale pink to white, medium-grained, and non-porphyritic. Both biotite and hornblende are present. Xenoliths of finer-grained rock of similar composition are common throughout. They are rounded, dixc-shaped, and are mostly about 5 cm across.

The associated aplites are pinker than the granite, fine-grained, and contain rare plagioclase phenocrysts up to 3 mm across.

PETROGRAPHY

A sample from the type locality sample 71840410) contains strongly zoned plagioclase ($An_{40}$-$An_{10}$) up to 2 mm across whose euhedral boundaries are rimmed by microperthite. Some of the plagioclases have highly sericitized cores. The plagioclase occurs together with quartz-perthite intergrowths (1 mm), anhedral green-brown hornblende, and brown biotite. The rock is partly recrystallized and a granoblastic texture is present in some of the quartz-potassium feldspar-rich areas of the slide. One xenocryst of hypersthene (1 mm) and its associated magnetite is surrounded by hornblende and biotite. The rock has probably been metamorphosed by the Pigeon Square Gabbro which crops out only 100 m away and is considered to have intruded the granite. The recrystallization could also have been caused by faulting along the Kennedy Range Fault. The modal composition of the rock is presented in Table 36. The abundance of feldspar indicates that the granite is richer in alkalis than the Spicers Creek Granodiorite and Starvation Point Adamellite.

The aplite associated with the granite is allotriomorphic equigranular and consists of quartz, potassium feldspar, plagioclase, and minor brown-green hornblende and brownish biotite. The potassium feldspar is weathered brown and the plagioclase black-brown. The plagioclase is zoned and tends to be slightly porphyritic with an average grainsize of about 0.5 mm. Although there are no graphic intergrowths of quartz and potassium feldspar, poikilitic quartz is present, and contains rounded plagioclase laths. The modal composition is shown in Table 36.

The Kennedy Range Granite, Spicers Creek Granodiorite, and Starvation Point Adamellite are all probably related to the Young Granodiorite to the north. Ashley et al. (1971) give analyses of the Young Granodiorite very similar to those obtained for the Spicers Creek Granodiorite and Starvation Point Adamellite. These intrusions and the Kennedy Range Granite are thus probably Late Silurian or Early Devonian. A K-Ar isotopic age determination (400 m.y., now revised to 410 m.y. - Beckineale & Gale, 1969) on the Young Granodiorite at Micalong Creek (Evernden & Richards, 1962) tentatively places the age of the mass near the base of the Devonian.

GEOCHEMISTRY OF THE YOUNG GRANODIORITE AND RELATED STOCKS

Chemical analyses and CIPW norms for the Spicers Creek Granodiorite, Starvation Point Adamellite, and 3 samples of the Young Granodiorite

TABLE 37. ANALYSES AND CIPW NORMS OF THE YOUNG GRANODIORITE AND RELATED STOCKS

| Igneous body | Starvation Point Adamellite | Spicers Creek Granodiorite | Young Granodiorite | Young Granodiorite | Young Granodiorite |
|---|---|---|---|---|---|
| Sample No. | 71840318 | 71840380 | 1 | 2 | 3 |
| G.R. | 391532 | 382527 | See Ashley et al. (1971) | | |
| Rock type | hornblende adamellite | biotite granodiorite | biotite granodiorite | biotite granodiorite | foliated biotite adamellite. |
| % | | | | | |
| $SiO_2$ | 71.7 | 69.0 | 68.76 | 69.87 | 69.92 |
| $TiO_2$ | 0.45 | 0.72 | 0.63 | 0.56 | 0.59 |
| $Al_2O_3$ | 13.4 | 13.8 | 14.14 | 14.21 | 13.58 |
| $Fe_2O_3$ | 0.89 | 0.77 | 0.35 | 0.87 | 0.74 |
| FeO | 2.65 | 3.60 | 4.08 | 3.09 | 3.19 |
| MnO | 0.08 | 0.13 | 0.10 | 0.08 | 0.10 |
| MgO | 0.45 | 1.47 | 2.69 | 2.24 | 2.16 |
| CaO | 1.62 | 2.60 | 2.61 | 3.24 | 2.03 |
| $Na_2O$ | 4.20 | 2.75 | 2.19 | 2.68 | 2.46 |
| $K_2O$ | 2.85 | 3.10 | 3.03 | 2.33 | 3.70 |
| $P_2O_5$ | 0.07 | 0.07 | 0.21 | 0.19 | 0.18 |
| $H_2O+$ | 0.73 | 1.52 | 0.97 | 0.68 | 0.75 |
| $H_2O-$ | 0.41 | 0.28 | 0.09 | 0.14 | 0.11 |
| $CO_2$ | 0.00 | 0.12 | 0.10 | 0.00 | 0.02 |
| Total | 99.50 | 99.93 | 99.95 | 100.18 | 99.53 |
| Q | 31.34 | 32.23 | 33.18 | 33.95 | 32.87 |
| C | 0.64 | 1.61 | 3.29 | 1.86 | 2.35 |
| or | 17.12 | 18.66 | 18.10 | 13.85 | 22.15 |
| ab | 36.11 | 23.70 | 18.73 | 22.81 | 21.09 |
| an | 7.70 | 11.90 | 11.07 | 14.93 | 8.89 |
| hy en | 1.14 | 3.73 | 6.77 | 5.61 | 5.45 |
| hy fs | 3.60 | 5.12 | 6.42 | 4.21 | 4.52 |
| mt | 1.31 | 1.14 | 0.51 | 1.27 | 1.09 |
| il | 0.87 | 1.39 | 1.21 | 1.07 | 1.14 |
| ap | 0.17 | 0.17 | 0.50 | 0.45 | 0.43 |
| cc | - | 0.28 | 0.23 | - | 0.05 |

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from Ashley et al. (1971) are shown in Table 37. Harker Diagrams of these samples, together with the Goobarragandra Beds volcanics are shown in Figure 31 (p. 181).

Although sampling is not yet adequate there are rough positive correlations of $Na_2O$ and $K_2O$ with $SiO_2$ and negative correlations of FeO total, MgO, CaO, and $Al_2O_3$ with $SiO_2$.

The $SiO_2$ content of the intrusives is very similar to that of the Goobarragandra Beds volcanics. This suggests that the volcanics are the extrusive equivalent of the Young Granodiorite magma.

## PIGEON SQUARE GABBRO (new name)

(D.W.)

The Pigeon Square Gabbro crops out in two areas, immediately south of the Kennedy Range Granite at the headwaters of Pigeon Square Creek (from which the name is derived) and to the northeast of that Granite. The gabbro probably intrudes the granite, as the granite appears recrystallized near the contact, but contact relations are obscured by lack of outcrop.

The southern outcrop is centred on G.R. 403632 and is about 1.5 $km^2$ in area. Outcrop is extremely good and consists of boulders up to 3 m across.

### TYPE SECTION

The type section is along the Peppercorn Trail which trends east-west across the middle of the southern outcrop from G.R. 408620 to G.R. 394630 (about 6 km west of Peppercorn Hill). Immediately west of the gabbro, brecciated and sheared Goobarragandra Beds crop out. The contact is also brecciated and includes a north-trending band of olivine gabbro about 30 cm wide by 10 m long (G.R. 393629), which has probably been caught up in movements along the Kennedy Range Fault. This olivine gabbro is a dark green coarse-grained rock, badly weathered, and contains surficial solution cavities up to 1 cm across and 2 cm deep, probably formed by weathering of olivine. Farther east along the Peppercorn Trail extremely coarse-grained leucogabbro crops out. This is a massive rock consisting mostly of white plagioclase, but is mottled pale green with augite crystals up to 8 mm across and darker hornblende of similar dimensions. This rock crops out along the

Peppercorn Trail for about 1000 m until about 200 m from the eastern contact of the gabbro. There, the rock is darker and finer-grained, a dolerite rather than a gabbro. The darker colour is due to an increase in green amphibole (sample 71840396 from G.R. 403623).

The other outcrop of Pigeon Square Gabbro, to the northeast of the Kennedy Range Granite, is mainly a medium-grained variety similar to the dolerite from the eastern end of the Peppercorn Trail type section. This outcrop is about 2 km long and 300 m wide, and in general is not as well exposed as the southern outcrop.

Associated with the gabbro are late-stage pegmatitic aggregations which occur along fractures and joints. These contain euhedral plagioclase laths and pyroxene crystals up to 1 cm across, and masses of epidote up to 2 cm across, with minor prehnite (identified in thin section, sample 71840543, G.R. 395627).

PETROGRAPHY

The three main rock types are: (1) olivine gabbro, (2) leucogabbro, (3) dolerite.

(1) Olivine gabbro (sample 71840397, G.R. 393629) is composed of abundant subhedral plagioclase ($An_{75}$) sub-ophitic to augite ($2V_Z = 50°$) both up to 2 mm across. Almost all the augite has orthopyroxene lamellae exsolved parallel to (100). Rounded olivine up to 1 mm across is scattered throughout and contains alteration selvedges of iddingsite and magnetite up to 0.5 mm across. The olivine has $2V_X \simeq 80°$ and so contains about 60% forsterite. Also present is a dark brown hornblende ($2V_X \simeq 70°$, $\alpha$ = olive brown, $\beta$ = reddish brown, $\gamma$ = dark reddish brown) which is poikilitic and up to 5 mm across but contains mostly included subhedral augite, plagioclase, and olvine up to 1 mm across. Orthopyroxene (probably bronzite) occurs as subhedral grains up to 1 mm across and as irregular poikilitic grains up to 2 mm across. It has $2V_X = 70°$ and is faintly pleochroic from pale pink to colourless with a greenish tinge. The rock is only slightly altered, with some of the augite rimmed with actinolite and with olivine altered to iddingsite. The modal composition is shown in Table 38.

Leucogabbro (sample 71840398, G.R. 402626) is allotriomorphic and consists of anhedral augite ($2V_Z = 55°$) up to 3 mm across surrounded by poikilitic plagioclase ($An_{70-80}$) up to 5 mm across. A few of the augite grains

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TABLE 38. MODAL COMPOSITIONS OF PIGEON SQUARE GABBRO

| | | |
|---|---|---|
| Sample No. | 71840397 | 71840398 |
| G.R. | 393629 | 402626 |
| Rock type | olivine gabbro | leucogabbro |
| Plagioclase | 57.0 | 64.5 |
| augite (+actinolite alteration) | 20.5 | 26.7 |
| olivine (+iddingsite alteration) | 11.0 | - |
| hornblende | 5.2 | 5.1 |
| tremolite-actinolite | - | 2.2 |
| hypersthene | 6.1 | - |
| chlorite | - | 1.5 |
| opaques | 0.2 | 0.1 |

have exsolved orthopyroxene along (100) and others are rimmed with brown-green amphibole. Within some of the larger plagioclase grains are graphic and bleb-shaped augite inclusions up to 0.5 mm across. Adjacent blocks are in optical continuity and are relict early augite. Some of the blebs may have been orthopyroxene and now appear as tremolite-actinolite intergrowths. Opaques are rare. A few patches of interstitial chlorite are up to 2 mm across. The modal composition of this rock is shown in Table 38.

(3) Dolerite (sample 71840396, G.R. 403623) has a subophitic texture of subhedral plagioclase (strongly zoned - $An_{70}$ cores and $An_{45}$ rims) surrounded by anhedral actinolite ($2V_x = 65°$, $\alpha$ = pale yellow green, $\beta$ = brownish green, $\gamma$ = blue green) as an alteration product of augite. Some original augite is present in the cores of actinolite masses. Also present is a brown hornblende occupying the interstices, which appears to be the last phase of primary crystallization and is similar to the brown hornblende in the olivine gabbro. It has $2V_x = 70°$ with pleochroism: $\alpha$ = olive brown, $\beta$ = pale brown with a red tint, $\gamma$ = brown. The actinolite alteration is probably a late stage deuteric effect related to the pegmatitic phase occurring in the leucogabbro. A visual estimate of modes is : plagioclase 40%, actinolite (+augite) 50%, hornblende 8%, opaques 2%.

## CONTACT EFFECTS

Recrystallization of the Goobarragandra Beds is evident in rocks up to 200 m away from the nearest gabbro outcrop. The groundmass of dacite porphyry is coarser and paler than normal Goobarragandra Beds.

Under the microscope these contact rocks (e.g., sample 71840393 from G.R. 410653) have a strongly recrystallized groundmass of polygonal quartz grains up to 0.7 mm across, subhedral orthoclase, and spherulitic, micrographic, and symplectic intergrowths of quartz and orthoclase up to 1 mm across. Also present are minor brown-green hornblende and green biotite both partly altered to chlorite. The hornblende is up to 0.1 mm across and is interstitial to quartz and orthoclase. It is unlikely that the hornblende and biotite are of volcanic origin so the rocks surrounding the gabbro have undergone contact metamorphism at least to hornblende hornfels facies.

## GENESIS

The Pigeon Square Gabbro has intruded the Goobarragandra Beds and Kennedy Range Granite after major movements on the Kennedy Range Fault but before final movements. This is evident from the lack in the gabbro of a broad breccia zone, which is present in the granite. The age of the gabbro is not known but it probably postdates the Young Granodiorite and would thus be younger than Early Devonian.

It is probable that the gabbro has undergone some differentiation in situ as is evident by the presence of an olivine cumulate on the western side. The eastern side is finer-grained and has been affected by abundant volatiles. Both these features on the eastern and western sides indicate that the body is now dipping to the east. The dip is probably only slight as the contact zone to the east is over 200 m wide, and the dolerite zone is also 200 m wide.

To the north of the Pigeon Square Gabbro, gabbro and dolerite intrusions are common. These are all in the Brindabella 1:100 000 Sheet area and their descriptions will be included in Owen and Wyborn (in prep.a). One large gabbro intrusion near Horseshoe Mine (G.R. 364703) extends into the northwest corner of the Tantangara 1:100 000 Sheet area. Other intrusions occur east of Goobarragandra and at Micalong Swamp.

Chemical analyses and norms for 2 rocks from the Pigeon Square Gabbro, 1 from the gabbro near the Horseshoe Mine, and 2 from the intrusions at Micalong Swamp are shown in Table 39. Their extremely low $K_2O$ contents

TABLE 39. CHEMICAL ANALYSES AND CIPW NORMS FOR PIGEON SQUARE GABBRO AND OTHER RELATED INTRUSIVES

| Sample No.<br>G.R.<br>Rock type | 71840397<br>393629<br>olivine gabbro | 71840398<br>402626<br>leucogabbro | 72840124<br>362723<br>dolerite | 72840132<br>921366<br>dolerite | 72840219<br>379952<br>gabbro |
|---|---|---|---|---|---|
| $SiO_2$ | 49.4 | 46.4 | 54.5 | 49.9 | 49.5 |
| $TiO_2$ | 0.43 | 0.31 | 1.82 | 1.07 | 0.27 |
| $Al_2O_3$ | 17.5 | 20.0 | 14.6 | 16.1 | 17.2 |
| $Fe_2O_3$ | 1.55 | 1.45 | 4.55 | 2.15 | 1.05 |
| FeO | 4.65 | 3.25 | 7.35 | 7.45 | 4.00 |
| MnO | 0.11 | 0.08 | 0.16 | 0.22 | 0.11 |
| MgO | 10.1 | 9.95 | 3.55 | 7.65 | 9.40 |
| CaO | 12.2 | 14.5 | 6.40 | 11.1 | 15.0 |
| $Na_2O$ | 2.10 | 1.16 | 4.30 | 2.10 | 1.70 |
| $K_2O$ | 0.12 | 0.18 | 0.08 | 0.12 | 0.06 |
| $P_2O_5$ | 0.03 | 0.02 | 0.21 | 0.12 | 0.02 |
| $H_2O+$ | 1.51 | 2.20 | 1.98 | 1.50 | 1.60 |
| $H_2O-$ | 0.19 | 0.22 | 0.10 | 0.06 | 0.07 |
| $CO_2$ | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Total | 99.94 | 99.77 | 99.65 | 99.56 | 100.03 |
| Q | - | - | 10.08 | 2.05 | - |
| or | 0.72 | 1.09 | 0.48 | 0.72 | 0.36 |
| ab | 18.08 | 10.08 | 37.27 | 18.12 | 14.62 |
| an | 38.65 | 50.16 | 20.81 | 34.84 | 39.78 |
| di ) wo | 9.36 | 9.71 | 4.17 | 8.43 | 14.78 |
| di ) en | 6.72 | 7.39 | 2.25 | 5.13 | 10.62 |
| di ) fs | 1.80 | 1.31 | 1.79 | 2.84 | 2.83 |
| hy ) en | 11.70 | 6.45 | 6.81 | 14.30 | 7.89 |
| hy ) | 3.14 | 1.15 | 5.42 | 7.92 | 2.10 |
| ol ) fo | 5.03 | 8.13 | - | - | 3.70 |
| ol ) fa | 1.49 | 1.59 | - | - | 1.09 |
| mt | 2.29 | 2.16 | 6.76 | 3.18 | 1.55 |
| il | 0.83 | 0.60 | 3.54 | 2.07 | 0.52 |
| ap | 0.07 | 0.05 | 0.51 | 0.29 | 0.05 |
| cc | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 |

( <0.2%) and their similar $SiO_2$ contents suggest that they are all related.

The chemistry and mineralogy of these basic intrusives show that they are from a tholeiitic parent magma. Sample 72840124 (G.R. 362723) has a higher silica content (54.5%) than the other samples and shows strong iron enrichment typical of a fractionated tholeiite ($FeO_{total}$ = 11.45%). The less fractionated samples with lower silica contents as little as 4.55% $FeO_{total}$ in sample 71840398 (G.R. 402626).

The rocks are undersaturated with as much as 10% olivine in the norms (sample 71840398) and normative plagioclase is as lime-rich as $An_{83}$ in sample 71840398.

The gabbros and dolerites are concentrated along a number of north to northwest-trending faults which probably have controlled their emplacement.

## BOGGY PLAIN GRANITE (defined herein)

(D.W.)

### NOMENCLATURE

Ivanac & Glover (1949) mapped granitic rocks north of the Happy Jacks Granite and called them the Boggy Plain Granite. The name is considered valid and is defined herein.

### DERIVATION OF NAME

The name is taken from Boggy Plain, a grassy plain surrounded by low tree covered hills about 2 km east of Tantangara Mountain. The plain is about 5 km by 2 km and is drained to the north by Boggy Plain Creek.

### TYPE LOCALITY

The type locality for the granite is designated as G.R. 429315 at the northern end of Boggy Plain, where the most common rock type in the granite, hornblende-biotite adamellite, crops out on a low grassy ridge as rounded elongate tors up to 10 m high. The tors are elongated parallel to prominant south-trending joint planes.

FIELD OCCURRENCE

The Boggy Plain Granite is a large composite stock of over 40 $km^2$. It is slightly elongated east-west, about 9 km long and 5 km wide. The eastern third has been displaced about 5 km northwards by the Boggy Plain Fault. This eastern section underlies the entire area of Boggy Plain. The western section crops out in the depression surrounded by Tantangara Mountain, Sawyers Hill, Four Mile Hill, and Alpine Hill and includes the hilly country near Conners Hill and the flat country at Rocky Plain.

The granite is well exposed, commonly as tors and boulders up to 10 m high. Fresh samples are relatively easy to obtain except for the more acid types.

The most common rock type is a massive pink well jointed medium-grained hornblende-biotite adamellite. This occurs in all the western two-thirds of the stock except for a minor occurrence of granodiorite at G.R. 431241. Beneath Boggy Plain the stock is more complex. At the northern end the rock is predominantly hornblende granodiorite. Towards the south, adamellite, then more granodiorite, and finally diorite are present. These have been shown separately on the Tantangara 1:100 000 map.

FIELD RELATIONS

The Boggy Plain Granite intrudes Late Ordovician and Early Silurian sedimentary rocks and the Late Silurian to Early Devonian Happy Jacks Granite. Contacts with the surrounding sediments are generally poorly exposed but at G.R. 390237 a sharp contact occurs. A transitional contact has been mapped.on the eastern side of Boggy Plain with a progression from hornblende-biotite adamellite to andalusite-bearing leucogranite and to mica-andalusite-plagioclase-orthoclasse-quartz hornfels. It is probable that the leucogranite is an isolated body of Happy Jacks Granite. The contact on the western side of Boggy Plain and the eastern side of the granite along Alpine Creek is faulted by the Boggy Plain Fault.

Contact metamorphism of the country rock consists of an inner zone, within 25 m of the granite, that reaches the hornblende-hornfels facies, and an outer zone up to 1 km wide in which the country rock has been less strongly hornfelsed. The hornfels forms prominent ridges bordering the granite on the north and east sides of the Boggy Plain, and the north and west sides of Rocky Plain. Contact metamorphism has also affected the Happy Jacks Granite (see p. 241) and a prominent hill (Alpine Hill) has formed in this granite within the contact aureole of the Boggy Plain Granite.

## PETROGRAPHY

The Boggy Plain Granite is formed by two main and several minor rocktypes. The main ones are hornblende-biotite adamellite and clinopyroxene-bearing granodiorite; these have been distinguished on the Tantangara 1:100 000 map.

(a) Hornblende-biotite adamellite. This appears to be the most abundant type present in the intrusion, and crops out over much of the area from the Eucumbene River and Snowy Mountains Highway north to the southern slopes of Tantangara Mountain, and also in the central part of Boggy Plain.

The adamellite is medium-grained and consists of dark mafic minerals, pink potassium feldspar, white plagioclase, and grey quartz. Grainsize is very even, averaging 2 to 3 mm, with a marked lack of phenocrysts. Foliation is almost completely absent.

The plagioclase is subhedral to anhedral and generally zoned in the normal sense, though oscillatory zoning also occurs. Its composition ranges from $An_{45}$ to $An_{25}$, the more calcic cores being commonly saussuritized. Some myrmekite boundaries are present against orthoclase. Orthoclase, mostly microperthitic, is generally anhedral and commonly sericitized. Typically plagioclase forms about 35% and orthoclase 20 to 25% of the adamellite.

The biotite is strongly pleochroic ($\alpha$ = straw yellow, $\beta = \alpha$ = brown), apatite, zircon, and opaque inclusions are common, and alteration to chlorite is widespread. Hornblende is subhedral to anhedral and pleochroic ($\alpha$ = pale yellow brown, $\beta$ = green, $\gamma$ = olive green, absorption $\gamma > \beta > \alpha$). Twinning on (100) is common, $2Vx = 70^\circ$ and $Z \wedge c = 26^\circ$. Biotite and hornblende generally each form 5 to 10% of the rock. Diopsidic augite is commonly present in minor amounts; it is enclosed by hornblende, and is colourless to pale green, with $2V_z = 45^\circ$, generally twinned on (100), and has possible fine-scale exsolution parallel to (001).

Anhedral quartz forms 25 to 30% of the rock, and generally has relatively few inclusions. Accessory minerals include magnetite, zircon, apatite and sphene. Modes of two adamellites, numbers 71840181 and -0201, are in table 40.

Within the adamellite rare dykes of pink alkali granite up to 0.5 m across occur. Sample 73840173 (G.R. 432316) is a fine-grained alkali granite composed of about 40% orthoclase perthite, 40% quartz, and 20% albite all about 1 mm across. Very rare biotite occurs as irregular flakes less than

TABLE 40. MODAL COMPOSITION OF ROCKS FROM THE BOGGY PLAIN GRANITE

| Sample No.<br>G.R.<br>Rock type | 71840181<br>438318<br>Adamellite | 71840183<br>445324<br>granodiorite | 71840185<br>426329<br>hypersthene diorite | 71840189<br>435292<br>granodiorite |
|---|---|---|---|---|
| Quartz | 27.1% | 17.4% | 2.7% | 19.1% |
| K-feldspar | 22.6 | 6.4 | - | 11.0 |
| Plagioclase | 34.6 | 36.4 | 55.3 | 45.1 |
| Biotite | 8.7 | 3.7 | 4.9 | 8.2 |
| Muscovite | - | - | - | - |
| Hornblende | 5.3 | 23.3 | 0.4 | 12.3 |
| Clinopyroxene | 0.5 | 12.2 | 17.1 | 4.9 |
| Hypersthene | - | - | 19.3 | - |
| Accessary | 1.2 | 0.6 | 0.3 | 0.4 |

| Sample No.<br>G.R.<br>Rock type | 71840191<br>439291<br>granodiorite | 71840201<br>381172<br>adamellite |
|---|---|---|
| Quartz | 21.7% | 27.3% |
| K-feldspar | 4.2 | 20.8 |
| Plagioclase | 44.2 | 34.8 |
| Biotite | 7.4 | 6.7 |
| Muscovite | - | - |
| Hornblende | 16.6 | 8.4 |
| Clinopyroxene | 5.3 | 1.2 |
| Hypersthene | - | - |
| Accessory | 0.6 | 0.8 |

0.5 mm across.

(b) <u>Clinopyroxene-bearing granodiorite.</u> Granodiorite crops out in two large areas at the north and south ends of Boggy Plain, and also in a small area on the Snowy Mountains Highway (G.R. 431241). It is massive, with even-grained dark green or black mafic minerals, white plagioclase, and grey quartz crystals. The grainsize is 2 to 3 mm, and phenocrysts are absent. The field relations of the granodiorite and adamellite are uncertain. The two apparently grade into one another south of Boggy Plain although there seems to be a sharp contact in the north of Boggy Plain. No exposures showing this sharp contact were seen though outcrops of the two rock types were found only 2 m apart.

The granodiorite differs from the adamellite in that subhedral to anhedral plagioclase, pyroxene, and hornblende are poikilitically enclosed in quartz and orthoclase. The plagiocalse is strongly zoned with a compositional range of $An_{60}$ to $An_{30}$, oscillatory zoning is common in the cores, and saussuritization is widespread. Anhedral orthoclase is generally microperthitic and commonly sericitized, and rarely has myrmekitic grain boundaries when in contact with plagioclase. Plagioclase generally forms 35 to 45%, orthoclase less than 10%, and quartz about 20% of the rock. Plagioclase is commonly enclosed in orthoclase locally giving a monzonitic texture.

The clinopyroxene appears to be a diopsidic augite, is colourless to pale green with $2V_z \approx 55° - 60°$, and is in a similar form to that in the adamellite, that is, as relic crystals surrounded by a reaction rim of hornblende. However, reaction to produce hornblende has not been as complete in the granodiorite as in the adamellite. The diopsidic augite is commonly twinned on (100), has exsolution traces parallel to (100), and forms from 5% to 15% of the rock. Hornblende forms about 10% to 25% of the rock, and is similar to the hornblende present in the adamellite. Biotite occurs as anhedral flakes, and has similar properties to the biotite in the adamellite. It forms less than 10% of the granodiorite. Accessory minerals include magnetite, zircon, apatite, and sphene. The modal composition of three granodiorite samples 71840183, -0189 and -0191 are shown in Table 40.

(c) <u>Minor rock types.</u> Apart from the two major rock types described above there are two small bodies of more basic composition within the granite, both on Boggy Plain.

At the northern end of Boggy Plain a roughly circular stock of hypersthene diorite about 100 m across intrudes the granodiorite. The rock is very dark grey and is formed by medium-grained subhedral phenocrysts of hypersthene, augite, and plagioclase in a fine to medium-grained groundmass of plagioclase, clino-and orthopyroxene, hornblende, biotite, and quartz. In some places glomeroporphyritic groups of pyroxene up to 10 mm across are abundant. The hypersthene shows typical pleochroism; $\alpha$ = pink, $\beta$ = neutral, $\gamma$ = pale green, $2V_x$ is very low for hypersthene, possibly about 45° and the hypersthene has exsolution lamellae of clinopyroxene parallel to (100). Augite has $2V_z$ = 50° and has exsolution lamellae of orthopyroxene parallel to (100). Plagioclase is euhedral to subhedral and zoned from $An_{65}$ to $An_{35}$. Cores are commonly oscillatory zoned. Minor reaction of the pyroxenes has produced hornblende with $2V_x$ = 70°, $\alpha$ = pale green; $\beta$ = green, and $\gamma$ = green and absorption $\gamma > \beta > \alpha$. Biotite occurs as very irregular flakes commonly adjacent ot pyroxene. Quartz is interstitial and commonly poikilitically encloses plagioclase and pyroxene. A modal analysis of sample 71840185 (G.R. 426329) is shown in Table 40.

At the southern end of Boggy Plain a biotite-bearing hypersthene diorite similar to that to the north crops out over an area greater than 1 $km^2$. Hypersthene is the dominant mafic phase and both hypersthene and augite have narrow reaction rims of hornblende. Biotite occurs as anhedral grains up to 2 mm across embedded between plagioclase laths. Quartz is interstitial and orthoclase is rare. Sample 73840177 (G.R. 444278) contains xenocrysts of olivine with $2V_x$ = 80°, up to 1 mm across. These are surrounded by reaction rims of orthopyroxene with $2V_x$ = 70° (bronzite). They are distinct from the rest of the orthopyroxenes in the rock, which have a low 2V and are probably hypersthene or ferro-hypersthene. Also present in sample 73840177 are micro-xenoliths up to 2 mm across of orthopyroxene ($2V_x$ = 50°) and plagioclase about 0.1 mm across with a granular texture and triple-point boundaries. These are probably basic xenoliths that have been subjected to pyroxene hornfels facies metamorphism.

Near the contact of the diorite with the Happy Jacks Granite, quartz and orthoclase are more abundant and many of the mafic grains occur in glomeroporphyritic groups.

## AGE

The Boggy Plain Granite intrudes the probable Late Silurian/Early Devonian Happy Jacks Granite. It is mineralogically and chemically similar to the Coolamine Igneous Complex and is therefore likely to be of similar age. The Coolamine Igneous Complex is Early Devonian and this age is suggested for the Boggy Plain Granite. K-Ar dating (Appendix 1) indicates an age of about 408 m.y. Rb-Sr dating (Appendix 1) indicates an age of about 416 m.y.

GEOCHEMISTRY (M.S.)

Analyses of samples (see Table 41) from the Boggy Plain Granite show a silica content between 52.4 and 69.2%, that is they range from basic to acid, although most of the analyses fall in the intermediate to acid range between 60% and 68% $SiO_2$. Six of the analyses plotted in Figure 34 are BMR results, two are from Joplin (1963), and one from Kolbe & Taylor (1966). The correlation of silica with most oxides is good and satisfactory fractionation trend lines can be drawn. All samples except 71840185 are potash-rich, and the $K_2O/Na_2O$ ratio varies from 0.94 to 1.62. Sample 71840185 is the most basic rock analysed with 52.4% silica and must therefore be expected to have a lower $K_2O/Na_2O$ ratio than the other samples.

Trace element content shows a correlation with silica content, as nickel, cobalt, copper, zinc, and lead all decrease with increasing silica. This trend is unusual for lead which generally shows the opposite relation with silica, but the effect here may be due to lack of sufficient samples.

All samples analysed contain normative quartz, which ranges from 25.42% in the most siliceous rock to 2.61% in the least siliceous. Orthoclase in the norm increases with increasing silica content. Normative diopside and hypersthene increased with decreasing silica, hypersthene always being more abundant than diopside. Magnetite and ilmenite also increase with decreasing silica.

## HELL HOLE CREEK GRANITE (Bein, 1969)

(M.O.)

FIELD OCCURRENCE

The name Hell Hole Creek Granite was used by Bein (1969) for a subcircular intrusion that crops out in the eroded core of the semicircular Peak Back Ridge, drained by Hell Hole Creek, from which the unit takes its name. The granite forms a marked topographic low with an area of about 2.5 $km^2$, surrounded by hills of the more resistant contact-metamorphosed Tantangara Beds. The granite crops out as small boulders up to 2 m across, through generally not more than 1 m. It is deeply weathered, and fresh rock is difficult to obtain. Over much of the area the granite is covered by thick scrub, and the boundaries shown on the map are largely based on photo-interpretation. The type locality for the intrusion is here designed as a clearing on Hell Hole Creek at G.R. 449418, where scattered boulders of

TABLE 41. ANALYSES AND CIPW NORMS FROM THE BOGGY PLAIN GRANITE

| Sample No. | 71840181 | 71840183 | 71840185 | 71840191 |
|---|---|---|---|---|
| Rock type | hornblende adamellite | clinopyroxene granodiorite | hypersthene diorite | clinopyroxene granodiorite |
| G.R. | 438318 | 445324 | 426329 | 439291 |
| % | | | | |
| $SiO_2$ | 66.6 | 61.0 | 52.4 | 60.8 |
| $Al_2O_3$ | 14.6 | 14.6 | 16.9 | 14.7 |
| $Fe_2O_3$ | 2.00 | 2.05 | 2.10 | 2.05 |
| FeO | 2.30 | 4.20 | 7.50 | 4.30 |
| MgO | 2.50 | 4.75 | 6.75 | 4.75 |
| CaO | 4.00 | 6.45 | 9.30 | 6.45 |
| $Na_2O$ | 3.00 | 2.65 | 2.70 | 2.65 |
| $K_2O$ | 3.30 | 2.50 | 0.72 | 2.55 |
| $H_2O+$ | 0.38 | 0.37 | 0.05 | 0.28 |
| $H_2O-$ | 0.20 | 0.29 | 0.21 | 0.26 |
| $CO_2$ | 0.10 | 0.12 | 0.15 | 0.10 |
| $TiO_2$ | 0.49 | 0.61 | 0.80 | 0.61 |
| $P_2O_5$ | 0.15 | 0.24 | 0.27 | 0.22 |
| MnO | 0.07 | 0.12 | 0.18 | 0.12 |
| | 99.69 | 100.00 | 100.05 | 99.84 |
| ppm | | | | |
| Ni | 25 | 30 | 12 | 30 |
| Co | 10 | 20 | 8 | 20 |
| Cu | 30 | 65 | 40 | 100 |
| Zn | 45 | 70 | 18 | 70 |
| Pb | 20 | 25 | 22 | 35 |
| Cd | - | - | 2 | - |
| Mo | - | - | 3 | - |
| Qz | 24.64 | 15.90 | 2.61 | 15.27 |
| C | - | - | - | - |
| Or | 19.67 | 14.87 | 4.26 | 15.17 |
| Ab | 25.60 | 22.56 | 22.89 | 22.57 |
| An | 16.78 | 20.70 | 31.94 | 20.83 |
| Di (Wo | 0.67 | 3.69 | 4.83 | 3.88 |
| Di (En | 0.47 | 2.39 | 2.78 | 2.49 |
| Di (Fs | 0.14 | 1.06 | 1.83 | 1.14 |
| Hy (En | 5.81 | 9.52 | 14.06 | 9.42 |
| Hy (Fs | 1.77 | 4.21 | 9.24 | 4.32 |
| Mt | 2.93 | 2.99 | 3.05 | 2.99 |
| Il | 0.94 | 1.17 | 1.52 | 1.17 |
| Ap | 0.36 | 0.69 | 0.64 | 0.53 |
| Cc | 0.23 | 0.27 | 0.34 | 0.23 |

TABLE 41 (Cont'd)

| Sample No.<br>Rock type<br>G.R. | 71840201<br>adamellite<br>381172 | 71840573<br>granodiorite<br>435292 | 72840085<br>adamellite<br>387264 | 30ǂ<br>granite<br>417243 | 1*<br>adamellite | 7*<br>adamellite |
|---|---|---|---|---|---|---|
| % | | | | | | |
| $SiO_2$ | 65.7 | 62.9 | 66.8 | 69.21 | 66.6 | 65.94 |
| $Al_2O_3$ | 14.9 | 14.8 | 14.3 | 13.69 | 14.1 | 15.10 |
| $Fe_2O_3$ | 2.25 | 2.30 | 1.50 | | 1.55 | 1.20 |
| FeO | 2.45 | 3.30 | 2.75 | FeO = 4.63 | 3.00 | 2.34 |
| MgO | 2.65 | 3.35 | 2.55 | 2.65 | 2.50 | 2.53 |
| CaO | 3.90 | 5.50 | 4.15 | 3.08 | 4.05 | 4.48 |
| $Na_2O$ | 2.95 | 3.05 | 2.8 | 2.99 | 2.80 | 3.09 |
| $K_2O$ | 3.45 | 2.50 | 3.25 | 4.14 | 3.60 | 3.73 |
| $H_2O+$ | 0.40 | 0.75 | 0.74 | - | 0.72 | 0.80 |
| $H_2O-$ | 0.28 | 0.12 | 0.04 | - | 0.18 | 0.11 |
| $CO_2$ | 0.10 | 0.10 | 0.10 | - | - | 0.12 |
| $TiO_2$ | 0.52 | 0.69 | 0.54 | 0.36 | 0.58 | 0.55 |
| $P_2O_5$ | 0.17 | 0.20 | 0.14 | - | 0.16 | 0.21 |
| MnO | 0.08 | 0.11 | 0.07 | - | 0.06 | 0.04 |
| S | - | - | 0.01 | - | - | - |
| | 99.80 | 99.67 | 99.73 | 100.75 | 99.90 | 100.37 |
| ppm | | | | | | |
| Ni | 25 | | | | | |
| Co | 15 | | | | | |
| Cu | 30 | | | | | |
| Zn | 50 | | | | | |
| Pb | 30 | | | | | |
| Qz | 23.21 | 19.74 | 25.42 | 22.43 | 24.12 | 21.06 |
| C | - | - | - | - | - | - |
| Or | 20.56 | 14.95 | 19.41 | 24.28 | 21.48 | 22.20 |
| Ab | 25.17 | 26.11 | 23.93 | 25.10 | 23.92 | 26.32 |
| An | 17.38 | 19.55 | 17.04 | 11.65 | 15.43 | 16.44 |
| Di (Wo | 0.16 | 2.55 | 9.92 | 1.47 | 1.59 | 1.59 |
| Di (En | 0.11 | 1.70 | 0.58 | 0.66 | 0.97 | 1.06 |
| Di (Fs | 0.03 | 0.66 | 0.28 | 0.79 | 0.53 | 0.41 |
| Hy (En | 6.55 | 6.74 | 5.83 | 5.89 | 5.32 | 5.29 |
| Hy (Fs | 1.91 | 2.61 | 2.30 | 7.05 | 2.89 | 2.08 |
| Mt | 3.29 | 3.38 | 2.20 | - | 2.27 | 1.75 |
| Il | 1.00 | 1.33 | 1.04 | 0.68 | 1.11 | 1.05 |
| Ap | 0.41 | 0.48 | 0.34 | - | 0.38 | 0.50 |
| Cc | 0.23 | 0.23 | 0.23 | - | - | 0.27 |

* Joplin (1963 p. 65)
ǂ Kolbe & Taylor (1966, Table III)

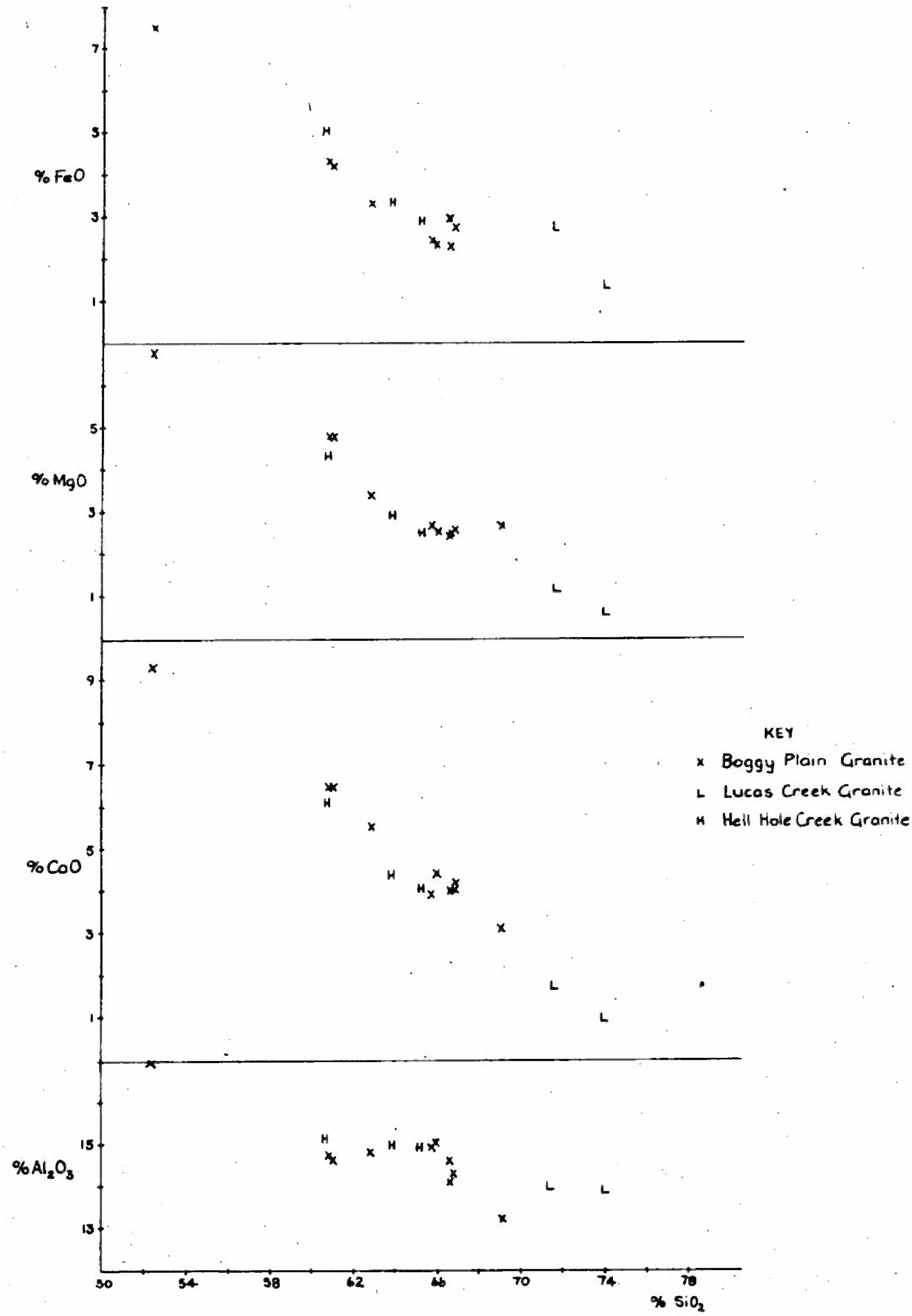


Fig. 34. Variation diagrams for the Boggy Plain Granite, Lucas Creek Granite, and Hell Hole Creek Granite.

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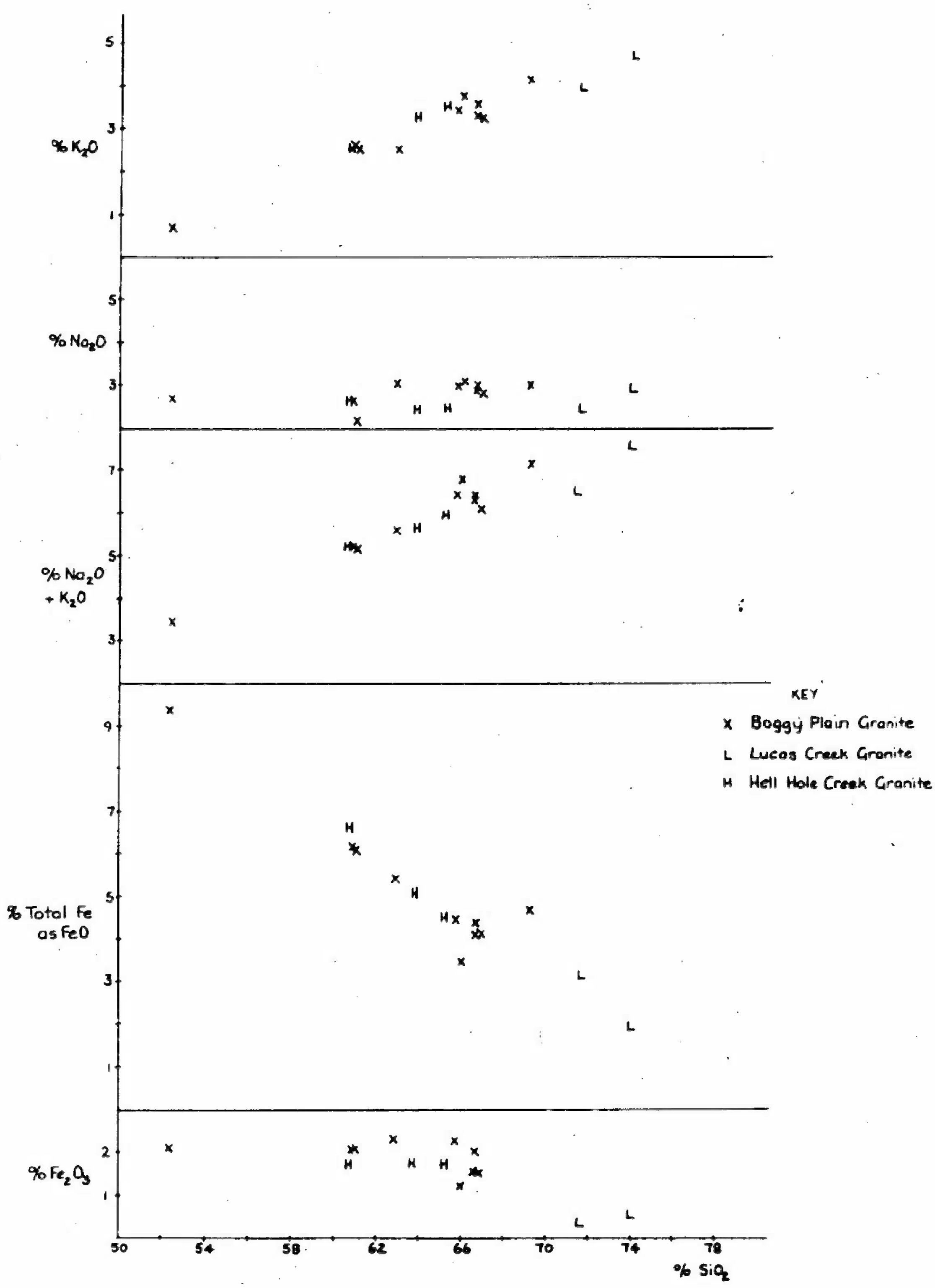


Fig. 34. (continued).

granite up to 2 m diameter are fairly common. This is the only clearing within the outcrop of the granite.

## FIELD RELATIONS

The contact of the intrusion and the surrounding rock is exposed where Hell Hole Creek leaves the Peak Back Ridge at G.R. 449416, where a medium to fine-grained granodiorite is in sharp contact with quartzite and hornfels of the Tantangara Beds. Metamorphism near to the contact reaches the hornblende hornfels facies (Fyfe, Turner, & Verhoogen, 1958) but quickly passes to a lower grade away from the contact. However, the thermal effects of the granite, in the form of spotted shale, are present up to 800 m from the intrusion (e.g. at G.R. 452438).

## PETROGRAPHY

The granite is a relatively uniform reddish pink, weathering to pale pink. The rock consists of scattered pale green plagioclase phenocrysts up to 5 mm in a granular matrix of pink, black, and white potassium feldspar, mafic minerals, plagioclase, and quartz grains 2 to 3 mm across. Near the margin of the intrusion the granite is medium grey, weathering darker, even-grained, with a grainsize of 1 to 2 mm, and has less potassium feldspar than the rest of the intrusion.

The granite has a hypidiomorphic granular texture with euhedral to subhedral plagioclase and mafic crystals surrounded by anhedral quartz and potassium feldspar. The plagioclase is rarely zoned, generally strongly saussuritized, and has a composition ranging from $An_{36-38}$ near the margin of the intrusion to $An_{30-32}$ in the centre. The anhedral potassium feldspar is generally strongly altered to a turgid brown, and in a few places graphic intergrowths with quartz. In contrast to plagiocalse, which everywhere forms 32 to 36% of the rock, the amount of potassium feldspar decreases from 19.5% near the centre of the intrusion to less than 7% at its margin. Quartz forms anhedral interstitial crystals, and shows a trend in abundance similar to the potassium feldspar, decreasing from 32.2% near the centre to 23% at the contact.

Biotite is present in fairly constant amounts, from 4.6 to 8.3%, and usually forms subhedral crystals, commonly partly or completely replaced by chlorite. The biotite is strongly pleochroic, $\alpha$ = pale yellowish brown, $\beta$ = $\gamma$ = dark brown. A colourless clinopyroxene with extinction angle of about 45° on 010 sections is fairly common (8.9%) near the edge of the intrusion but is rare towards its centre. This clinopyroxene, probably augite, is almost everywhere rimmed by green pleochroic hornblende and is partly the result of a more complete replacement of augite by hornblende. Hornblende also occurs as euhedral crystals that apparently crystallized directly from the magma. It is pleochroic, $\alpha$ = pale green, $\beta$ = green, and $\gamma$ = dark green, and has an extinction angle of 22° on 010 sections, and $2V_z \simeq 75°$. Alteration of hornblende to chlorite with minor epidote is fairly common. Accessory minerals include apatite, zircon, sphene, and opaque minerals.

The modal compositions of three rocks from the Hell Hole Creek Granite are shown in Table 42. Rock 71840413 was from near the centre of the intrusion, 71840415 within 1 m of the contact against the Tantangara Beds, and 71840414 was collected at the type locality, approximately midway between the other two samples.

An intrusion on the western ridge of the Peak Back Ridge appears to be related to the Hell Hole Creek Granite. It crops out on the ridge at G.R. 435422, and extends east towards the Hell Hole Creek Granite in the valley, 220 m below. Detailed relations between the two intrusions could not be determined with certainity owing to the thick scrub, but it is thought that they are not in contact with each other.

The composition of this intrusion ranges from tonalite to granodiorite, is medium grey, and consists of dark mafic minerals set in a white granular matrix of feldspar and quartz. Grainsize increases from about 1.5 mm near the margin of the body to about 3 mm through most of the intrusion. The rock has a hypidiomorphic granular texture and a mineralogy very similar to the Hell Hole Creek Granite; differences include more biotite (13-16%) and less quartz (12.5 - 20%). In addition, hypersthene, showing characteristic pale pink pleochroism, occurs in small quantities near the contact with country rock; it, and the augite also present, are enclosed by hornblende. Towards the centre of the intrusion replacement of pyroxene by amphibole is complete, and hornblende and biotite are the only mafic minerals present. The plagioclase is slightly more calcic than in the Hell Hole Creek Granite; the composition varies from $An_{44}$ near the contact to $An_{36}$ in the centre of the intrusion.

Modal compositions of two rocks from the intrusion are shown in Table 42. Rock 71840411 is from the margin of the intrusion and 71840412 from near the centre of the body.

TABLE 42. MODAL COMPOSITIONS OF INTRUSIONS FROM PEAK BACK RIDGE

| Sample No. | 71840411 | 71840412 | 71840413 | 71840414 | 71840415 |
|---|---|---|---|---|---|
| G.R. | 436419 | 437422 | 447423 | 449418 | 449416 |
| Quartz | 12.3% | 20.1% | 32.2% | 30.2% | 23.0% |
| K-feldspar | 8.5 | 14.1 | 19.5 | 15.5 | 6.7 |
| Plagioclase | 43.8 | 41.0 | 35.8 | 34.7 | 32.8 |
| Hornblende | 15.8 | 8.4 | 6.5 | 9.0 | 20.5 |
| Augite | 4.1 | - | 0.7 | 1.8 | 8.9 |
| Hypersthene | 1.7 | - | - | - | - |
| Biotite | 13.2 | 15.2 | 4.6 | 8.3 | 7.1 |
| Accessory | 0.6 | 1.2 | 0.7 | 0.5 | 1.0 |

## GEOCHEMISTRY (M.S.)

Three samples were analysed, of which 71840414 is from the main Granite body, and 71840411 and 71840412 from related smaller intrusions (see Table 43). The silica content of these rocks ranges from 60.7 to 65.2% so they are intermediate in composition.

Since from field relations and petrography and Hell Hole Creek Granite appeared to be related to the Boggy Plain Granite, it has been plotted on the same variation diagrams (Fig. 34). All three samples fall on the trend lines formed by the Boggy Plain Granite and Lucas Creek Granite, suggesting that all three intrusions are related. In addition, all the oxides determined in the three samples plot on a very nearly straight line indicating that the samples are unaltered and unweathered.

Normative corundum is present in the two more acid samples (71840412 and 71840414). Anorthite and albite are approximately equal in the norm so that the normative plagioclase is around $An_{50}$, which is slightly more calcic than the modal plagioclase composition of around $An_{35}$. The excess lime is present in hornblende, biotite and epidote in the mode. Diopside is present only in the least siliceous sample and the amount of hypersthene increases with decreasing silica.

TABLE 43. ANALYSES AND CIPW NORMS FROM THE HELL HOLE CREEK GRANITE AND RELATED INTRUSIONS

| Sample No. | 71840411 | 71840412 | 71840414 |
|---|---|---|---|
| Rock type | tonalite | diorite | granite |
| G.R. | 436419 | 437422 | 449416 |
| % | | | |
| $SiO_2$ | 60.7 | 65.2 | 63.8 |
| $Al_2O_3$ | 15.10 | 14.9 | 14.9 |
| $Fe_2O_3$ | 1.70 | 1.71 | 1.74 |
| FeO | 5.05 | 2.95 | 3.45 |
| MgO | 4.30 | 2.50 | 2.90 |
| CaO | 6.05 | 4.00 | 4.35 |
| $Na_2O$ | 2.65 | 2.45 | 2.40 |
| $K_2O$ | 2.50 | 3.50 | 3.25 |
| $H_2O+$ | 0.80 | 1.45 | 1.70 |
| $H_2O-$ | 0.14 | 0.19 | 0.24 |
| $CO_2$ | 0.05 | 0.07 | 0.05 |
| $TiO_2$ | 0.72 | 0.60 | 0.63 |
| $P_2O_5$ | 0.21 | 0.15 | 0.16 |
| MnO | 0.11 | 0.07 | 0.10 |
| Total | 100.08 | 99.74 | 99.67 |
| Qz | 15.47 | 24.93 | 23.05 |
| C | - | 0.34 | 0.03 |
| Or | 14.90 | 21.08 | 19.65 |
| Ab | 22.61 | 21.12 | 20.77 |
| An | 22.12 | 18.77 | 20.68 |
| Di( Wo | 2.69 | - | - |
| Di( En | 1.56 | - | - |
| Di( Fs | 1.00 | - | - |
| Hy( En | 9.24 | 6.34 | 7.39 |
| Hy( Fs | 5.94 | 3.20 | 4.14 |
| Mt | 2.49 | 2.53 | 2.58 |
| Il | 1.38 | 1.16 | 1.22 |
| Ap | 0.50 | 0.36 | 0.39 |
| Cc | 0.11 | 0.16 | 0.12 |

# GURRANGORAMBLA GRANOPHYRE (Stevens, 1958b)

(M.O. & D.W.)

## NOMENCLATURE

The Gurrangorambla Granophyre was first named by Stevens (1958b) for a pink felsitic rock which forms much of the Gurrangorambla Range south of Cooleman Plain and Seventeen Flat. No type locality was designated for the unit. Best et al. (1964) subsequently used the name Gurrangorambla Range Granophyre on the 2nd edition Canberra 1:250 000 geological map, but as the terminology of Stevens has priority it is followed herein.

## DERIVATION OF NAME

The Granophyre is named from the Gurrangorambla Range, a prominent ridge separating the Cave Creek drainage basin from creeks flowing south into Tantangara Dam.

## TYPE LOCALITY

No type locality was designated by Stevens when he introduced the name Gurrangorambla Granophyre. Accordingly, the type locality of the intrusion is here designated as the summit area of Tom O'Rourkes Peak (G.R. 484535) at the western end of the Gurrangorambla Range. An analysis of sample 71840327 from this locality is given in Table 44.

## DISTRIBUTION

The Gurrangorambla Granophyre crops out in five distinct places in the Cooleman area. The largest body extends from Tom O'Rourkes Peak to Blue Waterhole Saddle along the Gurrangorambla Range and covers an area of about 5 $km^2$. A second, smaller area is farther east along the Gurrangorambla Range around Howells Peak and is in effect a continuation of the first area, though the two are separated by a large, later, dioritic intrusion. This second area covers an area of just over 1 $km^2$. The form of these two bodies was considered by Stevens to be at least in part a sub-horizontal sheet, and he was uncertain if it was extrusive or intrusive. It is now considered that the Granophyre forms an elongate intrusive body, with steeply dipping contacts with the surrounding rocks, as the boundary appears to be little affected by topography.

The third area of outcrop of the Granophyre covers about 0.5 $km^2$ southeast of Spencers Hut. It is thought that the Granophyre is present in this area as a series of sills, or possibly dykes, since contact metamorphosed sediments are present; however, exposure is very poor and individual boundaries could not be mapped. The boundary shown on the accompanying 1:100 000 Sheet therefore represents the maximum extent of the Granophyre in this area.

The fourth area covers about 1.25 $km^2$ in The Pockets area, and is a continuation of the body around Howells Peak, displaced northwards some 2.5 km along the Black Mountain Fault. The fifth area of outcrop of the Granophyre is a small area on the Goodradigbee River about 0.5 km downstream of the junction with Cave Creek.

## PETROGRAPHY

A feature of the Gurrangorambla Granophyre is its marked similarity at all outcrops. Samples that have been contact metamorphosed by later intrusions have recrystallized into a white to pink sucroidal rock but unmetamorphosed samples are typically fine-grained, pinkish grey to pinkish purple rocks which weather to pale pink. Uncommon phenocrysts of feldspar are best seen as white crystals on weathered pink surfaces. Scattered throughout the rock are patches of green chlorite less than 1 mm across.

Widely scattered phenocrysts of subhedral sericitized plagioclase are up to 1 mm across, also scattered microphenocrysts about 0.3 mm across of subhedral opaques and chlorite possibly after hornblende. These are set in a groundmass (95%) of alkali feldspar, opaques, muscovite, and chlorite all about 0.04 mm across poikilitically enclosed in rounded granophyric growths of quartz about 0.6 mm across. In some areas the poikilitic quartz grains are separated by patches up to 0.5 mm across containing no quartz. In a few places there are patches of calcite about 0.5 mm across. Quartz occupies about 35% of the rock and alkali feldspar probably about 50%.

## RELATIONS AND AGE

The Gurrangoramba Granophyre appears from field evidence to be the oldest of the intrusive bodies in the Cooleman area. Evidence near Blue Waterhole Saddle indicates that the Granophyre is intruded by diorites of the Coolamine Igneous Complex, which is in turn intruded by the Jackson Granite. Furthermore, the Granophyre intrudes the Kellys Plain Volcanics, of latest

Pridolian age, so the age of the Granophyre must be early Gedinnian.

No extensive extrusive equivalents of the Granophyre are known, but some very small areas of a pale cream rhyolite (not shown on the Tantangara 1:100 000 map) e.g. at G.R. 527543, may be the remnants of extrusive equivalents of the Granophyre.

GEOCHEMISTRY (M.S.)

The Gurrangorambla Granophyre has been plotted on the same variation diagrams (Fig. 35) as the other rock suites of Cooleman area - the Coolamine Igneous Complex, Mountain Creek Volcanics, Jackson Granite, and minor intrusions - as all these units appear to be related from field evidence. Seven samples have been plotted, threee from BMR results and four which were analysed by Palmer (1972); they are listed in Table 44.

The Granophyre is an acid body because the samples analysed contain 73 to 74% silica. Alumina, magnesia, soda, and potash values from the Gurrangorambla Granophyre and the other rock units form fairly well defined fractionation trend-lines on the variation diagrams, except that lime and ferrous and ferric iron values for the Granophyre do not show such good correlation with silica. The Gurrangorambla Granophyre samples are lower in calcium than the Jackson Granite; sample 71840359 is exceptionally low. This sample is also too high in ferric iron compared with the other samples. The Granophyre is potassium-rich with the $K_2O/Na_2O$ ratio varying from 1.43 to 1.69.

The poor fit of the Granophyre samples to fractionation trend-lines and the variation between samples may be due to contamination of the body by country rocks, alteration, or possibly to an inhomogenous magma.

Some trace elements were determined for three samples; the values are typical of felsic rocks.

The samples all contain 2.4 to 2.9% normative corundum, a feature shared by the Jackson Granite. Normative anorthite is absent or very low, showing that the reason for the occurrence of corundum in the norm is the low lime content of the rocks (0.23 - 0.86%), rather than high alumina content. Diopside is therefore not present in the norm. Hypersthene is low because of the low Mg-Fe content of the rocks, but in one sample (71840359) there is normative hematite. This sample contains twice as much $Fe_2O_3$, possibly owing to weathering.

TABLE 44. ANALYSES AND CIPW NORMS FROM THE GURRANGORAMBLA GRANOPHYRE

| Sample No. | 71840327 | 71840328 | 71840359 | 160* | 161* |
|---|---|---|---|---|---|
| Rock type | granophyre | granophyre | granophyre | granophyre | granophyre |
| G.R. | 484535 | 502524 | 549513 | 503533 | 516526 |
| $SiO_2$ | 73.7 | 74.0 | 73.0 | 73.93 | 73.51 |
| $Al_2O_3$ | 12.9 | 12.6 | 13.2 | 12.73 | 12.66 |
| $Fe_2O_3$ | 0.66 | 0.83 | 1.85 | 0.83 | 0.81 |
| FeO | 1.10 | 0.96 | 0.84 | 0.75 | 0.88 |
| MgO | 0.26 | 0.26 | 0.25 | 0.24 | 0.26 |
| CaO | 0.86 | 0.81 | 0.23 | 1.04 | 0.88 |
| $Na_2O$ | 3.10 | 3.35 | 3.25 | 3.22 | 3.38 |
| $K_2O$ | 4.90 | 4.80 | 5.50 | 5.17 | 5.05 |
| $H_2O+$ | 0.59 | 0.58 | 0.69 | 0.81 | 0.69 |
| $H_2O-$ | 0.31 | 0.32 | 0.27 | 0.14 | 0.19 |
| $CO_2$ | 0.80 | 0.70 | 0.35 | 0.75 | 0.64 |
| $TiO_2$ | 0.40 | 0.40 | 0.31 | 0.34 | 0.35 |
| $P_2O_5$ | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 |
| MnO | 0.05 | 0.06 | 0.26 | 0.06 | 0.06 |
| S | - | - | - | 0.02 | 0.01 |
| | 99.66 | 99.70 | 100.04 | 100.06 | 99.41 |
| ppm | | | | | |
| Ni | 15 | 10 | <5 | - | - |
| Co | <5 | <5 | <5 | - | - |
| Cu | 5 | 5 | 8 | 0.5 | 1.1 |
| Zn | 50 | 55 | 48 | 29.2 | 43.3 |
| Pb | 15 | 25 | 290 | 8.1 | 15.1 |
| [illegible] | - | - | 3 | - | - |
| [illegible] | - | - | 6 | - | - |
| Qz | 37.02 | 36.23 | 33.58 | 35.18 | 34.40 |
| C | 2.90 | 2.14 | 2.41 | 1.75 | 1.68 |
| Or | 29.31 | 28.70 | 32.80 | 30.84 | 30.28 |
| Ab | 26.55 | 28.68 | 27.74 | 27.50 | 29.01 |
| An | - | - | - | 0.22 | 0.06 |
| Di | - | - | - | - | - |
| (En | 0.66 | 0.66 | 0.63 | 0.60 | 0.66 |
| (Fs | 0.92 | 0.53 | - | 0.24 | 0.49 |
| Mt | 0.97 | 1.22 | 2.68 | 1.22 | 1.19 |
| Hm | - | - | 0.02 | - | - |
| Il | 0.77 | 0.77 | 0.59 | 0.65 | 0.67 |
| Ap | 0.07 | 0.07 | 0.10 | 0.10 | 0.10 |
| Cc | 1.84 | 1.61 | 0.80 | 1.70 | 1.48 |

* Palmer (1972)

TABLE 44 (Cont'd)

| Sample No.<br>Rock type<br>G.R. | 159*<br>Granophyre<br>552514 | 169*<br>felsicdyke<br>491555 |
|---|---|---|
| % | | |
| $SiO_2$ | 73.95 | 73.99 |
| $Al_2O_3$ | 12.69 | 12.99 |
| $Fe_2O_3$ | 0.47 | 0.09 |
| FeO | 1.09 | 1.19 |
| MgO | 0.23 | 0.29 |
| CaO | 0.75 | 0.63 |
| $Na_2O$ | 3.53 | 3.19 |
| $K_2O$ | 5.02 | 5.53 |
| $H_2O+$ | 0.74 | 0.55 |
| $H_2O-$ | 0.14 | 0.25 |
| $CO_2$ | 0.47 | 0.58 |
| $TiO_2$ | 0.34 | 0.36 |
| $P_2O_5$ | 0.05 | 0.04 |
| MnO | 0.05 | 0.02 |
| S | 0.06 | 0.24 |
| | 99.59 | 99.95 |
| ppm | | |
| Ni | - | - |
| Co | - | - |
| Cu | 2.6 | 1.4 |
| Zn | 31.7 | 5.0 |
| Pb | 28.4 | 3.5 |
| Qz | 33.60 | 33.87 |
| C | 1.33 | 2.09 |
| Or | 30.08 | 33.03 |
| Ab | 30.28 | 27.27 |
| An | 0.43 | - |
| Di | - | - |
| Hy En | 0.58 | 0.73 |
| Hy Fs | 1.16 | 1.57 |
| Mt | 0.69 | 0.13 |
| Il | 0.65 | 0.69 |
| Ap | 0.12 | 0.10 |
| Cc | 1.08 | 1.33 |

* Palmer (1972)

## COOLAMINE IGNEOUS COMPLEX

(D.W.)

### NOMENCLATURE

The name Coolamine Igneous Complex is given to a series of intrusions of varied composition ranging from pyroxene-bearing adamellite and granodiorite through granogabbro to pyroxenite, which crop out in the Cooleman area, are closely related mineralogically and geochemically, and appear to be of closely similar age. Palmer (1972) used the name Coolamine Diorite for these bodies, a usage which is not considered to be strictly applicable in view of their wide range in composition, and occurrence as several separate intrusions. The separate intrusions will be given informal names in the text to aid description.

### DERIVATION OF NAME

The Complex is named from Coolamine homestead (G.R. 507580) on the track from Long Plain to Blue Waterhole.

### TYPE LOCALITY

No type locality is designated in view of the wide compositional and textural variation shown by the bodies forming the Complex. A reference locality for each intrusion will be mentioned in the individual descriptions of the petrography of the intrusions.

### DISTRIBUTION AND PETROGRAPHY

Ten individual intrusions form the Complex in the Cooleman area; the southernmost one cropping out on Currango Plain and the northernmost on the western side of McLeods Ridge. Each intrusion will be informally named and described separately. Because of their unusual mineralogical composition, most samples do not fit into the simple calcalkaline rock classification of Joplin (1971). The more comprehensive classification of Johannsen (1932a, b, 1939) has been used. Using a more recent chemical classification (Gulson, 1972) most samples are granodiorites, diorites, high-K diorites, and low-Si diorites.

1. 'Currango Plain intrusion'. This is an intrusion 700 m long and 200 m wide elongated north-south. It intrudes Kellys Plain Volcanics and is partly obscured by alluvium. The rock is very conspicuous because of its spotted glomeroporphyritic texture of clots of mafic minerals (30-40%) up to 10 mm across evenly distributed in a pale green, feldspathic groundmass.

Sample 71840304 (G.R. 547485) is a pyroxene-bearing granodiorite. It contains aggregates up to 6 mm across of anhedral grains of augite and altered anhedral grains of orthopyroxene. The orthopyroxene has in most places been completely altered to an optically continuous chlorite and talc intergrowth. The chlorite and talc flakes are aligned parallel to the C-axis of the original orthopyroxene. Most aggregates are monomineralic and composed of either augite or altered orthopyroxene, but some contain both minerals together and very rarely interstitial plagioclase. The aggregates have reaction rims of actinolite, brown biotite, and minor opaques. The aggregates are set in a groundmass of subhedral plagioclase and anhedral interstitial quartz and orthoclase perthite. The plagioclase occurs as phenocrysts up to 3 mm across commonly with wide calcic ($An_{50-60}$) cores and very narrow sodic rims ($An_{15-25}$). The cores are mostly altered to sericite epidote and rarely calcite. The modal analysis of sample 71840304 is shown in Table 45.

Sample 71840324 (G.R, 547484) is a biotite-bearing hypersthene granogabbro. The term granogabbro is used because of the presence of relatively large amounts of quartz and orthoclase with calcic plagioclase. It is similar to sample 71840304 in that it contains aggregates of pyroxene crystals in a feldspathic groundmass. The aggregates are up to 7 mm across and some, composed of a single augite grain are up to 6 mm across. Augite (10%) has $2V_z = 50°$ and is commonly twinned. This sample is not as altered as sample 71840304 as much of the orthopyroxene (20%) is unaltered. It has $2V_x = 70-80°$ (bronzite) and is up to 2 mm across. Plagioclase grains (40%) are commonly saussuritized but some have cores up to $An_{80}$. All have rims of $An_{15-25}$. Quartz 10% and perthitic orthoclase (8%) are interstitial and commonly intergrown. Biotite (7%) and actinolite (3%) form reaction rims around pyroxene aggregates and biotite is common in the groundmass.

2. 'Mosquito Creek intrusion'. This intrusion crops out on the Mosquito Creek Trail north of Mosquito Creek around G.R. 505510. It is elongated north-south, and is 2 km long and about 500 m wide. It is a composite intrusion composed mainly of even-grained pyroxene granodiorite, but at the north and south ends, circular stocks of glomeroporphyritic rock similar to the Currango Plain intrusion have intruded the even-grained granodiorite. The northern stock is about 300 m across and the southern stock about 500 m across.

TABLE 45. MODAL ANALYSES OF COOLAMINE IGNEOUS COMPLEX ROCKS

| Sample No.<br>G.R.<br>Intrusion | 71840304<br>547485<br>Currango Plain | 71840363<br>540534<br>Seventeen Flat | 71840447<br>527530<br>Seventeen Flat | 71840453<br>485579<br>Cave Creek | 71840457<br>476562<br>Skains Hill | 71840458<br>477555<br>Skains Hill | 71840460<br>488573<br>Cave Creek | 71840463<br>482616<br>Peppercorn Creek | 71840471<br>490596<br>Cooleman Mountains | 72840217<br>544674<br>Circuits Mountain |
|---|---|---|---|---|---|---|---|---|---|---|
| Quartz | 20.4 | 7.6 | 20.2 | 24.7 | 14.3 | 11.7 | 25.9 | 12.1 | 14.3 | 2.9 |
| Plagioclase | 30.6 | 47.6 | 34.2 | 25.2 | 41.2 | 39.7 | 43.3 | 54.0 | 51.1 | 46.0 |
| Orthoclase | 16.3 | 9.2 | 10.3 | 20.1 | 9.1 | 12.8 | 11.4 | 9.7 | 6.2 | 2.3 |
| Augite | 4.5 | } 32.8 | } 26.6 | 7.2 | 22.0 | 19.2 | } 9.8 | 5.0 | 8.3 | 3.0 |
| Hypersthene | 13.0 | | | 6.0 | 8.1 | 0.8 | | 7.4 | 7.0 | - |
| Hornblende | 4.7 | - | - | 9.6 | - | - | - | 4.5 | 4.0 | 41.1 |
| Biotite | 6.6 | - | 6.5 | 5.6 | - | 1.1 | 7.0 | 2.0 | 10.1 | - |
| Chlorite | 2.4 | - | - | - | - | - | - | 2.7 | - | - |
| Opaques | 0.5 | 2.3 | 1.9 | 1.6 | 4.2 | 3.8 | 2.2 | 2.3 | 1.2 | 3.0 |
| Apatite | 0.2 | 0.5 | 0.3 | - | 1.1 | 0.4 | 0.4 | 0.2 | 0.5 | 0.6 |
| Calcite | 0.8 | - | - | - | - | - | - | 0.1 | - | 1.1 |
| Anorthite content of plagioclase cores | 50-60 | 60-70 | 60-70 | 40-50 | 40-50 | 40-50 | 50-60 | 60-70 | 50-60 | 60-70 |
| Glomeroporphyritic | yes | no | no | no | no | no | no | yes | no | no |
| Rock type | Pyroxene grano-diorite | Pyroxene Grano-gabbro | Pyroxene Grano-gabbro | Pyroxene adamellite | Pyroxene grano-diorite | Pyroxene grano-diorite | Pyroxene grano-diorite | Pyroxene grano-gabbro | Pyroxene grano-diorite | hornblende gabbro |

groups still occur and any augite grains in the cores are unaltered. Biotite occurs as individual grains and grains adjacent to altered pyroxene.

Sample 71840363 (G.R. 540534) is not typical of the 'Seventeen Flat granogabbro'. It contains no biotite and much less quartz (see modal analysis, Table 45). The quartz occurs as micrographic intergrowths with orthoclase.

Sample 71840358 (G.R. 532551) has been contact metamorphosed by the Jackson Granite. It contains porphyroblasts of quartz up to 1 mm across and the biotite has been recrystallized to a mosaic of many flakes. Actinolite (altered from augite) has abundant opaque inclusions.

Sample 71840448 (G.R. 527536) comes from a western extension of the granogabbro, 1 km from outcrops of the Rolling Grounds Latite. The rock is much finer-grained than the rest of the granogabbro as the groundmass quartz and feldspar grains are less than 0.1 mm across. The rock is a pyroxene granodiorite-porphyry as it contains phenocrysts of unaltered augite, completely altered orthopyroxene and saussuritized plagioclase, all up to 1.5 mm across. It is probable that the western extension of the granogabbro was a feeder for the extrusion of lava of the Rolling Grounds Latite.

4. 'Skains Hill granodiorite'. This intrusion is about 2.5 km northeast of Skains Hill. It is elongated north-northwest, about 1.7 km long and 0.4 km wide and intrudes Kellys Plain Volcanics. The intrusion forms a prominent high-peaked hill west of Harris Hut. The rock is mottled pink, green, and grey, and fine to medium-grained.

Samples of the intrusion contain about 40% plagioclase, 10-15% quartz, 10% orthoclase, 20% augite, 10% altered orthopyroxene, 4% opaques, and minor biotite and apatite: see modal analyses of samples 71840457 (G.R. 476562) and 71840458 (G.R. 477555) in Table 45. Plagioclase occurs as phenocrysts up to 3 mm across with $An_{40-50}$ cores and narrow $An_{10-20}$ rims. Augite ($2V_z = 50^\circ$) occurs as subhedral to anhedral grains up to 1.5 mm across with orthopyroxene exsolved parallel to (100) in the cores. Orthopyroxene is subhedral and pseudomorphed by a mosaic of chlorite, talc, and actinolite. Some of the pyroxene grains occur in partly disaggregated glomeroporphyritic groups. Quartz and orthoclase occur as interstitial grains less than 1 mm across and commonly intergrown.

Sample 71840457 (G.R. 476562) contains rare microxenoliths up to 5 mm across composed of anhedral to subhedral augite and altered plagioclase and orthopyroxene all about 0.7 mm across. The xenoliths have a gabbroid texture.

The northern stock is a pyroxene-bearing granodiorite with about 24% plagioclase, 18% quartz, and 12% plagioclase, 18% quartz, and 12% orthoclase. The plagioclase is highly altered and up to 1 mm across. Quartz and orthoclase are anhedral and average 0.3 mm across. Aggregates containing augite and lesser altered orthopyroxene are up to 6 mm across and have reaction rims up to 1 mm across of pale green amphibole and opaques.

The southern stock is a biotite and orthopyroxene - bearing granogabbro. It is composed of about 30% saussuritized subhedral plagioclase (broad $An_{60-70}$ cores and narrow fresh $An_{20}$ rims) up to 2 mm, 20% micrographic intergrown quartz and orthoclase and 50% mafics. The mafics consist mainly of chloritized orthopyroxene and lesser augite in aggregates up to 4 mm across. Some of the aggregates have been partly disaggregated as micrographic quartz and orthoclase has penetrated along grain boundaries within the aggregates, and individual grains of chloritized orthopyroxene occur away from aggregates. Brown biotite flakes up to 2 mm long occur scattered throughout the rock and dotted around the pyroxene aggregates. Those around the aggregates are alteration products of pyroxene while those in the groundmass are primary. Chlorite and calcite are common interstital infillings and alteration products of calcic plagioclase.

3. 'Seventeen Flat granogabbro'. This is the largest intrusion in the Coolamine Igneous Complex. It crops out on Seventeen Flat and the Gurrangorambla Range east of Blue Waterhole Saddle as rounded boulders of massive dark homogeneous rock with a pale brown crumbly weathering skin. The intrusion is 4 km long and up to 1.5 km wide and is elongated northeast. It is very irregular in shape with lobate boundaries and is probably connected to the Mosquito Creek intrusion at depth. The granogabbro intrudes the Cooleman Limestone, Gurrangorambla Granophyre, and Kellys Plain Volcanics. It is intruded by the Jackson Granite.

The rock consists mostly of biotite and orthopyroxene-bearing granogabbro. The term granogabbro is used instead of granodiorite as the plagioclase present is labradorite and not andesine. The rock contains 30-40% plagioclase, 15-30% quartz, 5-10% orthoclase, 5-10% biotite, and 25-30% pyroxene. Plagioclase has broad euhedral cores up to 1 mm across of $An_{60-70}$ and very narrow rims of $An_{15-20}$. Quartz and orthoclase are interstitial and subpoikilitic. Sample 71840447 (G.R. 527530) contains poikilitic quartz up to 4 mm across enclosing saussuritized plagioclase, augite almost completely altered to actinolite, and orthopyroxene completely altered to actinolite and intergrown talc and chlorite. Orthoclase occurs as rarer sub-poikilitic grains up to 2 mm across.

Pyroxene in the 'Seventeen Flat granogabbro' is almost entirely altered, orthopyroxene to chlorite, talc and actinolite and clinopyroxene to actinolite. The pyroxene has been completely disaggregated but here and there glomeroporphyritic

5. '<u>Cave Creek complex</u>'. About 2 km north of Harris Hut and adjacent to Cave Creek at least six separate bodies have intruded the Blue Waterholes Beds, Cooleman Limestone, and Kellys Plain Volcanics. Even-grained granodiorites occur at G.R. 490572, G.R. 485579, and G.R. 479567. These bodies are up to 300 m across. Microgranodiorites occur at G.R. 487576, G.R. 488577, and G.R. 491578. These bodies are less than 200 m across. At G.R. 487575 a microgranodiorite intrusion is intruded by an even-grained granodiorite. At G.R. 488568 granodiorite has intruded an outlier of Kellys Plain Volcanics. Here the granodiorite is porphyritic with phenocrysts of pyroxene, plagioclase, and quartz up to 2 mm across in an aphanitic groundmass. A thin section of the porphyritic granodiorite (sample 71840456 from G.R. 488568) has rounded embayed quartz phenocrysts up to 1 mm across. These phenocrysts may be derived from contamination of the granodiorite by Kellys Plain Volcanics.

The microgranodiorite (sample 71840461 from G.R. 487576) contains about 10% quartz, 40% plagioclase, 40% actinolite, and minor orthoclase, calcite, and opaques, all about 0.1 mm across. The rock may be a microtonalite as orthoclase is rare.

The even-grained granodiorite contains subhedral plagioclase grains up to 3 mm across with broad oscillatory zoned cores about $An_{50-60}$ and narrow albitic rims. Augite and hypersthene have been mostly altered to actinolite and chlorite, but many actinolite grains have cores of augite. Brown biotite, quartz, and perthitic orthoclase are all anhedral and up to 2 mm across. A modal analysis of the rock is given in Table 45 (sample 71840460 from G.R. 491572).

Sample 71840453 (G.R. 485579) is similar to the even-grained granodiorites except that it contains more orthoclase and is an adamellite; see modal analysis Table 45.

6. '<u>Cooleman Mountains granodiorite</u>'. Granodiorite crops out as an elongate body on the northwest margin of the Cooleman Plain, on the eastern slopes of the Cooleman Mountains between G.R. 487584 and G.R. 500610. The intrusion is 2.7 km long and up to 0.5 km wide. The rock crops out as slightly rounded, grey boulders up to 2 m across. Aplite and quartz veins are absent and mesoscopic xenoliths are rare. The granodiorite intrudes Blue Waterhole Beds to the east, but dacite rubble obscures the contact with the Kellys Plain Volcanics to the west. Sample 71840454 (G.R. 484581) is a recrystallized dacite from the Kellys Plain Volcanics with abundant intergrowths of recrystallized biotite. It comes from within 100 m of the granodiorite intrusion and has probably been contact metamorphosed by it.

The granodiorite is very similar to the even-grained granodiorite of the Cave Creek complex to the south and is probably part of the same intrusion. Plagioclase (30-50%) occurs as subhedral grains up to 3 mm across with broad patchy zoned cores ($An_{50-60}$) and narrow $An_{20}$ rims. Others are more evenly zoned from $An_{60}$ to $An_{20}$. Augite is almost completely altered to actinolite and hypersthene is partly altered to chlorite and actinolite. Subhedral brown biotite up to 2 mm across is common (10%). Quartz and orthoclase perthite are anhedral, up to 1 mm across, and commonly intergrown. A modal analysis of sample 71840471 (G.R. 490596) is shown in Table 45.

Sample 71840474 (G.R. 501609) contains common unaltered grains of augite up to 1 mm across with actinolite reaction rims. Some of the augites have two sets of exsolution lamellae, one parallel to (100) and one parallel to (001). The lamellae parallel to (100) exsolved as orthopyroxene and the lamellae parallel to (001) exsolved as pigeonite (Hess, 1960) and probably later inverted to orthopyroxene. Also present in sample 71840474 are two adjacent subhedral grains of tourmaline 3 mm long. The tourmaline is zoned with cores pleochroic from pale green to dark green and rims pleochroic from pale brown to very dark bluish brown.

At the northern end of the 'Cooleman Mountains granodiorite' clinopyroxenite crops out as rounded boulders less than 1 m across in an area 200 m wide and 500 m long. The pyroxenite is separated from the granodiorite by 100 m of very poorly exposed Blue Waterhole Beds and Kellys Plain Volcanics. Veins of pink K-feldspar and yellow-green epidcte are common throughout the pyroxenite. The rock (sample 71840499, G.R. 503611) is composed of 90% subhedral to anhedral grains of augite ($2V_z = 60$) mostly about 0.4 mm across. Orthoclase is interstititial, and orthoclase, chlorite, and epidote occur in irregular veins and patches up to 5 mm across. Subhedral phenocrysts of augite are up to 4 mm across. The augite pheoncrysts are zoned with cores more Mg-rich (lower maximum extinction angle) than the rims. The difference between the extinction angle for the cores and for the rims is up to 5°. The maximum extinction angle on the finer-grained augites is $Z \wedge C = 44°$. The rock is similar to pyroxenite xenoliths from the Mountain Creek Volcanics (p. 201).

7. 'Coolamine homestead granodiorite porphyry'. This intrusion occurs on Cooleman Plain 100 m northeast of Coolamine homestead. The intrusion is elongated east-northeast and is about 800 m long and 300 m wide. It intrudes Blue Waterhole Beds and Cooleman Limestone. The rock is homogeneous throughout but the groundmass tends to be finer-grained towards the east. The

eastern end of the intrusion is within 150 m of outcrops of Rolling Grounds Latite. The porphyry intrusion is almost certainly a feeder for the latite.

Sample 71840433 (G.R. 506582) contains phenocrysts of euhedral plagioclase ($An_{50}$) up to 2 mm across, subhedral to anhedral augite up to 1 mm across, altered orthopyroxene up to 0.6 mm across, and a few rounded quartz phenocrysts up to 1 mm across. The phenocrysts occur in a groundmass of granophyric quartz and K-feldspar intergrowths 0.3 mm across, and minor biotite and opaques. A few microxenoliths composed of plagioclase, augite, and altered orthopyroxene are up to 4 mm across. The plagioclase phenocrysts and the plagioclase in the micro-xenoliths are both $An_{50}$. The phenocrysts and the xenolith plagioclases in contact with the groundmass of the rock have very narrow sodic rims. The xenolith plagioclases not in contact with the groundmass have no sodic rims.

8. '<u>McLeods Trail granogabbro porphyry</u>'. Granogabbro porphyry crops out as sparse subangular boulders on the McLeods Trail west of Jackson Trig. Station and on a rounded ridge southwest of the Trig. The porphyry intrudes Blue Waterhole Beds and Kellys Plain Volcanics and is about 2 x 1.5 km. The southern end of the intrusion is cut by a subsidiary fault of the Black Mountain Fault.

The rock is fairly homogeneous throughout although augite is the dominant mafic component in the north and altered orthopyroxene the dominant mafic in the south. Samples consist of scattered euhedral phenocrysts of altered labradorite 3 to 5 mm across with sodic rims, abundant subhedral labradorite 1 to 2 mm across, augite partly pseudomorphed by actinolite, and subhedral orthopyroxene pseudomorphed by chlorite, both 1 to 2 mm across, set in a groundmass of micrographic and granular quartz and orthoclase. Opaques are commonly associated with the altered mafics. Many of the unaltered augite grains contain exsolved lamellae of orthopyroxene parallel to (100) and pigeonite parallel to (001). The groundmass of samples 71840481 (G.R. 520599) and 71840482 (G.R. 519604) has recrystallized into a granoblastic texture so it is probable that the intrusion has formed by multiple injection, and earlier material has been hornfelsed by later injections of magma.

9. '<u>Circuits Mountain intrusion</u>'. This body is the northernmost intrusion of the Coolamine Igneous Complex. It occurs on the western side of McLeods Ridge northwest of Circuits Mountain. The intrusion is elongated north-south, and is about 3.5 km long and up to 0.8 km wide. It intrudes Blue Waterhole Beds

which dip about 50° to 60° east. An inlier of recrystallized limestone about 20 m across occurs at G.R. 540666, and about 500 m north of this (G.R. 542671) a doline about 10 m deep occurs within gabbro indicating the presence of limestone beneath. The intrusion is elongated parallel to the strike of the enclosing sediments and is probably a sill.

The body contains two varieties of rock, gabbro and granodiorite. It is roughly zoned, with a core of granodiorite and a rim of gabbro. The boundary between the two rock types is quite sharp and at some localities (e.g. at G.R. 544674) gabbro and granodiorite crop out less than 10 m apart.

The gabbro is a fine to medium-grained mottled dark green and white rock which crops out as rounded boulders up to 5 m across. At G.R. 534667 medium-grained gabbro crops out as a number of discontinuous cliffs up to 30 m high. The granodiorite forms very poor outcrop of angular blocks and float less than 0.5 m across. Where larger outcrops occur they are highly jointed and fractured and strongly weathered to a grey friable rock. The granodiorite is a fine to medium-grained white rock with about 10% dark minerals - mostly biotite.

Gabbro: The gabbro is a quartz-hornblende gabbro with abundant zoned hornblende moulded onto and partly penetrated by plagioclase laths. The hornblende occurs as subhedral to anhedral grains up to 2 mm across. They have cores with $2V_x = 80°$ and $\alpha$ = very pale yellow brown, $\beta = \gamma$ = brown with a reddish tinge. The rims have $2V_x = 70°$ and $\alpha$ = very pale yellow, $\beta$ = pale green with a brownish tinge, $\gamma$ = pale green with a bluish tinge and absorption $\beta > \gamma > \alpha$. In many grains the change from brown cores to green rims is very sharp. Some of the smaller hornblende grains do not have brown cores, but have irregular cores of augite - the hornblende being deuteric. The brown hornblendes are probably primary basaltic hornblendes. Widely scattered throughout the rock are patches up to 2 mm across of intergrown chlorite, actinolite, and opaques. These are probably alteration products of orthopyroxene.

Plagioclase occurs as abundant subhedral to euhedral laths up to 2 mm across but mostly less than 1 mm across. The laths are strongly zoned, with cores up to $An_{75}$ and narrow rims of $An_{20-30}$. Quartz, calcite, and orthoclase perthite occur as rare interstitial grains up to 2 mm across. Also present are irregular blebs of opaques up to 0.6 mm across commonly surrounded by sphene up to 0.4 mm across and euhedral needles of apatite up to 0.8 x 0.05 mm. The apatite is commonly included in large brown hornblende plates. A modal analysis of sample 72840217 (G.R. 544674) is shown in Table 45.

Sample 72840181 (G.R. 534666) is a biotite and hypersthene-bearing hornblende gabbro. It contains about 10% anhedral to subhedral brown flakes of biotite up to 1 mm across and about 5% anhedral grains of hypersthene ($2V_x = 60°$) up to 2 mm across partly altered to actinolite. The biotite commonly surrounds irregular patches of opaques.

Granodiorite. This is a hornblende-biotite granodiorite. It is hypidiomorphic with subhedral to euhedral laths of zoned plagioclase ($An_{40}$ cores and narrow $An_{20}$ rims) up to 2 mm across (40%), anhedral quartz (20%) up to 1.5 mm across, and anhedral orthoclase perthite (25%) up to 2 mm across. Biotite (10%) occurs as brown partly chloritized flakes (pleochroic from yellow brown to almost black) up to 1.5 mm across scattered throughout. Opaques (3%) are subhedral octahedra up to 0.4 mm across. Hornblende (2%) occurs as scattered green to brown green subhedral grains up to 0.6 mm across. Apatite is a minor accessory and epidote and sphene are alteration products of rare clusters of mafic minerals.

Sample 72840177 (G.R. 535657) is a metagranodiorite. It contains phenocrysts of sericitized plagioclase (30%) up to 0.8 mm across, pale green-yellow actinolite pseudomorphing pyroxene up to 1 mm across (10%), and a few grains of augite (5%) up to 1 mm across surrounded by first, actinolite and then fine-grained brown biotite. Brown biotite (13%) also occurs with chlorite (2%) as common recrystallized patches throughout. The groundmass of the rock consists of recrystallized granoblastic quartz (30%) and orthoclase (10%) with an average grain size of 0.1 mm. Some quartz porphyroblasts are up to 0.7 mm across. This sample has been contact metamorphosed and indicates that the intrusion has probably undergone multiple injection.

Contact effects. Sample 72840182 (G.R. 532662) is a contact metamorphosed Blue Waterhole Beds marl from within 10 m of the contact. It is composed of anhedral diopside (30%) as porphyroblasts up to 1 mm across in a granoblastic aggregate of quartz, plagioclase ($An_{30}$), diopside, and sphene with an average grainsize of 0.2 mm. Some of the plagioclase grains are up to 0.5 mm across. The presence of diopside in the rock indicates that hornblende hornfels facies conditions were achieved and the temperature must have been at least 400°C.

10. 'Peppercorn Creek granogabbro porphyry'. About 500 m northeast of Peppercorn Hut a stock about 200 x 400 m crops out as white rounded boulders up to several metres across. The rock is very conspicuous because of the presence of about 20% mafic minerals which occur as glomeroporphyritic clots up to 10 mm across evenly distributed throughout the rock. The body is homogeneous throughout and has no observable chilled margins. It intrudes Late Ordovician Temperance Chert.

Under the microscope the rock is seen to contain about 50% strongly zoned ($An_{70}$ cores $An_{30}$ margins) subhedral to euhedral plagioclase laths averaging 0.3 mm across but up to 3 mm across and interstitial plates of quartz and orthoclase about 0.5 mm across and minor patches of chlorite. Scattered throughout are aggregates of mafic minerals (20%) up to 8 mm across. These contain many grains of augite and chloritized orthopyroxene. Most of the grains are anhedral but some are euhedral. A few augite grains have irregular blebs of pyroxene (?orthorhombic) exsolved within them. Some of the aggregates are richer in augite, while others are richer in altered orthopyroxene. The aggregates are in reaction relation with the rest of the rock. Their margins have been altered to brown-green hornblende, opaques, and chloritized biotite. Opaques are more common around the margins of orthopyroxene-rich aggregates than augite-rich aggregates .

A modal analysis of sample 71840463 (G.R. 482616) is shown in Table 45.

A thin section of Temperance Chert from within 100 mm of the contact with the 'Peppercorn Creek granogabbro porphyry' (sample 71840497, G.R. 487616) shows that there was virtually no contact metamorphism. The rock contains fragments and crystals of augite and plagioclase in a cherty matrix. The matrix is almost isotropic and recrystallized only to the extent of other tuffaceous cherts in the Temperance Chert. It therefore seems that the 'Peppercorn Creek granogabbro porphyry' was intruded into its present position in a cool semi-solid state, possibly with all the pyroxene and the cores of the plagioclase laths already crystallized.

Age: Several bodies of the Coolamine Igneous Complex intrude Late Silurian Cooleman Limestone and Blue Waterhole Beds. Bodies also intrude the Kellys Plain Volcanics which unconformably overlie the Cooleman Limestone and Blue Waterhole Beds. The Complex is therefore no older than latest Silurian.

Stocks of the Coolamine Igneous Complex are almost certainly feeders for the Rolling Grounds Latite. On Cooleman Plain the intrusives and the extrusives are closely associated and fine-grained samples of parts of the 'Seventeen Flat granogabbro', 'Cave Creek Complex', and 'Coolamine homestead granodiorite porphyry' are very similar in hand specimen to the latite. Both the intrusives and the extrusives contain phenocrysts of augite (commonly with (100) exsolution) and chloritized orthopyroxene. Analyses of the latite (Table 26) are very similar to analyses of rocks from the Coolamine Igneous Complex (Table 46). Thus it is almost certain that the age of the Coolamine Igneous Complex is Early Devonian (page 199).

The relative ages of the various bodies within the Coolamine Igneous Complex is unknown. In the 'Mosquito Creek intrusion' glomeroporphyritic rocks intrude even-grained granodiorite, so it is possible that bodies with this spotted texture are later than the even-grained rocks. It is also possible that the glomeroporphyritic rocks grade into more even-grained rocks at depth as the glomeroporphyritic rocks only occur as small stocks and apophyses less than 500 m across.

GEOCHEMISTRY (M.S.)

The silica content of rocks from the Cooleman Igneous Complex ranges from 50 to 70.4%, but most samples fall in the intermediate range with only three containing more than 66% silica and seven containing less than 55% silica (Table 46). Forty-four samples have been plotted on variation diagrams (Fig. 35), 26 from BMR results, 13 rocks analysed by Palmer (1972) and five rocks taken from Joplin (1963). Other units from the Cooleman area are also on the same diagrams.

The scatter of the Coolamine Igneous Complex samples is fairly large; in particular, no fractionation trend-line can be drawn visually for alumina. A narrow fractionation band, rather than line, contains all the samples for lime, ferrous iron, total iron, and potash, but for ferric iron, magnesia, soda, and total alkalis a much broader band is needed to define the fractionation trend. Many of the rocks were seen in thin section or from field work to contain mafic minerals in various proportions in reaction relation with the rest of the rock, and these can reasonably be expected to show divergences from trend-lines for at least some oxides, but at least part of the scatter is due to alteration of the rocks. In thin section many of the rocks contain sericitized plagioclase and uralitized pyroxene, as well as chlorite and epidote, and this alteration may explain the wide variation in alumina (contained in sericite, amphiboles, and epidote) and spread in magnesia, iron, and soda. Much of the alteration is thought to be deuteric rather than caused by weathering.

The $K_2O/Na_2O$ ratio varies from 0.31 (sample 71840461; $SiO_2$ = 55.2%), to 1.61 (sample 71840304; $SiO_2$ = 60.4%), and in general it increases with increasing silica. Apart from sample 71840461 the lowest value of $K_2O/Na_2O$ is 0.71, and most of the rocks lie in the range from 0.7 to 1.2, so the Coolamine Igneous Complex is a potassium-rich body compared to average diorite.

Trace element values are also variable, although cobalt and lead show some correlation with silica content of the rocks. Two of the glomeroporphyritic rocks (71840446 and 71840304) have comparatively high nickel and magnesia values, suggesting that magnesium and nickel may have been incorporated into at least some of the rocks. Nickel is also high in the pyroxenite (71840499).

Normative corundum is present in only eight samples, which also show higher alumina values on the alumina-silica diagram. Normative quartz is present in all samples, ranging from 2.06 to 32.97%, and generally increases in abundance with increased silica content. Orthoclase, albite, and anorthite likewise change with silica content. Normative diopside is present in all samples except those containing corundum, but is always less abundant than normative hypersthene. Most samples have a high normative magnetite content, generally over 2% and up to 7%.

## JACKSON GRANITE (defined here)

(M.O. & D.W.)

### NOMENCLATURE

The name Jackson Granite was first published by Joplin et al. (1953) on the 1st edition Canberra 4-mile Geological Sheet and was later used by Best et al. (1964) on the 2nd edition. Previously, Walpole (1952) had used both Jackson Granite and Jackson Granodiorite when referring to the same intrusion. Stevens (1958) gave the name Black Mountain Granite to a granite cropping out south of Cave Creek, which we however consider to be a part of the Jackson Granite displaced south-southeast by the Black Mountain Fault. The name Black Mountain Granite is thus a junior synonym of the Jackson Granite.

### DERIVATION OF NAME

The Granite is named from Jackson Trig., altitude 1648 m, about 5.4 km north-northeast of Blue Waterhole (G.R. F40613).

### TYPE LOCALITY

The type locality is here designated as Jackson Trig. station

**TABLE 46. ANALYSES AND CIPW NORMS FROM THE COOLAMINE IGNEOUS COMPLEX**

| | Sample No. | 71840304 | 71840329 | 71840358 | 71840360 | 71840363 |
|---|---|---|---|---|---|---|
| | Rock type | pyroxene granodiorite porphyry | biotite bearing granogabbro | hornblende granodiorite | augite bearing granodiorite porphyry | pyroxene granogabbro |
| | G.R. | 547485 | 517518 | 532551 | 508518 | 540534 |
| | % | | | | | |
| | $SiO_2$ | 60.4 | 59.5 | 62.5 | 56.4 | 57.7 |
| | $Al_2O_3$ | 14.0 | 13.9 | 15.7 | 13.3 | 14.4 |
| | $Fe_2O_3$ | 0.70 | 1.55 | 2.75 | 3.35 | 2.05 |
| | FeO | 4.45 | 5.20 | 3.50 | 5.50 | 5.40 |
| | MgO | 5.65 | 5.15 | 2.45 | 6.15 | 5.55 |
| | CaO | 4.70 | 6.65 | 4.75 | 7.30 | 7.50 |
| | $Na_2O$ | 2.05 | 1.90 | 3.00 | 2.20 | 1.77 |
| | $K_2O$ | 3.30 | 2.30 | 2.95 | 2.10 | 1.89 |
| | $H_2O+$ | 2.10 | 1.71 | 0.64 | 2.05 | 1.53 |
| | $H_2O-$ | 0.57 | 0.31 | 0.14 | 0.17 | 0.25 |
| | $CO_2$ | 0.85 | 0.85 | 0.25 | 0.20 | 0.82 |
| | $TiO_2$ | 0.65 | 0.79 | 1.06 | 0.70 | 0.83 |
| | $P_2O_5$ | 0.15 | 0.24 | 0.29 | 0.20 | 0.27 |
| | MnO | 0.09 | 0.12 | 0.13 | 0.15 | 0.13 |
| | | 98.89 | 100.17 | 100.11 | 99.77 | 100.09 |
| | ppm | | | | | |
| | Ni | 115 | 55 | 5 | 10 | 35 |
| | Co | 20 | 20 | 8 | 20 | 25 |
| | Cu | 45 | 65 | 18 | 32 | 50 |
| | Zn | 60 | 85 | 45 | 45 | 80 |
| | Pb | 10 | 20 | 25 | 140 | 5 |
| | Cd | - | - | 3 | - | - |
| | Mo | - | - | 3 | - | - |
| | Qz | 16.14 | 18.55 | 20.38 | 12.15 | 16.87 |
| | C | - | - | 0.21 | - | - |
| | Or | 20.26 | 13.84 | 17.55 | 12.72 | 11.36 |
| | Ab | 18.02 | 16.37 | 25.54 | 19.07 | 15.23 |
| | An | 20.01 | 23.04 | 20.22 | 20.72 | 26.21 |
| Di | (Wo | 1.12 | 1.46 | - | 5.74 | 1.91 |
| Di | (En | 0.71 | 0.89 | - | 3.76 | 1.18 |
| Di | (Fs | 0.34 | 0.50 | - | 1.58 | 0.61 |
| Hy | (En | 13.91 | 12.18 | 6.14 | 11.94 | 12.87 |
| Hy | (Fs | 6.61 | 6.83 | 2.66 | 5.03 | 6.61 |
| | Mt | 1.05 | 2.29 | 4.01 | 4.98 | 3.02 |
| | Il | 1.28 | 1.53 | 2.03 | 1.36 | 1.6 |
| | Ap | 0.37 | 0.58 | 0.69 | 0.49 | 0.65 |
| | Cc | 0.19 | 1.97 | 0.57 | 0.47 | 1.90 |

TABLE 46 **(Cont'd)**

| Sample No. | 71840416 | 71840433 | 71840446 | 71840447 | 71840448 |
|---|---|---|---|---|---|
| Rock type | granogabbro porphyry | pyroxene granodiorite porphyry | granogabbro porphyry | pyroxene granogabbro | granodiorite porphyry |
| G.R. | 463500 | 506582 | 504505 | 527530 | 527536 |
| % | | | | | |
| $SiO_2$ | 56.8 | 63.6 | 55.8 | 60.0 | 59.2 |
| $Al_2O_3$ | 15.0 | 15.4 | 13.6 | 14.5 | 14.4 |
| $Fe_2O_3$ | 2.50 | 0.85 | 1.85 | 1.85 | 2.20 |
| FeO | 5.80 | 4.65 | 5.55 | 4.90 | 4.55 |
| MgO | 5.00 | 1.99 | 7.55 | 4.45 | 4.85 |
| CaO | 7.80 | 4.65 | 7.55 | 6.55 | 7.15 |
| $Na_2O$ | 1.77 | 2.85 | 1.75 | 1.97 | 2.20 |
| $K_2O$ | 1.71 | 3.15 | 2.05 | 2.45 | 2.15 |
| $H_2O+$ | 1.94 | 1.25 | 2.65 | 1.95 | 1.77 |
| $H_2O-$ | 0.20 | 0.21 | 0.31 | 0.27 | 0.17 |
| $CO_2$ | 0.12 | 0.10 | 0.10 | 0.10 | 0.10 |
| $TiO_2$ | 0.83 | 1.07 | 0.70 | 0.74 | 0.74 |
| $P_2O_5$ | 0.19 | 0.25 | 0.13 | 0.12 | 0.17 |
| MnO | 0.19 | 0.07 | 0.17 | 0.23 | 0.13 |
| | 99.85 | 100.09 | 99.76 | 100.08 | 99.78 |
| ppm | | | | | |
| Ni | | 20 | 120 | 35 | 35 |
| Co | | 5 | 30 | 20 | 20 |
| Cu | | 5 | 60 | 40 | 40 |
| Zn | | 50 | 75 | 70 | 65 |
| Pb | | 15 | 5 | 5 | 5 |
| Qz | 15.47 | 20.68 | 10.54 | 18.11 | 16.52 |
| C | – | – | – | – | – |
| Or | 10.34 | 18.87 | 12.51 | 14.79 | 12.98 |
| Ab | 15.32 | 24.44 | 15.29 | 17.03 | 19.02 |
| An | 28.59 | 20.21 | 23.97 | 24.00 | 23.58 |
| Di (Wo | 3.74 | 0.37 | 5.51 | 3.24 | 4.55 |
| Di (En | 2.21 | 0.16 | 3.61 | 1.92 | 2.91 |
| Di (Fs | 1.34 | 0.20 | 1.50 | 1.16 | 1.34 |
| Hy (En | 10.53 | 4.86 | 15.80 | 9.40 | 9.43 |
| Hy (Fs | 6.40 | 6.08 | 6.58 | 5.67 | 4.34 |
| Mt | 3.71 | 1.25 | 2.77 | 2.74 | 3.26 |
| Il | 1.61 | 2.06 | 1.37 | 1.44 | 1.44 |
| Ap | 0.46 | 0.60 | 0.32 | 0.29 | 0.41 |
| Cc | 0.28 | 0.23 | 0.23 | 0.23 | 0.23 |

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TABLE 46 (Cont'd)

| Sample No.<br>Rock type<br><br>G.R. | 71840455<br>pyroxene<br>granodiorite<br>487577 | 71840456<br>adamellite<br>porphyry<br>488568 | 71840457<br>pyroxene<br>granodiorite<br>476562 | 71840458<br>pyroxene<br>granodiorite<br>477555 | 71840459<br>pyroxene<br>granodiorite<br>491571 |
|---|---|---|---|---|---|
| % | | | | | |
| $SiO_2$ | 61.6 | 70.3 | 54.5 | 56.3 | 64.4 |
| $Al_2O_3$ | 15.0 | 13.9 | 15.2 | 15.3 | 14.7 |
| $Fe_2O_3$ | 1.35 | 0.50 | 3.80 | 3.30 | 1.15 |
| FeO | 4.85 | 3.20 | 5.40 | 4.65 | 4.00 |
| MgO | 2.55 | 1.60 | 4.65 | 4.05 | 1.61 |
| CaO | 5.55 | 1.93 | 8.20 | 7.05 | 3.55 |
| $Na_2O$ | 3.00 | 2.85 | 2.30 | 2.90 | 3.90 |
| $K_2O$ | 2.95 | 3.55 | 1.80 | 2.30 | 3.55 |
| $H_2O+$ | 1.44 | 1.38 | 1.98 | 2.40 | 1.60 |
| $H_2O-$ | 0.16 | 0.18 | 0.22 | 0.10 | 0.02 |
| $CO_2$ | <0.05 | 0.07 | 0.12 | 0.10 | 0.20 |
| $TiO_2$ | 0.80 | 0.56 | 0.94 | 0.99 | 0.98 |
| $P_2O_5$ | 0.31 | 0.12 | 0.48 | 0.38 | 0.22 |
| MnO | 0.12 | 0.05 | 0.17 | 0.15 | 0.11 |
| | 99.73 | 100.19 | 99.76 | 99.97 | 99.99 |
| ppm | | | | | |
| Ni | 25 | 25 | 35 | 35 | 15 |
| Co | 15 | 5 | 25 | 20 | 10 |
| Cu | 35 | 15 | 65 | 85 | 15 |
| Zn | 80 | 60 | 110 | 110 | 90 |
| Pb | 10 | 20 | 5 | 10 | 15 |
| Qz | 16.85 | 32.50 | 11.55 | 11.25 | 17.94 |
| C | - | 2.34 | - | - | - |
| Or | 17.76 | 21.27 | 10.90 | 13.94 | 21.32 |
| Ab | 25.86 | 24.44 | 19.94 | 25.16 | 33.53 |
| An | 19.11 | 8.46 | 26.48 | 22.51 | 12.33 |
| (Wo | 2.74 | - | 4.68 | 4.25 | 1.18 |
| Di (En | 1.31 | - | 2.97 | 2.75 | 0.52 |
| (Es | 1.38 | - | 1.42 | 1.21 | 0.65 |
| Hy (En | 5.16 | 4.04 | 8.90 | 7.60 | 3.55 |
| (Fs | 5.44 | 4.70 | 4.26 | 3.36 | 4.41 |
| Mt | 1.99 | 0.74 | 5.65 | 4.91 | 1.70 |
| Il | 1.55 | 1.08 | 1.83 | 1.93 | 1.89 |
| Ap | 0.75 | 0.29 | 1.17 | 0.92 | 0.53 |
| Cc | 0.12 | 0.16 | 0.28 | 0.23 | 0.46 |

TABLE 46 (Cont'd)

| Sample No. | 71840460 | 71840461 | 71840463 | 71840464 | 71840471 |
|---|---|---|---|---|---|
| Rock type | pyroxene granodiorite | microgranodiorite | granogabbro porphyry | pyroxene granodiorite | pyroxene granodiorite |
| G.R. | 491572 | 487576 | 482616 | 513618 | 490596 |
| % | | | | | |
| $SiO_2$ | 60.6 | 55.2 | 57.3 | 61.2 | 54.5 |
| $Al_2O_3$ | 15.7 | 15.5 | 17.7 | 15.3 | 15.7 |
| $Fe_2O_3$ | 1.55 | 0.85 | 1.45 | 1.75 | 3.60 |
| FeO | 5.00 | 8.10 | 5.20 | 4.40 | 5.45 |
| MgO | 2.80 | 4.85 | 3.10 | 3.75 | 5.15 |
| CaO | 5.60 | 7.55 | 7.15 | 6.30 | 8.05 |
| $Na_2O$ | 3.55 | 2.90 | 2.80 | 2.50 | 2.50 |
| $K_2O$ | 2.70 | 0.90 | 2.00 | 2.05 | 1.77 |
| $H_2O+$ | 1.14 | 2.45 | 1.93 | 1.81 | 1.30 |
| $H_2O-$ | 0.04 | 0.14 | 0.21 | 0.13 | 0.12 |
| $CO_2$ | 0.15 | 0.55 | 0.20 | $<0.05$ | $<0.05$ |
| $TiO_2$ | 0.84 | 0.74 | 0.70 | 0.56 | 0.93 |
| $P_2O_5$ | 0.33 | 0.18 | 0.22 | 0.11 | 0.40 |
| MnO | 0.12 | 0.16 | 0.10 | 0.11 | 0.16 |
| | 100.12 | 100.07 | 99.86 | 100.02 | 99.68 |
| ppm | | | | | |
| Ni | 25 | 15 | | 25 | 45 |
| Co | 15 | 25 | | 20 | 25 |
| Cu | 40 | 30 | | 50 | 70 |
| Zn | 70 | 95 | | 75 | 95 |
| Pb | 5 | $<5$ | | 10 | 5 |
| Qz | 13.12 | 9.04 | 12.13 | 19.10 | 9.36 |
| C | - | - | - | - | - |
| Or | 16.12 | 5.45 | 12.07 | 12.35 | 10.64 |
| Ab | 30.35 | 25.16 | 24.18 | 21.56 | 21.52 |
| An | 19.14 | 27.31 | 30.46 | 24.95 | 26.86 |
| Di (Wo | 2.42 | 2.64 | 1.25 | 2.44 | 4.51 |
| Di (En | 1.21 | 1.25 | 0.63 | 1.42 | 2.90 |
| Di (Fs | 1.17 | 1.37 | 0.60 | 0.90 | 1.31 |
| Hy (En | 5.84 | 11.14 | 7.25 | 8.09 | 10.15 |
| Hy (Fs | 5.64 | 12.22 | 6.94 | 5.13 | 4.59 |
| Mt | 2.27 | 1.26 | 2.15 | 2.59 | 5.31 |
| Il | 1.61 | 1.44 | 1.36 | 1.08 | 1.80 |
| Ap | 0.79 | 0.44 | 0.53 | 0.27 | 0.97 |
| Cc | 0.34 | 1.28 | 0.46 | 0.12 | 0.12 |

TABLE 46 (Cont'd)

| Sample No. | 109≠ | 117≠ | 81≠ | 72≠ | 47≠ | 148≠ |
|---|---|---|---|---|---|---|
| Rock type | diorite | granodiorite | granodiorite | granodiorite | granod-iorite | granodiorite |
| G.R. | 491572 | 507582 | 509607 | 527624 | 539532 | 449484 |
| % | | | | | | |
| $SiO_2$ | 61.40 | 62.83 | 63.10 | 63.31 | 64.08 | 68.19 |
| $Al_2O_3$ | 15.17 | 15.40 | 15.05 | 14.85 | 12.91 | 14.07 |
| $Fe_2O_3$ | 2.17 | 1.17 | 2.12 | 2.24 | 1.72 | 0.99 |
| FeO | 4.00 | 4.24 | 2.90 | 2.94 | 3.71 | 3.15 |
| MgO | 2.42 | 1.86 | 2.91 | 2.96 | 3.59 | 1.98 |
| CaO | 5.47 | 4.56 | 5.55 | 5.44 | 4.52 | 1.58 |
| $Na_2O$ | 3.05 | 3.15 | 2.11 | 2.30 | 2.06 | 2.62 |
| $K_2O$ | 3.02 | 3.17 | 2.79 | 2.71 | 2.93 | 3.64 |
| $H_2O+$ | 0.95 | 1.20 | 1.94 | 1.55 | 2.10 | 2.22 |
| $H_2O-$ | 0.11 | 0.20 | 0.23 | 0.18 | 0.20 | 0.23 |
| $CO_2$ | 0.17 | 0.08 | 0.04 | 0.05 | 0.53 | 0.34 |
| $TiO_2$ | 0.80 | 1.14 | 0.46 | 0.59 | 0.63 | 0.60 |
| $P_2O_5$ | 0.33 | 0.30 | 0.12 | 0.18 | 0.21 | 0.14 |
| MnO | 0.13 | 0.16 | 0.11 | 0.09 | 0.12 | 0.11 |
| S | 0.02 | 0.01 | 0.01 | 0.01 | 0.22 | 0.01 |
| | 99.21 | 99.47 | 99.94 | 99.40 | 99.53 | 99.87 |
| ppm | | | | | | |
| Cu | 40.5 | 1.0 | | | 44.9 | 19.5 |
| Zn | 81.5 | 72.7 | | | 82.9 | 69.0 |
| Pb | 15.2 | 12.1 | | | 19.3 | 23.7 |
| Qz | 17.56 | 19.23 | 24.31 | 24.13 | 26.72 | 32.97 |
| C | - | - | - | - | - | 4.21 |
| Or | 18.18 | 19.11 | 16.94 | 16.39 | 17.84 | 22.07 |
| Ab | 26.28 | 27.18 | 18.34 | 19.91 | 17.96 | 22.74 |
| An | 19.22 | 18.90 | 24.14 | 22.86 | 17.83 | 4.90 |
| Di Wo | 2.14 | 0.69 | 1.29 | 1.35 | 0.17 | - |
| Di En | 1.18 | 0.32 | 0.84 | 0.91 | 0.11 | - |
| Di Fs | 0.88 | 0.36 | 0.35 | 0.34 | 0.05 | - |
| Hy En | 4.96 | 4.40 | 6.60 | 6.63 | 9.11 | 5.06 |
| Hy Fs | 3.68 | 4.97 | 2.75 | 2.47 | 4.66 | 4.29 |
| Mt | 3.21 | 1.73 | 3.16 | 3.32 | 2.57 | 1.47 |
| Il | 1.55 | 2.21 | 0.90 | 1.15 | 1.23 | 1.17 |
| Ap | 0.80 | 0.73 | 0.29 | 0.44 | 0.51 | 0.34 |
| Cc | 0.39 | 0.19 | 0.09 | 0.12 | 1.24 | 0.79 |

≠ Palmer (1972)

TABLE 46 (Cont'd)

| Sample No.<br>Rock type<br>G.R. | 103≠<br>diorite<br>489574 | 149≠<br>diorite<br>457481 | 106≠<br>diorite<br>487582 | 143≠<br>diorite<br>483614 | 74≠<br>diorite<br>522523 |
|---|---|---|---|---|---|
| % | | | | | |
| $SiO_2$ | 53.50 | 55.13 | 55.91 | 56.47 | 58.36 |
| $Al_2O_3$ | 15.00 | 14.70 | 15.31 | 17.34 | 13.88 |
| $Fe_2O_3$ | 0.63 | 1.26 | 2.28 | 1.33 | 1.88 |
| FeO | 8.63 | 6.19 | 5.19 | 5.00 | 5.03 |
| MgO | 5.55 | 5.32 | 4.44 | 3.17 | 5.41 |
| CaO | 8.96 | 7.56 | 7.70 | 7.37 | 7.50 |
| $Na_2O$ | 1.71 | 2.36 | 2.48 | 2.81 | 1.86 |
| $K_2O$ | 1.00 | 1.87 | 2.33 | 2.17 | 2.33 |
| $H_2O+$ | 2.28 | 2.35 | 1.85 | 2.02 | 1.55 |
| $H_2O-$ | 0.26 | 0.19 | 0.21 | 0.14 | 0.16 |
| $CO_2$ | 1.09 | 1.60 | 0.15 | 0.33 | 0.04 |
| $TiO_2$ | 0.75 | 0.76 | 0.77 | 0.68 | 0.70 |
| $P_2O_5$ | 0.18 | 0.17 | 0.33 | 0.23 | 0.27 |
| MnO | 0.17 | 0.14 | 0.14 | 0.11 | 0.13 |
| S | 0.39 | 0.69 | 0.02 | 0.04 | 0.01 |
| | 100.08 | 100.29 | 99.06 | 99.21 | 99.11 |
| ppm | | | | | |
| Cu | | 49.5 | | | |
| Zn | | 90.3 | | | |
| Pb | | 11.0 | | | |

| | | | | | |
|---|---|---|---|---|---|
| Qz | 10.82 | 11.54 | 10.55 | 11.00 | 15.43 |
| C | - | - | - | - | - |
| Or | 6.08 | 11.39 | 14.19 | 13.22 | 14.13 |
| Ab | 14.88 | 20.57 | 21.62 | 24.50 | 16.14 |
| An | 31.18 | 24.73 | 24.47 | 29.06 | 23.29 |
| Di (Wo | 2.61 | 0.98 | 4.89 | 2.06 | 5.35 |
| Di (En | 1.26 | 0.55 | 2.90 | 1.05 | 3.34 |
| Di (Fs | 1.31 | 0.39 | 1.74 | 0.95 | 1.68 |
| Hy (En | 12.96 | 13.10 | 8.50 | 7.08 | 10.48 |
| Hy (Fs | 13.51 | 9.23 | 5.10 | 6.43 | 5.26 |
| Mt | 0.94 | 1.88 | 3.41 | 1.99 | 2.80 |
| Il | 1.47 | 1.49 | 1.51 | 1.33 | 1.36 |
| Ap | 0.44 | 0.42 | 0.81 | 0.56 | 0.66 |
| Cc | 2.55 | 3.75 | 0.35 | 0.77 | 0.09 |

≠ Palmer (1972)

TABLE 46 (Cont'd)

| Sample No. | 3* | 4* | 134≁ | 102≁ | 2* |
|---|---|---|---|---|---|
| Rock type | altered monzonite | altered monzonite | hornblendite xenolith | diorite | altered monzonite |
| G.R. | | | 535623 | 533613 | |
| % | | | | | |
| $SiO_2$ | 55.73 | 55.56 | 54.10 | 52.72 | 56.65 |
| $Al_2O_3$ | 17.65 | 17.97 | 7.93 | 16.17 | 15.80 |
| $Fe_2O_3$ | 3.12 | 2.01 | 1.38 | 3.55 | 4.78 |
| FeO | 3.98 | 4.74 | 4.22 | 5.61 | 4.46 |
| MgO | 3.55 | 4.21 | 11.53 | 5.34 | 3.98 |
| CaO | 6.66 | 6.36 | 15.29 | 8.82 | 7.61 |
| $Na_2O$ | 2.99 | 2.65 | 1.80 | 2.17 | 1.64 |
| $K_2O$ | 2.98 | 2.34 | 1.48 | 1.75 | 2.94 |
| $H_2O+$ | 1.69 | 0.45 | 1.04 | 1.46 | 0.62 |
| $H_2O-$ | 0.14 | 0.09 | 0.12 | 0.17 | 0.06 |
| $CO_2$ | 1.25 | 3.60 | 0.23 | 0.04 | 0.94 |
| $TiO_2$ | 0.53 | 0.82 | 0.47 | 0.86 | 0.69 |
| $P_2O_5$ | 0 | 0 | 0.20 | 0.43 | 0 |
| MnO | 0.10 | 0.06 | 0.34 | 0.16 | 0.07 |
| | 100.37 | 100.86 | 100.14 | 99.28 | 100.24 |
| ppm | | | | | |
| Cu | | | 10.2 | 91.5 | |
| Zn | | | 72.8 | 87.2 | |
| Pb | | | 4.9 | 10.1 | |
| Qz | 9.07 | 18.46 | 0.13 | 7.66 | 15.87 |
| C | 0.35 | 7.86 | - | - | - |
| Or | 17.86 | 13.77 | 8.84 | 10.59 | 17.44 |
| Ab | 25.66 | 22.33 | 15.39 | 18.80 | 13.92 |
| An | 25.50 | 8.76 | 9.29 | 30.01 | 27.18 |
| Di (Wo | - | - | 26.98 | 4.87 | 1.98 |
| Di (En | - | - | 19.90 | 3.10 | 1.37 |
| Di (Fs | - | - | 4.49 | 1.46 | 0.45 |
| Hy (En | 8.97 | 10.44 | 9.03 | 10.52 | 8.57 |
| Hy (Fs | 4.10 | 5.78 | 2.04 | 4.94 | 2.80 |
| Mt | 4.59 | 2.90 | 2.02 | 5.27 | 6.96 |
| Il | 1.02 | 1.55 | 0.90 | 1.67 | 1.32 |
| Ap | - | - | 0.48 | 1.04 | - |
| Cc | 2.88 | 8.16 | 0.53 | 0.09 | 2.15 |

* Joplin (1963, p. 90)

≁ Palmer (1972)

TABLE 46 (Cont'd)

| Sample No. | 72840215 | 72840217 | 72840218 | 4* | 5* |
|---|---|---|---|---|---|
| Rock type | hornblendite xenolith | dolerite | granodiorite | quartz monzonite | monzonite porphyry |
| G.R. | 536623 | 544674 | 542672 | | |
| % | | | | | |
| $SiO_2$ | 53.8 | 49.8 | 65.3 | 57.18 | 57.08 |
| $Al_2O_3$ | 7.0 | 15.3 | 15.6 | 14.13 | 13.62 |
| $Fe_2O_3$ | 1.5 | 2.55 | 1.95 | 1.90 | 1.30 |
| FeO | 4.7 | 6.95 | 3.45 | 5.85 | 6.21 |
| MgO | 12.7 | 5.8 | 0.85 | 7.00 | 8.07 |
| CaO | 15.3 | 11.2 | 3.25 | 7.64 | 7.54 |
| $Na_2O$ | 1.47 | 2.65 | 3.85 | 2.36 | 2.50 |
| $K_2O$ | 1.36 | 1.00 | 3.39 | 2.30 | 2.50 |
| $H_2O+$ | 0.57 | 1.48 | 0.69 | 0.45 | 0.19 |
| $H_2O-$ | 0.05 | 0.10 | 0.13 | 0.07 | 0.05 |
| $CO_2$ | 0.05 | 0.85 | 0.1 | - | - |
| $TiO_2$ | 0.41 | 1.76 | 0.95 | 0.60 | 0.65 |
| $P_2P_5$ | 0.09 | 0.30 | 0.13 | 0.21 | 0.21 |
| MnO | 0.38 | 0.18 | 0.12 | 0.11 | 0.14 |
| | 99.38 | 99.92 | 99.76 | 99.80 | 100.06 |
| Qz | - | 2.06 | 21.05 | 8.05 | 4.88 |
| C | - | - | 0.24 | - | - |
| Or | 8.14 | 6.01 | 20.24 | 13.69 | 14.80 |
| Ab | 12.59 | 22.79 | 32.91 | 20.11 | 21.18 |
| An | 8.59 | 27.36 | 14.80 | 21.25 | 18.54 |
| Di (Wo | 28.11 | 9.05 | - | 6.49 | 7.33 |
| Di (En | 20.62 | 5.49 | - | 4.11 | 4.66 |
| Di (Fs | 4.84 | 3.07 | - | 1.98 | 2.20 |
| Hy (En | 10.63 | 9.20 | 2.14 | 13.45 | 15.47 |
| Hy (Fs | 2.49 | 5.15 | 3.41 | 6.47 | 7.33 |
| Ol (Fo | 0.54 | - | - | - | - |
| Ol (Fa | 0.14 | - | - | - | - |
| Mt | 2.20 | 3.76 | 2.86 | 2.78 | 1.89 |
| Il | 0.79 | 3.40 | 1.82 | 1.15 | 1.24 |
| Ap | 0.22 | 0.72 | 0.31 | 0.50 | 0.50 |
| Cc | 0.12 | 1.97 | 0.23 | - | - |

* Joplin (1963, p. 85)

TABLE 46 (Cont'd)

| Sample No.<br>Rock type<br><br>G.R. | 71840472<br>pyroxene<br>granodiorite<br>498605 | 71840478<br>granodiorite<br>porphyry<br>508582 | 71840481<br>granogabbro<br>porphyry<br>520599 | 71840482<br>granogabbro<br>porphyry<br>519604 | 71840499<br>pyroxenite<br><br>503611 |
|---|---|---|---|---|---|
| % | | | | | |
| $SiO_2$ | 62.4 | 63.7 | 62.6 | 61.5 | 50.8 |
| $Al_2O_3$ | 15.3 | 15.3 | 16.1 | 16.2 | 10.4 |
| $Fe_2O_3$ | 2.20 | 1.35 | 1.40 | 2.35 | 1.85 |
| FeO | 3.75 | 4.60 | 4.35 | 2.50 | 3.75 |
| MgO | 2.40 | 1.75 | 3.15 | 3.10 | 11.0 |
| CaO | 5.00 | 4.15 | 5.25 | 6.25 | 17.2 |
| $Na_2O$ | 3.45 | 3.15 | 1.98 | 1.78 | 0.99 |
| $K_2O$ | 3.05 | 3.05 | 2.35 | 1.59 | 1.34 |
| $H_2O+$ | 0.71 | 1.21 | 1.45 | 2.25 | 1.63 |
| $H_2O-$ | 0.31 | 0.19 | 0.27 | 0.20 | 0.31 |
| $CO_2$ | $<0.05$ | $<0.05$ | 0.05 | 0.15 | 0.20 |
| $TiO_2$ | 0.79 | 1.23 | 0.52 | 0.63 | 0.37 |
| $P_2O_5$ | 0.29 | 0.28 | 0.12 | 0.11 | 0.07 |
| MnO | 0.12 | 0.15 | 0.09 | 0.06 | 0.10 |
| | 99.82 | 100.16 | 99.68 | 99.67 | 99.56 |
| ppm | | | | | |
| Ni | 20 | 10 | 15 | 25 | 150 |
| Co | 10 | 5 | 15 | 15 | 25 |
| Cu | 35 | 5 | 30 | 15 | 30 |
| Zn | 85 | 65 | 70 | 55 | 45 |
| Pb | 10 | 10 | 5 | 5 | 5 |
| | | | | | |
| Qz | 16.88 | 20.87 | 24.34 | 26.91 | - |
| C | - | 0.06 | 1.18 | 0.82 | - |
| Or | 18.24 | 18.25 | 14.17 | 9.66 | 8.07 |
| Ab | 29.53 | 26.98 | 17.09 | 15.49 | 8.54 |
| An | 17.47 | 18.67 | 25.46 | 30.17 | 20.37 |
| (Wo | 2.25 | - | - | - | 27.08 |
| Di (En | 1.29 | - | - | - | 20.59 |
| (Fs | 0.86 | - | - | - | 3.71 |
| (En | 4.76 | 4.41 | 8.01 | 7.94 | 4.11 |
| Hy (Fs | 3.17 | 5.65 | 6.27 | 3.66 | 0.74 |
| (Fo | - | - | - | - | 2.26 |
| Ol (Fa | - | - | - | - | 0.45 |
| Mt | 3.23 | 1.98 | 2.07 | 3.50 | 2.74 |
| Il | 1.52 | 2.37 | 1.01 | 1.23 | 0.72 |
| Ap | 0.70 | 0.67 | 0.29 | 0.27 | 0.17 |
| Cc | 0.12 | 0.12 | 0.12 | 0.35 | 0.46 |

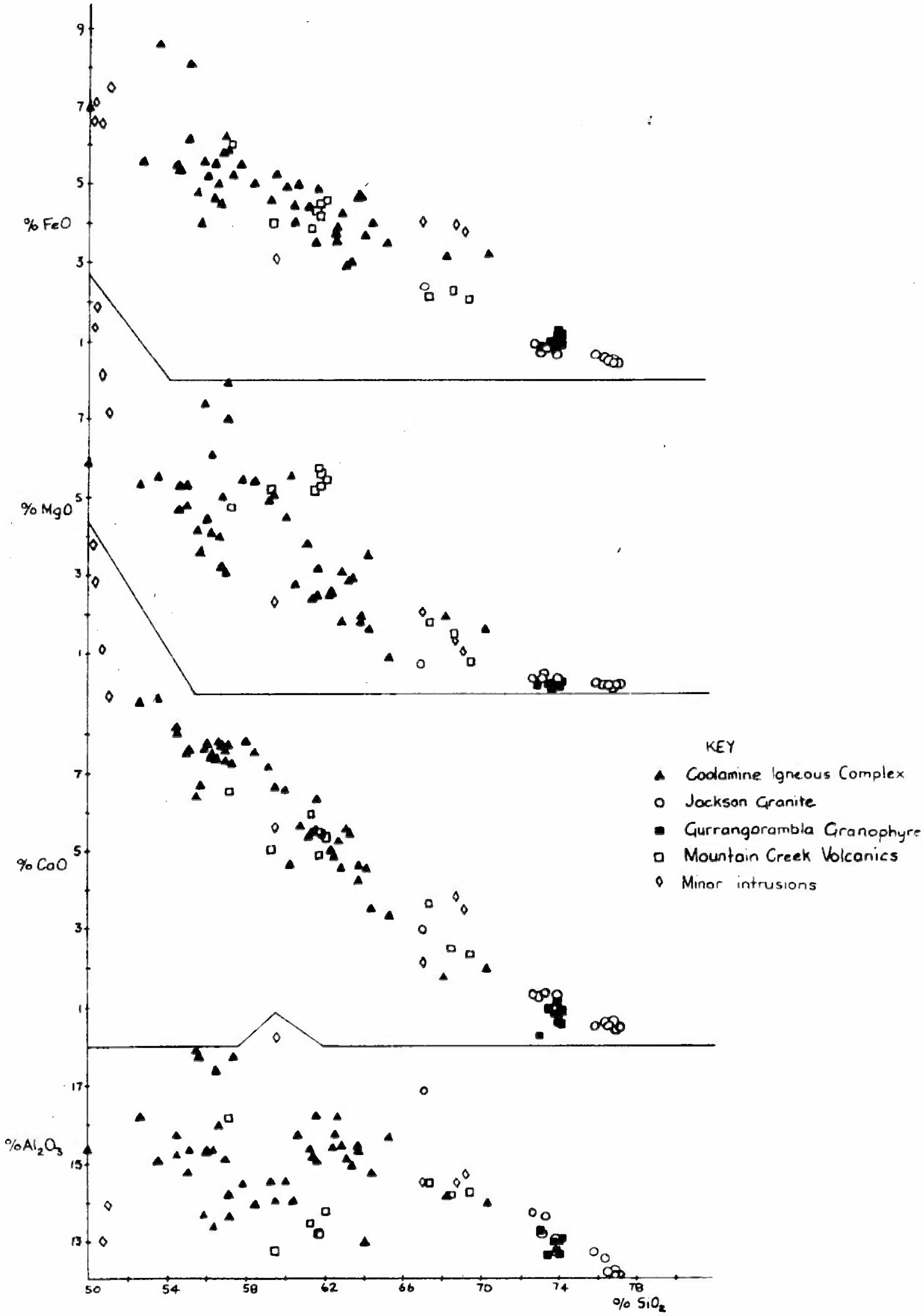


Fig. 35. Variation diagrams for the Coolamine Igneous Complex, Jackson Granite, Gurrangorambla Granophyre, Mountain Creek Volcanics.

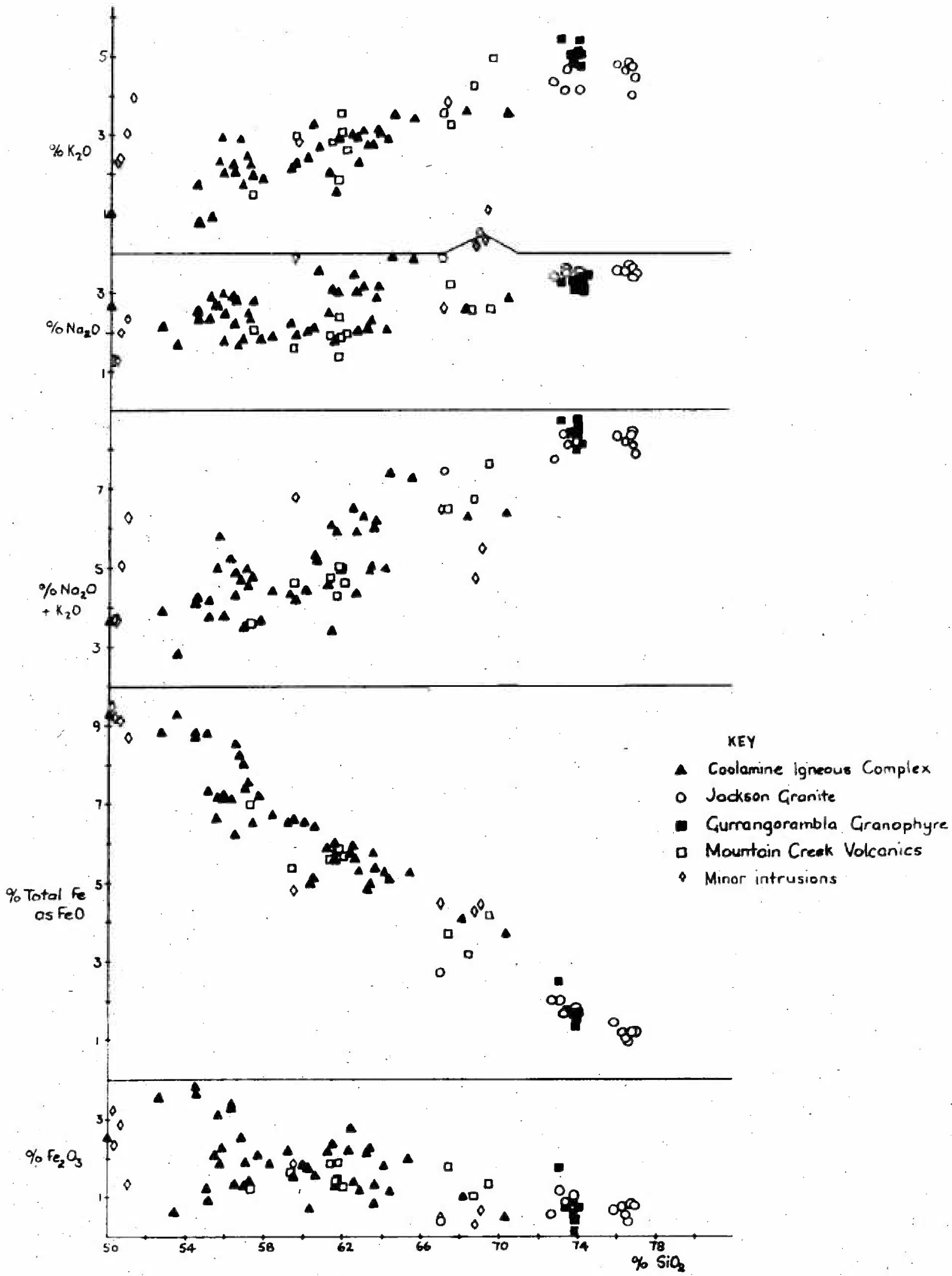


Fig. 35 (continued).

(G.R. 540613), where there are extensive outcrops of medium to coarse-grained pink granite cut by rare fine-grained aplitic veins.

DISTRIBUTION

The Jackson Granite crops out in three separate areas; Black Mountain, Jackson Trig., and the northern end of McLeods Ridge. The largest of these is the Jackson Trig. mass, covering a roughly semi-circular area of 16 $km^2$, the diameter of which is formed by the Black Mountain Fault, with Jackson Trig. roughly at the centre of the northern edge of the mass. The area of granite forming Black Mountain, south of Cave Creek, covers an area of 2.8 $km^2$ and is considered to be part of the Jackson Trig. mass displaced about 3.5 km to the south-southeast along the Black Mountain Fault. The third area of outcrop of the Jackson Granite covers an area of about 3.5 $km^2$, including that part which lies in the Brindabella Sheet area.

LITHOLOGY

The Jackson Granite crops out as rounded tors commonly up to 10 m high, and as slabs and cliffs on steeper slopes. At G.R. 563678 sloping cliffs are up to 100 m high. Outcrop is extremely good with never more than a few metres between boulders. Jointing, though evident in outcrop, has no preferred orientation and is not reflected in topography. Weathering is very deep (greater than 2 m). The rock is a medium to coarse-grained pink granite with pink K-feldspar up to 10 mm across. Biotite is generally fine-grained and occupies less than 5%. Pink aplite dykes are present at some outcrops. At a few localities, such as at the top of Black Mountain (G.R. 538548) the granite is fine-grained with an average grainsize of 1 mm. In most places the rock is medium to coarse-grained even at contacts with country rock though it may locally be fine-grained (Fig. 68). On the western side of McLeods Ridge to the west of Mt Ginini, there are many small isolated intrusions of Jackson Granite, some less than 2 m across. These small intrusions are medium-grained and white to very pale pink, with plagioclase and biotite much more common than in the main bodies. They are adamellite.

Xenoliths are uncommon in most of the granite outcrops, but within 50 m of the contacts with Blue Waterhole Beds in the Lower Peppercorn Creek and Goodradigbee River valleys (Brindabella 1:100 000 Sheet area) they are abundant. Angular blocks of Blue Waterhole Beds chert and cherty siltstone are up to 1 m across. Also present are subrounded xenoliths of blue-grey porphyritic rhyodacite (probably Kellys Plain Volcanics). At some localities (e.g. at G.R. 563712, Fig. 69) xenoliths of rhyodacite and Blue Waterhole Beds averaging 10 to 20 cm across form about 50% of the rock. Also present in the Peppercorn Creek valley, but farther from the contact, are rounded xenoliths up to 100 mm across of fine-grained hornblendite (Fig. 70).

Fig. 68 Contact between fine-grained Jackson Granite (darker rock) and Cooleman Limestone. 0.5 km downstream of Cave Creek Falls, G.R. 543568. (Neg. no. GA/8030)

The most typical granite is allotriomorphic equigranular with an average grainsize of 3 to 4 mm. Quartz and perthitic K-feldspar are abundant, each between 35 and 45%. The quartz occurs as anhedral grains, commonly slightly rounded when over 3 mm across. Some of these large grains may have been quartz. Smaller quartz grains are highly angular.

Fig. 69 Xenoliths, mainly of Blue Waterhole Beds, in Jackson Granite, Goodradigbee River, G.R. 563712 (Neg. no. GA/8156).

Fig. 70 Hornblendite xenoliths, with porphyroblasts of potassium feldspar, in Jackson Granite, Goodradigbee River, G.R. 565707. (Neg. no. GA/8139).

K-feldspar occurs as sericitized xenomorphic grains with fingers penetrating between adjacent quartz grains to give a sub-poikilitic texture. Twinning is common on the Baveno law and less common on the Carsbad law; cross-hatched twinning is absent. Some samples, e.g. sample 71840465 (G.R. 540613), contain poikilitic grains of perthite up to 10 mm across containing abundant inclusions of quartz, minor albite, and rare biotite. The centres of these grains are free of inclusions. It is probable that the centre was an original feldspar phenocryst that has undergone grain overgrowth incorporating the adjacent quartz grains as inclusions. Perthite exsolution lamellae are abundant in all K-feldspar grains. The lamellae occur as film, vein, and patch perthite with some patches up to 1 mm across. In some rocks vein and patch perthite lamellae are multiply twinned on the albite and pericline laws. In some grains there is a tendency for perthite lamellae to be more abundant at the edges of the grain and absent at the centre. In sample 71840430 (G.R. 532559) one grain 3 mm across is surrounded by a rim of albite giving the grain a rapakivi texture. The albite rim is optically continuous with the perthite lamellae which are more abundant towards the edge of the grain.

Plagioclase (less than 15%) occurs as subhedral to anhedral zoned grains up to 3 mm across, with $An_{20}$ cores and albite rims. Rarely cores are as calcic as $An_{40}$. Most cores are highly sericitized. Biotite is present in amounts less than 5%, and is more common in the coarse-grained samples such as sample 71840365 (G.R. 538548) where it occurs in groups. Generally it occurs as scattered partly chloritized grains up to 1 mm across. Opaques, euhedral to subhedral sphene, and apatite are associated with the biotite.

Sample 72840145 (G.R. 553678) is an adamellite from a 2 m-wide intrusion on McLeods Ridge. It consists of subhedral plagioclase (45%) up to 2 mm across (zoned with $An_{40}$ cores and $An_{20}$ rims), subhedral orthoclase perthite (30%) up to 3 mm across, anhedral quartz (18%) up to 2 mm across, and partly chloritized biotite (7%) up to 1 mm across. Opaques, apatite, and zircon are associated with the biotite. The orthoclase grains in this sample do not exhibit grain overgrowth, and do not have perthite lamellae concentrated near the rims.

Sample 72840180 (G.R. 563707) is a hornblendite xenolith from the Jackson Granite. The rock is composed of about 50% pale green hornblende, 5% biotite, 20% plagioclase, 15% orthoclase, and 10% quartz, with all grains less than 0.2 mm across. In some parts of the xenolith orthoclase, quartz, and green hornblende all up to 2 mm across occur together as porphyroblastic groups. There are also a few subhedral grains of plagioclase up to 1.5 mm across, with sericitized rims. These may be relic igneous phenocrysts.

AGE

The Jackson Granite intrudes the Lower Devonian Mountain Creek Volcanics, but the upper limit of its age is unknown. K-Ar dating is not possible at present because of deep weathering and alteration of biotite in the samples collected. The Jackson Granite is lithologically very similar to the Bogong Granite to the west, which has been dated by K-Ar as 385 m.y. (Ashley et al., 1971). Early Middle Devonian is the most likely age for the Jackson Granite.

GEOCHEMISTRY (M.S.)

Six BMR samples, four rocks analysed by Palmer (1972) and one rock quoted in Joplin (1963) are discussed in this section. The Jackson Granite is related to the other rocks of the Cooleman area and has been plotted on the same variation diagrams (Fig. 35) as the Coolamine Igneous Complex, Gurrangorambla Granophyre, Mountain Creek Volcanics, and minor intrusions.

Ten out of the eleven samples have a very limited silica range of 72 to 77% (Table 47), whilst the eleventh sample (72840145), taken from a small body about 2 m across several kilometres north of the others, contain 67% $SiO_2$. This last sample has probably been contaminated by the sediments it intrudes. The oxide content is also very similar in all the samples, and they fit well on to fractionation trends for rocks from the Cooleman area. The Gurrangorambla Granophyre also has a very restricted range of silica and other oxides and the composition of the samples from it is very close to those from the Jackson Granite, possibly suggesting that the two rock types are closely related even though the Jackson Granite is the latest magmatic event in the Cooleman area and the Granophyre is one of the earliest. Scatter of the Granite samples from trend-lines is slight when compared to the Coolamine Igneous Complex, being greatest for potash, total alkalis, and ferric iron. These elements are easily affected by weathering which is probably the cause of the scatter as the Granite as a whole is deeply weathered.

Palmer (1972), divides the rock suites of the Cooleman area into two rock series, a dioritic series (consisting mainly of the Coolamine Igneous Complex) and an acidic series ( consisting of the Jackson Granite and the

Gurrangorambla Granophyre), using regression lines to find the best fractionation trend-lines. The division into two series is best seen in the trace element variation diagrams rather than major oxides. The samples plotted here may show two different trends for $Al_2O_3$, MgO, $Na_2O$, and total alkalis, although no separation is noticeable for the other elements. More samples of acidic rocks containing less than 72% $SiO_2$ would be needed to reach any definite conclusions. To prove or disprove Palmer's theory, therefore, more detailed sampling, and data for trace elements such as barium, strontium, and rubidium are needed.

Some trace elements have been determined for a few samples. Nickel, cobalt, and copper are very low as can be expected for acid rocks, and lead and zinc values are typical of felsic rocks (Hawkes & Webb, 1962).

All the samples contain more than 30% quartz in the norm, reflecting the high silica content of the rocks. Normative orthoclase and albite are also high (both greater than 20%) owing to the high alkali and silica content. The low lime content of the Granite results in normative anorthite being low or even absent (sample 71840356), and in the occurrence of normative corundum as alumina is greater than the total of lime plus alkalis. Because corundum is present in all samples except 72842001, diopside is absent in the norm, and hypersthene is also very low because of the low magnesia and iron contents of the rocks. Normative hematite is present in several samples, which may indicate that the rocks are weathered and ferrous iron has been partly converted to ferric iron.

## MINOR INTRUSIONS IN THE ORDOVICIAN AND EARLY SILURIAN

(D.E.G.)

There are many minor basic and acidic intrusions near the boundary of the Bolton Beds and Temperance Chert. Exclusively acidic intrusions occur at widely scattered localities in the Temperance Chert and Nine Mile Volcanics, and sporadically in the Tantangara Beds. The largest are boss-like, and include one in the chert unit, and a smaller one in the interbedded chert and tuff unit of the Temperance Chert, two small intrusions in the Nine Mile Volcanics and two in the Tantangara Beds. Minor basic intrusions are present throughout the interbedded chert and tuff of the Temperance Chert, but stratigraphically above that are recorded, doubtfully, at only two localities. There is also a fairly

## TABLE 47. ANALYSES AND CIPW NORMS FROM THE JACKSON GRANITE

| Sample No. | 71840356 | 71840357 | 71840365 | 71840465 | 71840544 |
|---|---|---|---|---|---|
| Rock type | alkali granite | granite | granite | alkaligranite | alkali granite |
| G.R. | 539548 | 537550 | 537553 | 539613 | 537609 |
| % | | | | | |
| $SiO_2$ | 76.7 | 73.3 | 72.6 | 76.8 | 76.30 |
| $Al_2O_3$ | 12.1 | 13.7 | 13.7 | 12.1 | 12.50 |
| $Fe_2O_3$ | 0.85 | 0.95 | 1.16 | 0.80 | 0.65 |
| FeO | 0.44 | 0.81 | 0.93 | 0.45 | 0.60 |
| MgO | 0.16 | 0.45 | 0.42 | 0.15 | 0.19 |
| CaO | 0.29 | 1.29 | 1.29 | 0.47 | 0.57 |
| $Na_2O$ | 3.35 | 3.50 | 3.45 | 3.45 | 3.55 |
| $K_2O$ | 4.80 | 4.70 | 4.35 | 4.50 | 4.70 |
| $H_2O+$ | 0.01 | 0.43 | 0.35 | 0.34 | 0.38 |
| $H_2O-$ | 0.37 | 0.29 | 0.37 | 0.36 | 0.24 |
| $CO_2$ | 0.30 | 0.15 | 0.79 | <0.05 | 0.05 |
| $TiO_2$ | 0.15 | 0.26 | 0.41 | 0.18 | 0.17 |
| $P_2O_5$ | 0.02 | 0.05 | 0.06 | 0.01 | 0.02 |
| MnO | 0.06 | 0.05 | 0.08 | 0.03 | 0.04 |
| | 99.61 | 99.93 | 99.96 | 99.69 | 99.96 |
| ppm | | | | | |
| Ni | <5 | | 10 | <5 | |
| Co | <5 | | <5 | <5 | |
| Cu | 8 | | 5 | 5 | |
| Zn | 30 | | 60 | 20 | |
| Pb | 38 | | 25 | 20 | |
| Cd | 3 | | - | - | |
| Mo | 5 | | - | - | |
| Qz | 39.18 | 32.18 | 35.00 | 38.85 | 36.45 |
| C | 1.62 | 0.99 | 2.97 | 0.85 | 0.71 |
| Or | 28.58 | 27.99 | 25.90 | 26.86 | 27.95 |
| Ab | 28.56 | 29.84 | 29.40 | 29.48 | 30.22 |
| An | - | 5.16 | 1.02 | 1.97 | 2.40 |
| Di | - | - | - | - | - |
| Hy En | 0.40 | 1.13 | 1.05 | 0.38 | 0.48 |
| Hy Fs | - | 0.37 | 0.22 | - | 0.36 |
| Mt | 1.19 | 1.39 | 1.69 | 1.04 | 0.95 |
| Hm | 0.04 | - | - | 0.09 | - |
| Il | 0.29 | 0.50 | 0.78 | 0.35 | 0.32 |
| Ap | 0.05 | 0.12 | 0.14 | 0.02 | 0.05 |
| Cc | 0.69 | 0.34 | 1.81 | 0.11 | 0.11 |

TABLE 47 (Cont'd)

| Sample No.<br>Rock type<br>G.R. | 72840145<br>adamellite<br>553678 | 24*<br>granite | 139¢<br>granite<br>540605 | 162¢<br>granite<br>536551 | 137¢<br>granite<br>542613 | 140¢<br>granite<br>527614 |
|---|---|---|---|---|---|---|
| % | | | | | | |
| $SiO_2$ | 67.0 | 76.6 | 73.16 | 73.88 | 75.85 | 76.57 |
| $Al_2O_3$ | 16.8 | 12.1 | 13.21 | 13.13 | 12.72 | 12.14 |
| $Fe_2O_3$ | 0.38 | 0.68 | 1.22 | 1.02 | 0.68 | 0.54 |
| FeO | 2.35 | 0.53 | 0.77 | 0.64 | 0.66 | 0.48 |
| MgO | 0.80 | 0.10 | 0.42 | 0.35 | 0.33 | 0.22 |
| CaO | 2.95 | 0.66 | 1.22 | 1.25 | 0.45 | 0.47 |
| $Na_2O$ | 3.55 | 3.60 | 3.73 | 3.51 | 3.58 | 3.52 |
| $K_2O$ | 3.95 | 4.80 | 4.65 | 4.69 | 4.82 | 4.85 |
| $H_2O+$ | 0.82 | 0.42 | 0.65 | 0.64 | 0.52 | 0.44 |
| $H_2O-$ | 0.06 | 0.13 | 0.16 | 0.23 | 0.16 | 0.18 |
| $CO_2$ | 0.05 | - | 0.23 | 0.16 | 0.10 | 0.07 |
| $TiO_2$ | 0.63 | 0.18 | 0.33 | 0.28 | 0.19 | 0.16 |
| $P_2O_5$ | 0.11 | 0.02 | 0.06 | 0.06 | 0.03 | 0.03 |
| MnO | 0.08 | 0.05 | 0.05 | 0.05 | 0.04 | 0.02 |
| S | 0.08 | - | 0.01 | 0.02 | 0.01 | 0.01 |
| | 99.61 | 99.87 | 99.87 | 99.91 | 100.14 | 99.70 |
| ppm | | | | | | |
| Ni | | | - | | - | - |
| Co | | | - | | - | - |
| Cu | | | 1.8 | | 3.5 | 0.6 |
| Zn | | | 24 | | 42.3 | 12.8 |
| Pb | | | 17 | | 27.9 | 12.4 |
| Qz | 23.08 | 36.05 | 31.57 | 33.29 | 35.55 | 36.77 |
| C | 1.73 | - | 0.50 | 0.50 | 1.09 | 0.45 |
| Or | 23.66 | 28.55 | 27.73 | 27.99 | 28.63 | 28.93 |
| Ab | 30.44 | 30.66 | 31.84 | 29.98 | 30.44 | 30.05 |
| An | 13.78 | 2.71 | 4.24 | 4.84 | 1.41 | 1.71 |
| Di | - | 0.38 | - | - | - | - |
| Hy (En | 2.02 | 0.15 | 1.06 | 0.88 | 0.83 | 0.55 |
| Hy (Fs | 3.15 | 0.12 | - | - | 0.41 | 0.21 |
| Mt | 0.56 | 0.99 | 1.70 | 1.43 | 0.99 | 0.79 |
| Hm | - | - | 0.06 | 0.04 | - | - |
| Il | 1.21 | 0.34 | 0.63 | 0.54 | 0.36 | 0.31 |
| Ap | 0.26 | 0.05 | 0.14 | 0.14 | 0.07 | 0.07 |
| Cc | 0.12 | - | 0.53 | 0.37 | 0.23 | 0.16 |

* Joplin (1963, p.15)

¢ Palmer (1972)

extensive belt of boss-like intermediate intrusions in the interbedded chert and tuff.

Joplin (1958) has already investigated minor intrusives of basic to acidic compositions within the area drained by the upper Tumut and Happy Jacks Rivers.

## Porphyritic acid intrusions

### Bolton Beds and Temperance Chert

Minor acidic intrusions are plentiful between Sawyers Hill and Tantangara Mountain; they are also present on a spur that runs north from Tantangara Mountain, and on the northern side of Blanket Hill. North of Blanket Hill they are uncommon in the Temperance Chert; individual intrusions were mapped at five localities between grid northings 397 (about 1.5 km north of Tantangara Plain) and 512 (near McPhersons Creek).

Between Sawyers Hill and Tantangara Mountain there intrusions occur as dykes and ?sills, less than 500 m to either side of the boundary between the Bolton Beds and Temperance Chert,; they are most abundant less than 200 m from the boundary. The intrusions are porphyritic in quartz, plagioclase, and less commonly orthoclase, with a fine to very fine-grained matrix. They range from dellenite through toscanite to dacite. Their approximate compositions are summarized in Table 48.

Minor acidic porphyries inturde the interbedded chert and tuff of the Temperance Chert in the spur that extends north from Tantangara Mountain, at the edge of Boggy Plain. One at G.R. 421306 (T.S. 71 840287), near a faulted boundary with the Bolton Beds, is a rhyolite with phenocrysts of orthoclase, plagioclase, and quartz in a fine-grained matrix. Its approximate composition is given in Table 49.

A minor intrusion at G.R. 450351 (T.S. 71840162), one of three in the Bolton Beds on the northern side of Blanket Hill, is a dellenite (Table 49). Farther north, a granophyre porphyry rich in K-feldspar and devoid of mafic minerals (T.S, 71840298, Table 49) intrudes interbedded chert and tuff of the Temperance Chert at G.R. 404396, on the western side of Tantangara Creek east-southeast of Bullock Hill. It is almost in contact with one of the bosses

**TABLE 48. MINOR ACIDIC INTRUSIONS: ESTIMATED MODE**

| Intruded rock | Bolton Beds | | | | Temperance Chert | | | | |
|---|---|---|---|---|---|---|---|---|---|
| General locality | | (1) | | (2) | | (1) | | (3) | |
| Thin section No. | 71840071 | 71840075 | 7180138 | 71840162 | 71840012 | 71840054 | 71840289 | 71840287 | 71840298 |
| G.R. | 409295 | 401296 | 373272 | 450351 | 386283 | 386284 | 406302 | 421306 | 404396 |
| Orthoclase | 40 | 1 | 20 | 32 | 33 | 45 | 35 | 35 | 50 |
| Plagioclase | 18 | 20 | 40 | 22 | 25 | 15 | 35 | 15 | 27 |
| Quartz | 25 | 65 | 25 | 35 | 40 | 40 | 25 | 35 | 22 |
| Amphibole | - | - | 5 | 10 | - | - | 1 | 5 | - |
| Biotite | 7 | - | - | - | - | - | - | - | - |
| Actinolite | 5 | - | } | - | 2 | - | - | - | - |
| Zoisite | - | - | 10} | - | - | - | - | - | - |
| Epidote | 5 | } | - | - | - | - | - | 5 | - |
| Opaques | - | }14 | - | - | - | - | - | 5 | - |
| Unidentified | - | | - | - | - | - | - | - | - |
| Chlorite | - | - | - | - | - | <1 | - | - | - |
| Name | dellenite | dacite porphyry | toscanite | dellenite | dellenite | dellenite or rhyodacite | dellenite | rhyolite | granophyre porphyry |

(1) Sawyers Hill to Tantangara Mountain

(2) North of Tantangara Mountain

(3) North of Blanket Hill

making up Gooandra Creek Diorite. Two small intrusions of acid porphyry in the chert unit of the Temperance Chert are exposed along a westerly-flowing part of the Murrumbidgee River below the mouth of Tantangara Creek.

A small porphyritic acid intrusion was mapped in the Temperance Chert east of Long Plain at G.R. 429512; it appears in outcrop to be a quartz porphyry, probably dacitic.

Tantangara Beds

Minor bodies of acid porphyry intrude the Tantangara Beds northwest of Blanket Hill near Tantangara Creek, in the area sloping down towards Nungar Creek east of Blanket Hill and Blanket Plain, and farther north near the junction of Tantangara Creek with the Murrumbidgee River. Their approximate compositions are given in Table 49. One of those northwest of Blanket Hill (G.R. 415350, T.S. 71840156) is a dacite or quartz keratophyre with less than 1 per cent K-Feldspar. Another is a porphyritic micro-granodiorite with a medium-grained matrix; it contains about 15% K-feldspar.

The minor intrusions west of Nungar Creek are quartz porphyries, probably dacitic. Amongst this group of intrusions, at G.R. 451362, is an outcrop a few metres across of a coarser-grained rock which appears to be biotite granite.

There are similar but slightly larger intrusives on a spur of Peak Back Ridge that trends northwest from the top of Hell Hole Creek. A dyke at least 500 m long forms the crest of the spur and reaches to within 100 m of the summit; it is granophyric at G.R. 431432 (T.S. 71840427), where it has the composition of a dellenite, and rhyolitic at its eastern end (G.R. 434430, T.S. 71840429) near the summit. A dellenite dyke runs north through the ridge at G.R. 436429 (T.S. 71840428) 50 m or so east of the summit. A small intrusion of rhyolite porphyry at G.R. 422445 (T.S. 71840426), on a branch of the spur 1.5 km to the northwest, is similar in composition to T.S. 71840429.

There are other minor acidic intrusions in the general northern area of the Tantangara Beds, not yet mapped in detail; for example, a slightly coarser-grained porphyry occurs at G.R. 421471.

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TABLE 49: MINOR PORPHYRITIC ACID INTRUSIONS IN TANTANGARA BEDS: ESTIMATED MODES

| Intruded rocks | | Tantangara Beds | | | |
|---|---|---|---|---|---|
| General locality | (1) | (2) | | | |
| Thin section No.<br>G.R. | 7180156<br>415350 | 71840426<br>422445 | 71840427<br>431432 | 71840428<br>436429 | 71840429<br>434430 |
| Orthoclase | 1 | 35 | 30 | 35 | 25 |
| Plagioclase | 60 | 15 | 40 | 20 | |
| Quartz | 30 | 45 | 20 | 40 | 25 |
| Chlorite | - | - | 5 | - | 5 |
| Epidote | 10 | - | - | ) 5 | - |
| Sericite | - | - | - | ) | - |
| Opaques | - | - | 5 | - | - |
| Matrix | | | | | Microlites in devitrified glass 45 |
| Name | dacite or quartz kerato-phyre | rhyolite porphyry | granophyric dellenite | dellenite | rhyolite porphyry |

(1) Northwest of Blanket Hill

(2) Peak Back Ridge, north and northwest of Hell Hole Creek

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## Medium to coarse-grained acid intrusions

Small stocks and bosses of medium to coarse-grained acidic rocks intrude the Tantangara Beds on Nattung Hill near the northern boundary of the outcrop of these beds, and also occur at several widely spaced localities in the Temperance Chert and Nine Mile Volcanics. None were found in the Bolton Beds. In their compositions (Table 50) they are close to granodiorite; some with more orthoclase are monzonite and others with less are tonalite.

A rounded mass of coarse-grained granitic rock in the interbedded chert and tuff of the Temperance Chert, at G.R. 399392 on the eastern side of Tantangara Creek, is probably granodiorite. There is a similar intrusion near the top of the unit at G.R. 406459, east of Rules Point. A large boss intrudes the chert unit south of the junction of Tantangara Creek with the Murrumbidgee River. A sample from it at G.R. 410355 (T.S. 71840301) is a quartz monzonite, containing a much higher proportion of mafic minerals than the other acidic intrusions (Tables 48 and 49) with comparably large proportions of K-feldspar. There are small outcrops, probably dykes, of microtonalite near the bottom of the formation at G.R. 372280 (T.S. 71840139) and in the upper part of the chert unit at G.R. 413501 (T.S. 71840368). The latter differs from the usual acidic intrusion, having the composition of a diorite to which quartz and orthoclase have been added.

The Nine Mile Volcanics is intruded by four bodies of medium to coarse-grained acidic rock containing less K-feldspar than those in the Temperance Chert. Approximate compositions are given in Table 50. One, at G.R. 422525 (T.S. 71840517), is a fairly large mass of granodiorite within the interbedded sediment and tuff at the base of the formation. An intrusion in the lava unit at G.R. 355324 (T.S. 71840104) consists of sub-potassic granite with interstitial calcite; it contains many xenoliths of hornfelsed andesite. The lava unit is intruded at two other localities: at G.R. 388418 (T.S. 71840505) there is a probable dyke of microgranodiorite, and at G.R. 357388 (T.S. 71840511) a quartz diorite forms scattered tors in an area 100 m or so across.

The Tantangara Beds are intruded by quartz monzonite at the crest of Nattung Hill (G.R. 450471, T.S. 71840520). This is a medium-grained rock consisting of orthoclase, altered plagioclase, quartz, brown hornblende, hypersthene, and chlorite pseudomophing biotite; graphic intergrowths of quartz and orthoclase are common (Table 50). At a subsidiary crest 100 m to the south-southeast, the intrusion appears to be of microgranodiorite.

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TABLE 50. MINOR MEDIUM TO COARSE-GRAINED ACID INTRUSIONS IN THE TEMPERANCE CHERT, NINE MILE VOLCANICS, AND TANTANGARA BEDS: ESTIMATED MODES

| Intruded rock | Temperance Chert | | | Tantangara Beds | Nine Mile Volcanics | | | |
|---|---|---|---|---|---|---|---|---|
| General locality | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Thin section No. | 71840139 | 71840301 | 71840368 | 71840520 | 71840104 | 71840505 | 71840511 | 71840517 |
| G.R. | 372280 | 410355 | 413501 | 450471 | 355324 | 388418 | 357388 | 422525 |
| Orthoclase | 7 | 20 | 5 | 15 | <1 | 10 | 10 | 10 |
| Plagioclase | 55 | 15 | 40 | 15 | 10 | 10 | 40 | 35 |
| Quartz | 15 | 20 | 15 | 20 | 42 | 22 | 10 | 10 |
| Pyroxene | | 20 | Chlor-itized 35 | 25 | | | 40 | 20 |
| Amphibole | 20 | | | 10 | | 18 | | 10 |
| Biotite | | | | | | 10 | | |
| Chlorite | 3 | - | - | 10 | 20 | 6 | - | 5 |
| Epidote | | - | - | 5 | - | 12 | <1 | 10 |
| Calcite | - | - | 5 | - | 10 | 6 | - | - |
| Actinolite | - | 25 | - | - | - | - | - | - |
| Muscovite | - | - | - | - | 15 | - | - | - |
| Pumpellyite | - | - | - | - | - | 5 | - | - |
| Name | micro-tonalite | quartz micro-monzo-nite | micro-tonalite | quartz monzonite | granite, sub-potassic | micro-grano-diorite | ortho-clase-bearing quartz diorite | granodiorite |

1. North of Sawyers Hill
2. South of mouth of Tantangara Creek
3. East of Jennetts Hut, Long Plain
4. Nattung Hill
5. Charcoal Creek
6. Between Bullock Hill and mouth of Tantangara Creek
7. South of Bullock Hill, west of highway
8. Long Plain, north of mouth of McPhersons Creek

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## Intermediate intrusions

Small bosses of intermediate igneous rock intrude the interbedded chert and tuff of the Temperance Chert in a narrow belt 4.5 km long that extends northwards from a point about 1 km southeast of Gooandra homestead. There are two other small bosses in the same general area, one 1.5 km southeast of the main belt near the junction of Kiandra and Tantangara Creeks, and the other 500 m east of the middle part of the belt. Monzonite associated with basic rocks northwest of Sawyers Hill and in the Gooandra Inlier, is described under 'Basic and Intermediate Intrusions'.

Intermediate intrusions are not plentiful elsewhere in the mapped area. There are scattered small ones between Sawyers Hill and Tantangara Mountain, in the Bolton Beds west of Blanket Hill, in the interbedded chert and tuff of the Temperance Chert near the northern end of the Monaro Range, and in the Tantangara Beds at Nattung Hill.

### Gooandra Creek Diorite

There are six intrusive bosses in a narrow north-trending belt between points 1.5 km southeast and 3.5 km north-northeast of Gooandra Homestead; the largest is 2.5 km long and nearly 1 km wide. It is proposed that these intrusions be named the Gooandra Creek Diorite, from Gooandra Creek just west of the bodies. The type locality is a steep hill that forms a cliff at the west bank of Tantangara Creek, 1 km due east of the abandoned 'Gooandra' homestead. One of the smaller intrusions at the northern end of the belt (G.R. 404400, T.S. 71840299) is a monzonite; a larger intrusive immediately south of it is an orthoclase-bearing quartz diorite. The intrusion at Kiandra Creek (G.R. 408345, T.S. 71840280) is an orthoclase-bearing diorite. Approximate compositions for these are given in Table 51; The remainder were not sampled, but appear to be similar in composition.

### Sawyers Hill to Tantangara Mountain

Medium to moderately coarse-grained intermediate intrusives crop out at two localities on the ridge immediately west of Sawyers Hill, above the Eucumbene River. Fine to medium-grained porphyritic intrusions and a very fine-grained non-porphyritic intrusion have been mapped on the ridge north of Sawyers Hill and northwest of Tantangara Mountain. Their compositions are summarized in Table 51. At the northern end of the ridge west of Sawyers Hill (G.R. 365266, T.S. 71840028), coarse-grained orthoclase-bearing diorite occurs

TABLE 51. INTERMEDIATE INTRUSIONS: ESTIMATED MODES

| Intruded Rock | Temperance Chert | | | | | | | Boltons Beds | | | Tantangara Beds |
|---|---|---|---|---|---|---|---|---|---|---|---|
| General locality | GOOANDRA CREEK DIORITE (1) | | | (2) | | (3) | (2) | | | (4) | (5) |
| Thin section No. G.R. | 71840280 408345 | 71840297 406392 | 71840299 404400 | 71840140 372283 | 71840037 379289 | 71840236 401331 | 71840028 365266 | 71840030 363253 | 71840076 395291 | 71840166 420332 | 71840518 446477 |
| Orthoclase | 10 | 10 | 25 | 25 | ? | 25 | 20 | 25 | 15 | 20 | 35 |
| Plagioclase | 47 | 30 | 30 | 45 | 45 | 20 | 45 | 15 | 42 | 30 | 40 |
| Quartz | - | 5 | 2 | 10 | - | 1 | 1 | 10 | 5 | 5 | 4 |
| Pyroxene | - | 25 | 35 | - | - | altered 7 | - | 10 | - | )20 | - |
| Amphibole | 37 | 20 | - | 20 | 30 | 35 | 20 | 10 | - | ) | 6 |
| Biotite | - | - | altered 5 | - | - | - | - | 10 | - | 15 | - |
| Chlorite | ) | - | 2 | - | <1 | - | 10 | - | - | - | - |
| Opaques | )5 | 5 | - | - | - | - | - | - | - | - | - |
| Epidote | ) | 5 | - | - | - | - | 1 | - | 2 | - | - |
| Calcite | - | - | - | - | - | ) | - | - | - | - | - |
| Actinolite | - | - | 1 | - | 4 | )10 | - | 20 | 35 | - | 10 |
| Pumpellyite | - | - | - | - | - | - | - | - | - | 10 | - |
| Matrix of Chlorite) and plagioclase ) | - | - | - | - | )20 ) | - | - | - | - | - | - |
| Name | orthoclase-bearing diorite | orthoclase-bearing pyroxene diorite | monzonite | orthoclase-bearing micro-diorite | andesite | lamprophyre (spessartite or vogesite) | orthoclase-bearing diorite | monzonite | trachy-andesite | orthoclase-bearing diorite or micro-monzonite | trachy-andesite or lampro-phyre |

(1) Tantangara Plain
(2) Sawyers Hill to Tantangara Mountain
(3) Near northern end of Monaro Range
(4) West of Blanket Hill
(5) North-northwest of Nattung Hill

Tantangara Plain Diorite, and near the top of the Temperance Chert south-east of Rules Point. No basic intrusives were found higher in the stratigraphic sequence, either in the Nine Mile Volcanics or the Tantangara Beds.

The basic rocks are nearly all moderately coarse-grained; exceptionally, they are porphyritic and have a medium-grained matrix. Some are gabbro and basic monzonite, others are almost intermediate in composition being a little more basic than the diorite and orthoclase-bearing diorite.

Sawyers Hill

Three samples were obtained from the dyke or sill near Sawyers Hill that separates the Bolton Beds and Temperance Chert. Approximate compositions are given in Table 52. One (G.R. 377278, T.S. 71840011) is a meta-gabbro without any K-feldspar; another (G.R. 376275, T.S. 71840007) is a diorite with about 5% K-feldspar; the third (G.R. 365266, T.S. 71840028) is an orthoclase-bearing diorite with about 10% K-feldspar. The minor intrusions in the Bolton Beds include a monzonite with 35% K-feldspar forming an outcrop 100 m or so across (G.R. 388288, T.S. 71840057), and a smaller intrusion (G.R. 389286, T.S. 71840053) also of monzonite. There is a minor basic dyke in the interbedded chert and tuff northwest of T.S. 71840057, about 600 m above the boundary with the Bolton Beds.

The approximate compositions of the basic and intermediate intrusives near Sawyers Hill and Tantangara Mountain are given in Table 52.

Other Localities

There are two fairly large monzonitic intrusions in the interbedded chert and tuff that surrounds the Bolton Beds of the 'Gooandra Inlier'; the approximate composition of one that was sampled (G.R. 413362, T.S. 71840283) is given in Table 52 which also gives the composition of three of several minor monzonite intrusions that occur on either side of the margin of the inlier.

The minor basic to intermediate intrusions in the interbedded chert and tuff near Boggy Plain Fault include monzonite near Boggy Plain (G.R. 421317, T.S. 71840290), and northwest of the junction of Kiandra and Tantangara Creeks (G.R. 401354, T.S. 71840237). Their approximate compositions are given in Table 52. At the latter locality a second small intrusion, of porphyritic augite microdiorite (G.R. 400354, T.S. 71840150), is similar in composition to the nearby Gooandra Creek Diorite. The interbedded in a displaced segment of a large dyke or sill, predominantly basic in composition, at the boundary between the Bolton Beds and Temperance Chert (Table 52). At the southern end of the ridge (G.R. 363253, T.S. 71840030) Bolton Beds are intruded by a dyke of medium-grained monzonite about 20 m thick.

Of the porphyritic intrusions, two are in interbedded chert and tuff north of Sawyers Hill; one (G.R. 372283, T.S. 71840140) is an orthoclase-bearing quartz diorite, the other (G.R. 379289, T.S. 71840037) a fine-grained andesite, presumably a thin dyke. Two narrow dykes intrude the Bolton Beds north-northwest and west of Tantangara Mountain: one (G.R. 395291 T.S. 71840076) is an even-grained, very fine-grained trachy-andesite similar in composition to the orthoclase-bearing diorites: the other was not sampled but appeared to be intermediate or basic in composition.

Other localities

In the area mapped there are three more small intermediate intrusions whose compositions are summarized in Table 51. One, near the northern end of the Monaro Range (G.R. 401331, T.S. 71840236) in the interbedded chert and tuff, has a typical lamprophyric texture: well-formed euhedral phenocrysts of hornblende, in the shapes of acute wedges and prisms, are embedded in a fine matrix of orthoclase, plagioclase, and minor quartz. West of Blanket Hill, an orthoclase-bearing diorite or monzonite (G.R. 420332, T.S. 71840166) intrudes the Bolton Beds; the texture of its matrix is in part monzonitic. In the northern part of the area mapped, 900 m north-northwest of Nattung Hill at G.R. 446477 (T.S. 71840518), a small ?dyke of trachyandesite or lamprophyre intrudes the Tantangara Beds. Phenocrysts of sericitized K-feldspar and altered amphibole are embedded in a very fine-grained matrix of plagioclase, orthoclase, and wedge-shaped hornblende. The texture tends towards lamprophyric.

## Basic to intermediate intrusions

Below the northwest side of Sawyers Hill, an intrusion of intermediate to basic rock separates the Temperance Chert from the Bolton Beds. Minor basic intrusions are present in each of the outcrop areas of the Bolton Beds; they are also in the interbedded chert and tuff near its boundary with the Bolton Beds, and at scattered localities near the Boggy Plain Fault, near the

TABLE 52. BASIC TO INTERMEDIATE INTRUSIONS; ESTIMATED MODES

| Intruded rock | Boltons Beds | | | | | | Temperance Chert | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| General locality | (1) | (2) | | | | | (1) | | | (3) | | | (4) | | (5) |
| | | Minor intrusions | | Large dyke or sill | | | Large intrusion | Small intrusions | | | | | | | |
| Thin section No.<br>G.R. | 71840291<br>431361 | 71840053<br>389286 | 71840057<br>388288 | 71840007<br>376275 | 71840011<br>377278 | 71840028<br>365266 | 71840283<br>413362 | 71840240<br>420362 | 71840241<br>416359 | 71840150<br>400354 | 71840237<br>401354 | 71840290<br>421317 | 71840504<br>402450 | 71840506<br>392408 | 71840507<br>399380 |
| Orthoclase | 20 | 15? | 37 | 5 | - | 20 | 30 | 20 | 25 | 10 | 25 | 30 | 10 | 10? | <1 |
| Plagioclase | 15? | 15? | 32 | 25 | - | 46 | 30 | 25 | 25 | 40 | 15 | 15 | 30 | 30 | 42 |
| Quartz | - | - | - | 2 | - | 1 | - | - | - | - | - | - | <2 | 1 | - |
| Pyroxene | - | 15 | 20 | - | 5 | - | 30 | 40 | 35 | 30 | 45 | 55 | 40 | 49 | 57 |
| Amphibole | 40 | - | - | 45 | 15 | 21 | - | - | - | - | - | - | - | - | - |
| Biotite | - | - | 5 | - | - | - | 2 | - | - | - | - | - | - | - | - |
| Actinolite | 10 | 20 | 5 | - | 37 | - | - | ) | - | - | - | - | - | - | - |
| Epidote | 10 | 20 | - | 10 | 32 | 1 | - | )8 | - | - | - | - | 15 | - | - |
| Chlorite | 5 | 10 | - | 5 | 5 | 10 | - | - | 5 | 15 | 10 | - | - | 5 | - |
| Opaques | - | - | - | 10 | 5 | - | 5 | 5 | 10 | - | 5 | - | 5 | 5 | - |
| Name | monzonite or ortho-clase-bearing diorite | monzo-nite | monzo-nite | diorite | gabbro | ortho-clase-bearing diorite | micro-monzo-nite | monzonite or orthoclase-bearing gabbro | | ortho-clase-bearing augite diorite | monzo-nite or ortho-clase-bear-ing gabbro | monzo-nite | ortho-clase-bearing gabbro | ortho-clase-bearing gabbro | gabbro |

1. 'Gooandra Inlier' 2 km west of Gooandra homestead
2. Sawyers Hill to Tantangara Mountain
3. Near Boggy Plain Fault
4. East-southeast and southeast of Rules Point
5. Northern margin of Tantangara Plain

chert and tuff is intruded also by a small body of gabbro (G.R. 399388, T.S. 71840507) west of the central part of the Tantangara Plain Diorite, and by orthoclase-bearing gabbro at two localities, one (G.R. 392408, T.S. 71840506) west of the northern end of the diorite belt and the other (G.R. 402450, T.S. 71840504) near the top of the unit east-southeast of Rules Point. The approximate compositions of these minor intrusions are given in Table 52.

GEOCHEMISTRY OF MINOR INTRUSIONS (M.S.)

Eight samples were collected from minor intrusions, but as many of the outcrops were too weathered for reliable geochemical sampling, they may not be representative of the range of composition of all the intrusions. The more acid intrusions in particular were highly weathered, and so no samples containing more than 70% silica were analysed, even though many of the intrusions are rhyolite or granophyre. Results are tabulated in Table 53.

These minor intrusions are related to the rocks of the Cooleman area and therefore have been plotted on the variation diagrams with the Coolamine Igneous Complex, Jackson Granite, Gurrangorambla Granophyre, and Mountain Creek Volcanics (Fig. 35).

The results are very scattered, as are the Coolamine Igneous Complex samples; for instance the rocks containing about 50% silica have widely differing percentages of the other oxides. The reason for this could be that such small intrusions would be easily contaminated by country rocks during intrusion. Alteration is shown in thin section by the presence of actinolite, chlorite, and epidote.

Because the range of composition is very wide, the norms vary considerably between samples. The more acid samples contain normative quartz and corundum; one of the most basic rocks contains normative nepheline, and several basic rocks contain normative olivine. The $K_2O/Na_2O$ ratio varies from 0.13 (sample 71840156) to 1.82 (sample 71840057); this difference in alkali content may be due to alteration.

TABLE 53. ANALYSES AND CIPW NORMS FROM MINOR INTRUSIONS

| Sample No.<br>Rock type<br>G.R. | 71840057<br>monzonite<br>388288 | 71840071<br>dacite<br>409297 | 71840156<br>dacite<br>413349 | 71840240<br>monzonite<br>421363 |
|---|---|---|---|---|
| % | | | | |
| $SiO_2$ | 50.2 | 69.1 | 68.7 | 50.3 |
| $Al_2O_3$ | 11.2 | 14.7 | 14.5 | 11.1 |
| $Fe_2O_3$ | 3.25 | 0.70 | 0.35 | 2.35 |
| FeO | 6.7 | 3.85 | 4.0 | 7.15 |
| MgO | 9.4 | 1.1 | 1.45 | 9.9 |
| CaO | 12.9 | 3.5 | 3.8 | 11.9 |
| $Na_2O$ | 1.29 | 4.35 | 4.2 | 1.29 |
| $K_2O$ | 2.35 | 1.12 | 0.54 | 2.45 |
| $H_2O+$ | 1.45 | 0.70 | 1.02 | 2.05 |
| $H_2O-$ | 0.09 | 0.05 | 0.09 | 0.06 |
| $CO_2$ | 0.25 | 0.10 | 0.1 | 0.15 |
| $TiO_2$ | 0.41 | 0.51 | 0.53 | 0.45 |
| $P_2O_5$ | 0.30 | 0.11 | 0.13 | 0.34 |
| MnO | 0.21 | 0.06 | 0.09 | 0.22 |
| | 100.00 | 99.95 | 99.50 | 99.71 |
| Qz | - | 28.58 | 30.15 | - |
| C | - | 0.47 | 0.65 | - |
| Or | 14.10 | 6.67 | 3.24 | 14.83 |
| Ab | 11.08 | 37.09 | 36.10 | 11.18 |
| An | 18.11 | 16.14 | 17.65 | 17.69 |
| (Wo | 18.07 | - | - | 16.51 |
| D( En | 11.98 | - | - | 10.69 |
| (Fs | 4.78 | - | - | 4.71 |
| Hy( En | 8.03 | 2.76 | 3.67 | 9.31 |
| (Fs | 3.20 | 5.81 | 6.45 | 4.10 |
| (Fo | 2.63 | - | - | 3.68 |
| Ol (Fa | 1.16 | - | - | 1.79 |
| Mt | 4.79 | 1.02 | 0.52 | 3.49 |
| Il | 0.79 | 0.98 | 1.02 | 0.88 |
| Ap | 0.72 | 0.26 | 0.31 | 0.83 |
| Cc | 0.58 | 0.23 | 0.23 | 0.35 |

TABLE 53 (Continued)

| Sample No. | 71840283 | 71840297 | 71840429 | 71840506 |
|---|---|---|---|---|
| Rock type | monzonite | diorite | rhyolite porphyry | monzonite |
| G.R. | 412363 | 407393 | 436431 | 392408 |
| % | | | | |
| $SiO_2$ | 51.0 | 59.5 | 67.0 | 50.6 |
| $Al_2O_3$ | 13.9 | 18.2 | 14.5 | 13.0 |
| $Fe_2O_3$ | 1.35 | 1.90 | 0.50 | 2.8 |
| FeO | 7.5 | 3.1 | 4.05 | 6.6 |
| MgO | 7.2 | 2.4 | 2.1 | 8.2 |
| CaO | 9.0 | 5.55 | 2.1 | 10.2 |
| $Na_2O$ | 2.3 | 3.95 | 2.6 | 2.0 |
| $K_2O$ | 4.0 | 2.85 | 3.85 | 3.1 |
| $H_2O+$ | 1.88 | 1.26 | 1.94 | 2.3 |
| $H_2O-$ | 0.11 | 0.05 | 0.09 | 0.03 |
| $CO_2$ | 0.10 | 0.10 | 0.05 | 0.15 |
| $TiO_2$ | 0.52 | 0.35 | 0.68 | 0.46 |
| $P_2O_5$ | 0.45 | 0.24 | 0.13 | 0.37 |
| MnO | 0.20 | 0.14 | 0.08 | 0.20 |
| | 99.51 | 99.59 | 99.67 | 100.01 |
| Qz | - | 9.95 | 27.94 | - |
| C | - | - | 2.73 | - |
| Or | 24.23 | 17.13 | 23.30 | 18.75 |
| Ab | 18.12 | 33.99 | 22.52 | 17.32 |
| An | 16.20 | 23.93 | 9.47 | 17.75 |
| Ne | 0.99 | - | - | - |
| Di( Wo | 10.82 | 0.77 | - | 12.78 |
| Di( En | 6.17 | 0.45 | - | 8.17 |
| Di( Fs | 4.19 | 0.28 | - | 3.77 |
| Hy( En | - | 5.63 | 5.35 | 4.29 |
| Hy( Fs | - | 3.59 | 6.20 | 1.98 |
| Ol( Fo | 8.56 | - | - | 5.91 |
| Ol( Fa | 6.40 | - | - | 3.01 |
| Mt | 2.01 | 2.80 | 0.74 | 4.16 |
| Il | 1.01 | 0.68 | 1.32 | 0.89 |
| Ap | 1.09 | 0.58 | 0.32 | 0.90 |
| Cc | 0.23 | 0.23 | 0.12 | 0.35 |

## SUMMARY OF REGIONAL IGNEOUS ROCK GEOCHEMISTRY

(M.S.)

### 1. Variation Diagrams

a) FMA diagram The FMA daigram is the variation diagram most commonly used to defferentiate between the three main magmatic lineages; tholeiitic, alkalic, and calcalkalic.

The Ordovician Nine Mile Volcanics (Fig. 36) do not show any definite trend-lines as the very few samples analysed do not have a large spread in composition. The FMA diagram therefore cannot be used to classify the Nine Mile Volcanics.

The rocks of the Cooleman area - the Coolamine Igneous Complex, Mountain Creek Volcanics (including the Rolling Grounds Latite), Jackson Granite, Gurrangorambla Granophyre, and minor intrusions - have been plotted together with the Boggy Plain Granite in Figure 37. These rocks fit a calcalkaline trend as they lack the iron-enrichment curve towards the F apex, (and the 01' -Ne' - Q' diagram precludes an alkaline composition). Also reproduced are the limits of Kuno's 'hypersthenic series' (Kuno, 1968) of calcalkaline rocks from Japan, which show the same trend-line as the Tantangara rocks. The trend-line is most definite near the A apex where the Jackson Granite and Gurrangorambla Granophyre are clustered closely together over a narrow range of composition. The Coolamine Igneous Complex samples show the most scatter from the trend-line and also to be closer to the F apex than the other samples of comparable composition.

The Gingera Granite, McLaughlin Flat Granodiorite, Murrumbidgee Batholith, and Kellys Plain Volcanics are plotted on one diagram (Fig. 37), on which Kuno's 'hypersthenic series' has again been superimposed. (Murrumbidgee Batholith analyses on this and the following diagrams are those taken from Joyce's (1971) thesis, and the norms were calculated by BMR). The samples are of calcalkaline composition and show very little scatter from the trend-line. The trend-line can be superimposed on that of the Cooleman area rocks and easily fits within the limits of Kuno's 'hypersthenic series'. The Kellys Plain Volcanics show a little scatter which is probably due to post-depositional alteration.

The Goobarragandra Beds and Young Granodiorite also fit a calc-alkaline trend-line (Fig. 36). This line is slightly different from the two previous calcalkaline groups as the F component is more constant whilst M and A are

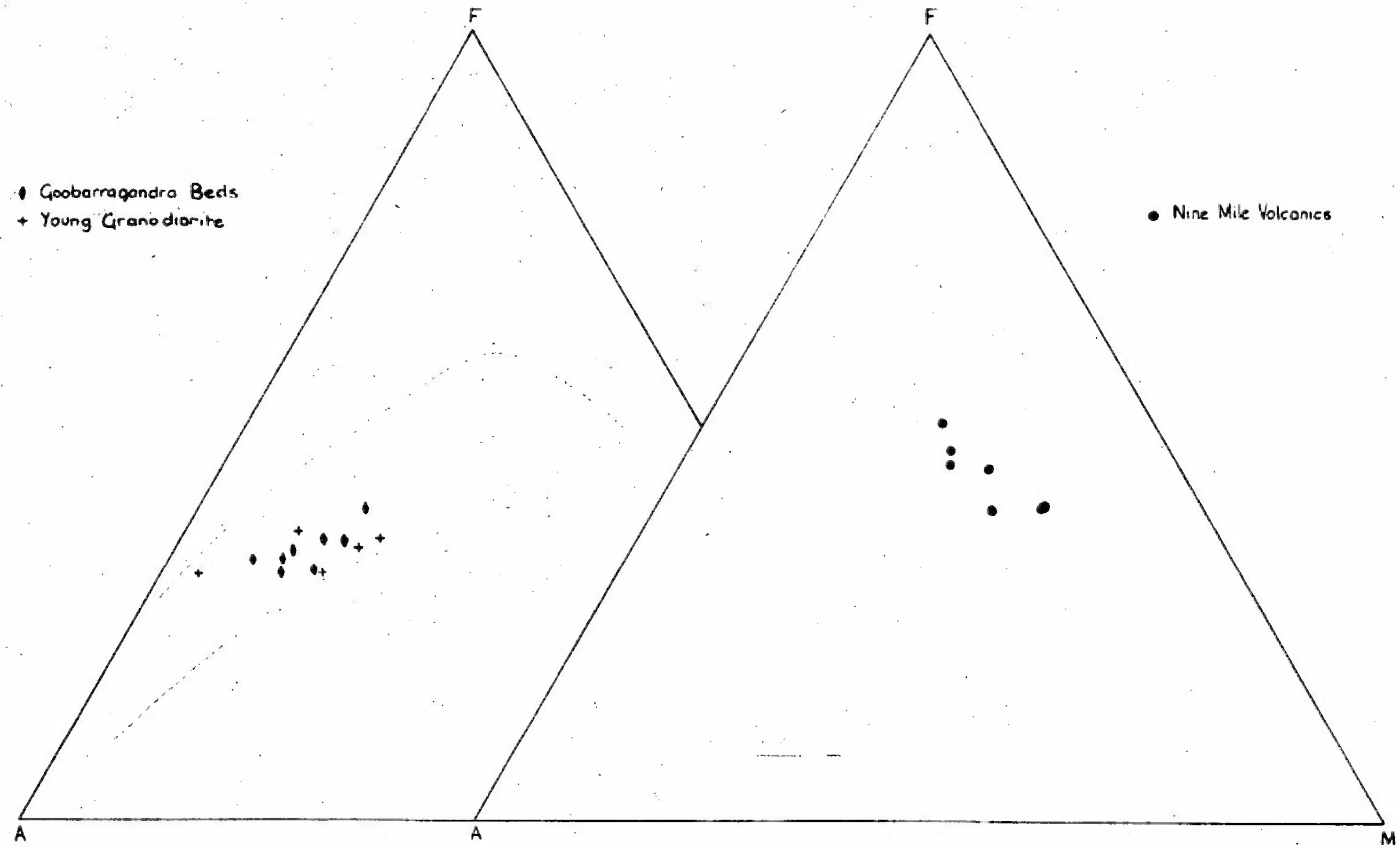


Fig. 36. FMA diagrams for the Nine Mile Volcanics, Goobarragandra Beds and Young Granodiorite
The dashed lines indicate Kuno's 'hypersthenic series'

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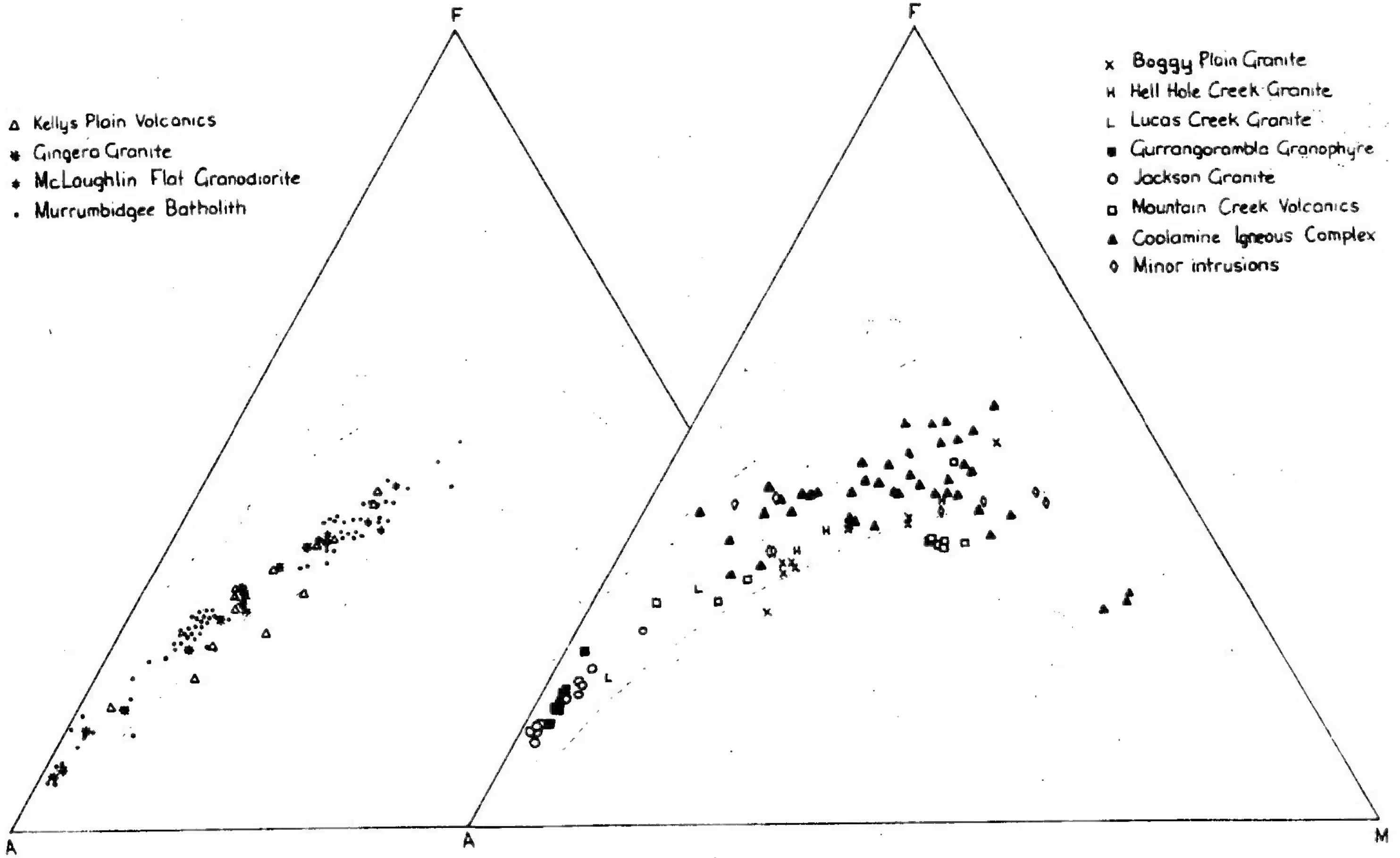


Fig. 37 FMA diagrams for rocks of the Cooleman area, Boggy Plain Granite, Kellys Plain Volcanics, Gingera Granite, McLoughlin Flat Granodiorite and Murrumbidgee Batholith.

The dashed lines indicate Kuno's "hypersthenic series"

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changing; however, more samples would be needed to attach any significance to this.

b) Alkali-silica diagram. The alkali-silica diagram (Fig. 38) is commonly used to distinguish between tholeiitic and alkaline rocks. Rocks falling in the field between the two types may be transitional between tholeiitic and alkaline, or they may be high-alumina basalts. Calcalkaline rocks tend to fall in this intermediate field or in the tholeiitic field.

On this diagram the Nine Mile Volcanics fall in the alkaline field. However, care must be taken in the acceptance of this result as these rocks have been affected by burial metamorphism. That the amounts of sodium and potassium may have been altered is suggested by the large range in alkali percentage for a small range of silica variation.

Very few of the other samples fall in the alkaline field, with about half lying in the tholeiitic region and half in the transitional field. The Gingera Granite, McLaughlin Flat Granodiorite, Goobarragandra Beds, and Young Granodiorite fall almost entirely in the tholeiitic field, whilst the other suites fall in both fields, and two samples from the minor intrusions lie in the alkaline field. So although it is difficult to say from the alkali-silica diagram whether the rocks are calcalkaline, it shows that they are definitely not alkaline.

c) Alkali-alumina diagram. The alkali-alumina diagram (Kuno, 1968) is very similar to the previous diagram, although it tends to separate out high-Al basalts more clearly. It has been used here for the Nine Mile Volcanics only (Fig. 39) in the hope of deciding their magmatic lineage. Five rocks fall in the alkali olivine basalt field, while only two fall in the tholeiitic field. However, from thin section evidence these two are the least altered rocks sampled, and they come from a sill intruding the volcanics, so it is possible that they represent the closest remaining approach to the original composition of the magma. The tholeiitic affinities of the Nine Mile Volcanics are suggested by their low titania contents (Table 20), which are characteristic of island arc tholeiites (e.g. Jakes & White, 1972). The absence of olivine and titanaugite in thin section also indicates that these rocks are not alkali olivine basalts.

d) Ol'-Ne'-Q' diagram. The purpose of the Ol'-Ne'-Q' diagram (which is a projection of the Cpx-Ol-Ne-Q tetrahedron) is to distinguish between alkaline and subalkaline rocks (as the plane Cpx-Ol-Ab is very close to the thermal divide) and to distinguish between rocks with Ne (critically undersaturated), Opx + Ol (undersaturated) and Opx + Q (oversaturated) in the norm. The dividing line between subalkaline and alkaline rocks used here is that of Irvine & Baragar (1971).

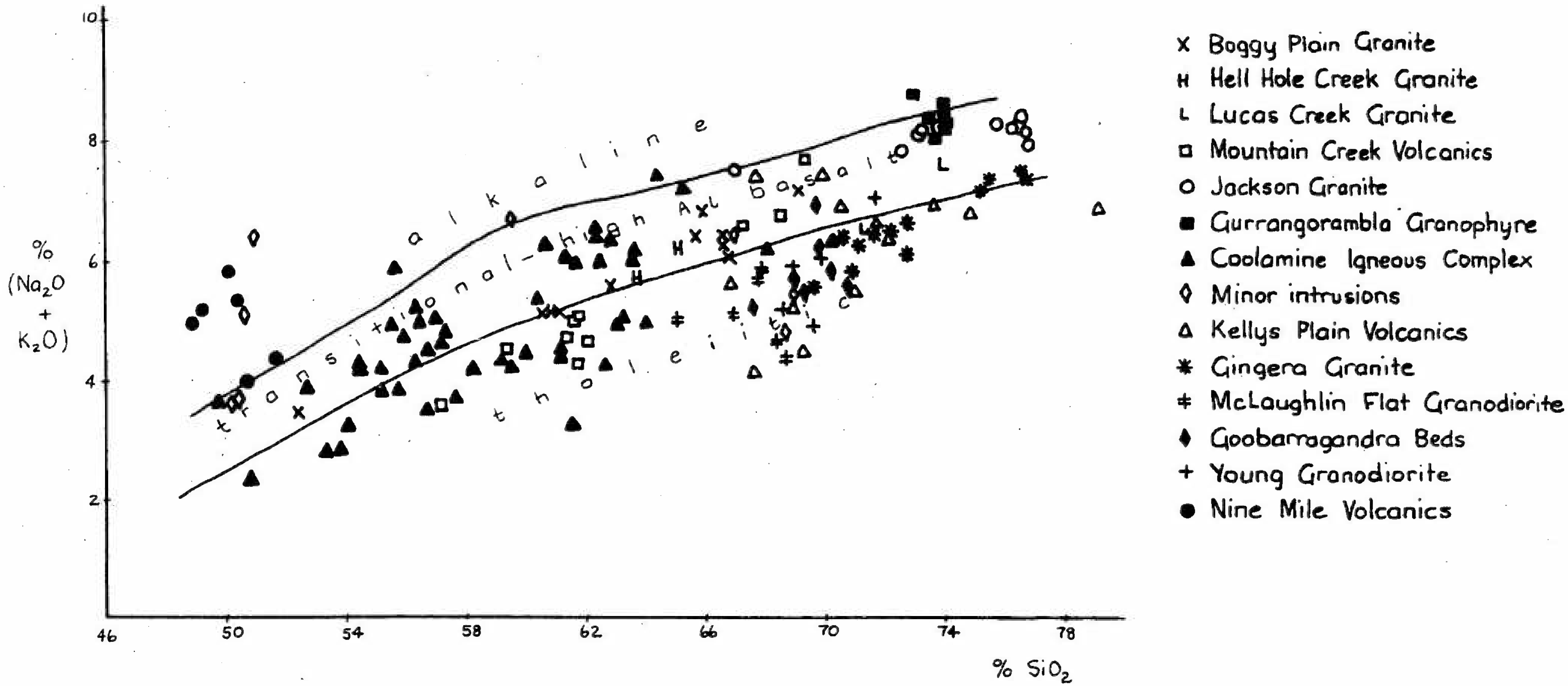


Fig. 38. Alkali - silica diagram for the igneous rocks (after Kuno, 1968)

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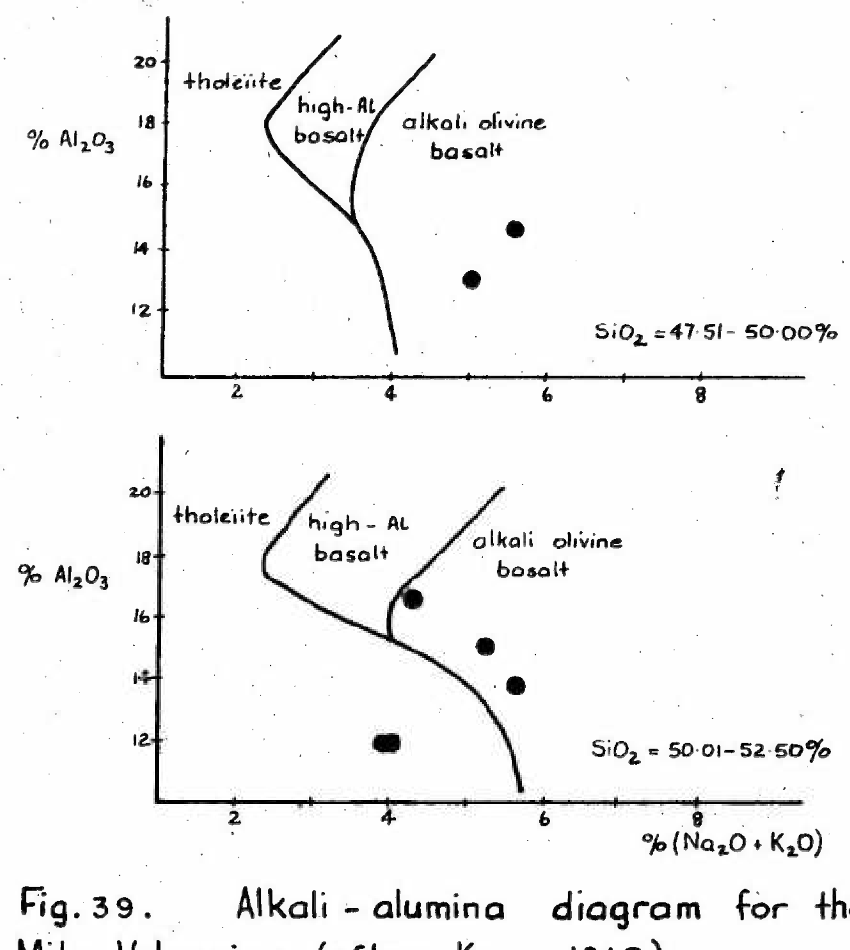


Fig. 39. Alkali - alumina diagram for the Nine Mile Volcanics (after Kuno, 1968).

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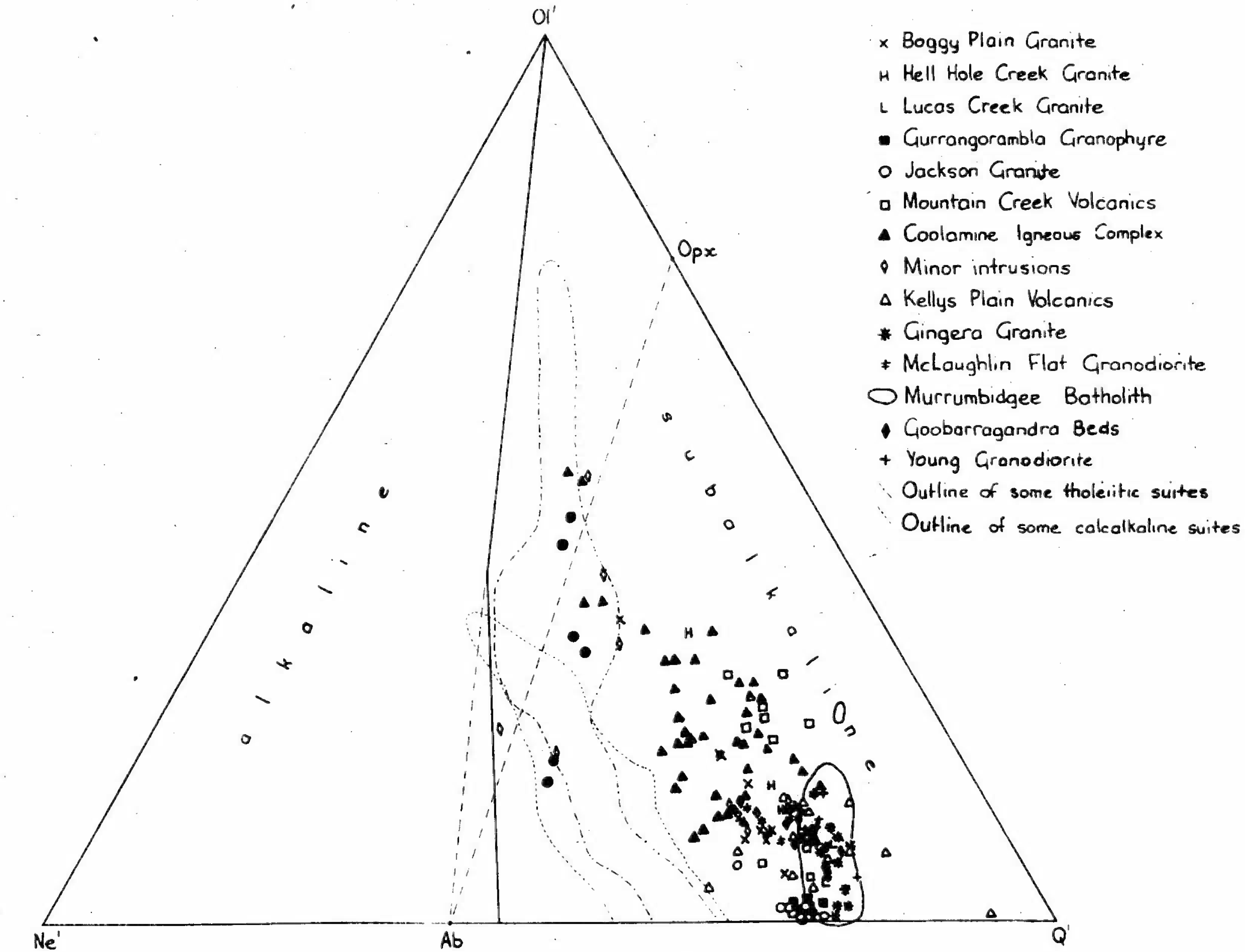


Fig. 40. Ol'-Ne'-Q' diagram showing all the samples analysed.

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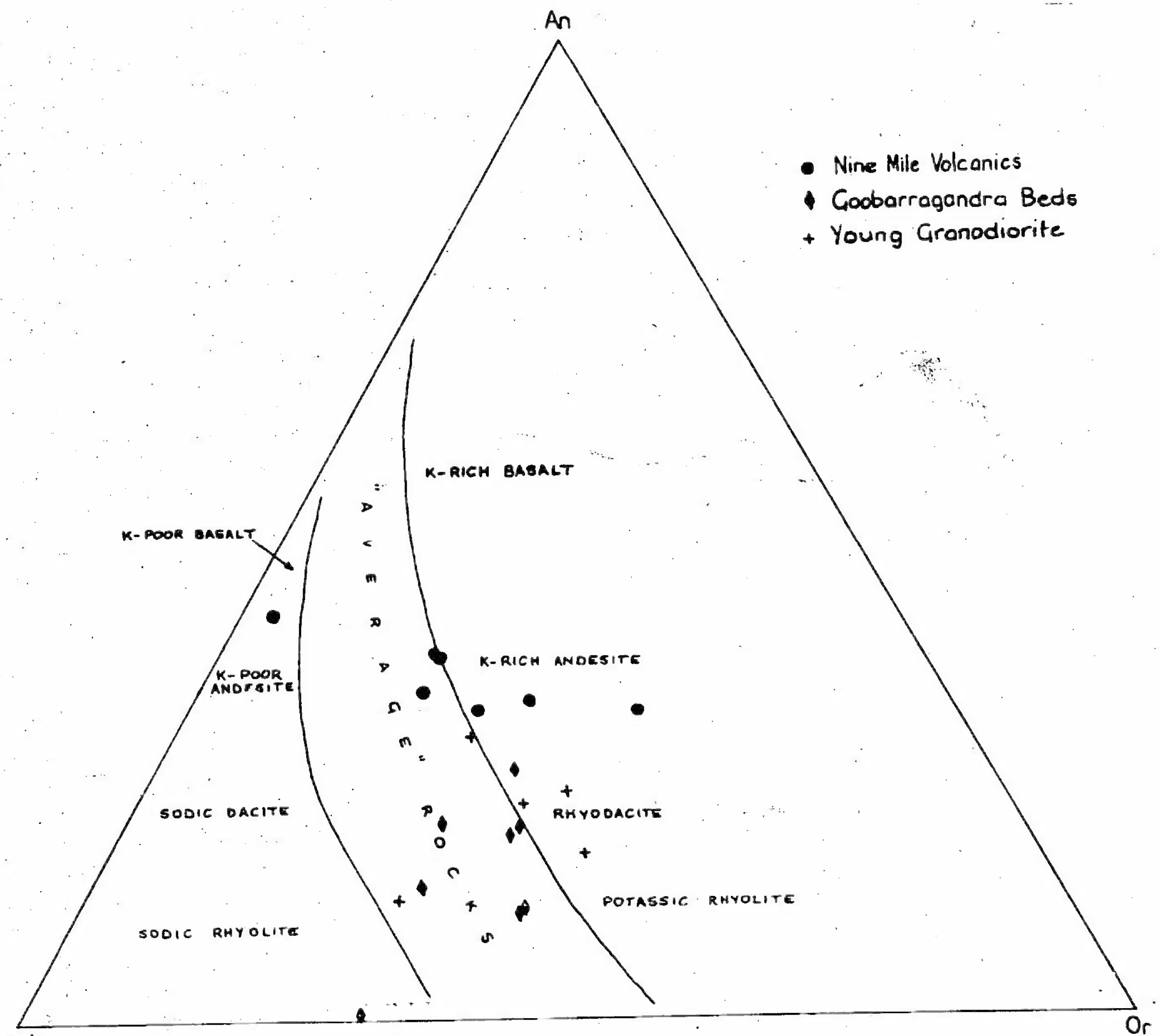


Fig. 41. An-Ab'-Or diagram for the Nine Mile Volcanics, Goobarragandra Beds and Young Granodiorite

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All the rocks analysed fall in the subalkaline field (Fig. 40) and none are nepheline-normative. In this diagram therefore, the Nine Mile Volcanics do not fall in the alkaline field as in the alkali-silica or alkali-alumina diagrams. This diagram is more convincing than the other two as more components are taken into account, but the alteration undergone by the rocks makes any definite statement a risk. Within the suite the Ne'/Q' ratio remains fairly constant while the amount of olivine changes over the composition range. The rocks fall in the normative Ol'-Opx-Ab or the Opx-Q'-Ab fields. Tholeiitic rocks from the Mid-Atlantic, Columbia River, Hawaii and Thingmuli are delineated on the diagram (after Irvine & Baragar, 1971) and the Nine Mile Volcanics trend is similar to these rocks.

The other igneous rocks from the Tantangara sheet fall much nearer the quartz apex. Apart from four rocks all are Ab-Opx-Q' normative. The Jackson Granite, Gurrangorambla Granophyre, Gingera Granite, Murrumbidgee Batholith, and Young Granodiorite fall over a restricted area, whilst the less acid rocks tend to be more scattered. Calcalkaline rocks from the Cascades, Mt. Hood, the Aleutians, and Paricutin (after Irvine & Baragar, 1971) are delineated on the diagram, and follow a similar pattern to the Tantangara rocks although the latter are closer to the Ol'-Q' join. The distinction between tholeiitic and calcalkaline patterns is fairly clear on this diagram.

e) Ab'-An-Or diagram. The Ab'-An-Or diagram is used to distinguish between sodic and potassic rocks. The subdivision used here (Figs. 41-43) is after Irvine & Baragar (1971) and is used for subalkaline (i.e. tholeiitic or calcalkaline) rocks.

The Nine Mile Volcanics do not fit the natural subdivision formed by the other rocks. The An (i.e. calcium) content is fairly constant (Fig. 41) in all samples whilst Ab' or Or vary, so that the samples vary from K-rich to K-poor. This is due to the alteration in these rocks, as noted earlier.

The Goobarragandra Beds and Young Granodiorite samples (Fig. 41) fall in the potassium-rich and the 'average' fields, although one Goobarragandra Beds sample falls in the sodic field with less than 1% anorthite. This last sample, however, has been albitized and calcitized so the normative composition does not give a true indication of its original composition.

Most of the rocks from the Cooleman area (Fig. 42) fall in the K-rich field, apart from the more acid rocks, i.e. the Jackson Granite and Gurrangorambla Granophyre. The trend in the Tantangara area does not completely follow the natural subdivision of rocks because at the more acid end the trend of the Tantangara rocks does not curve towards the Or apex.

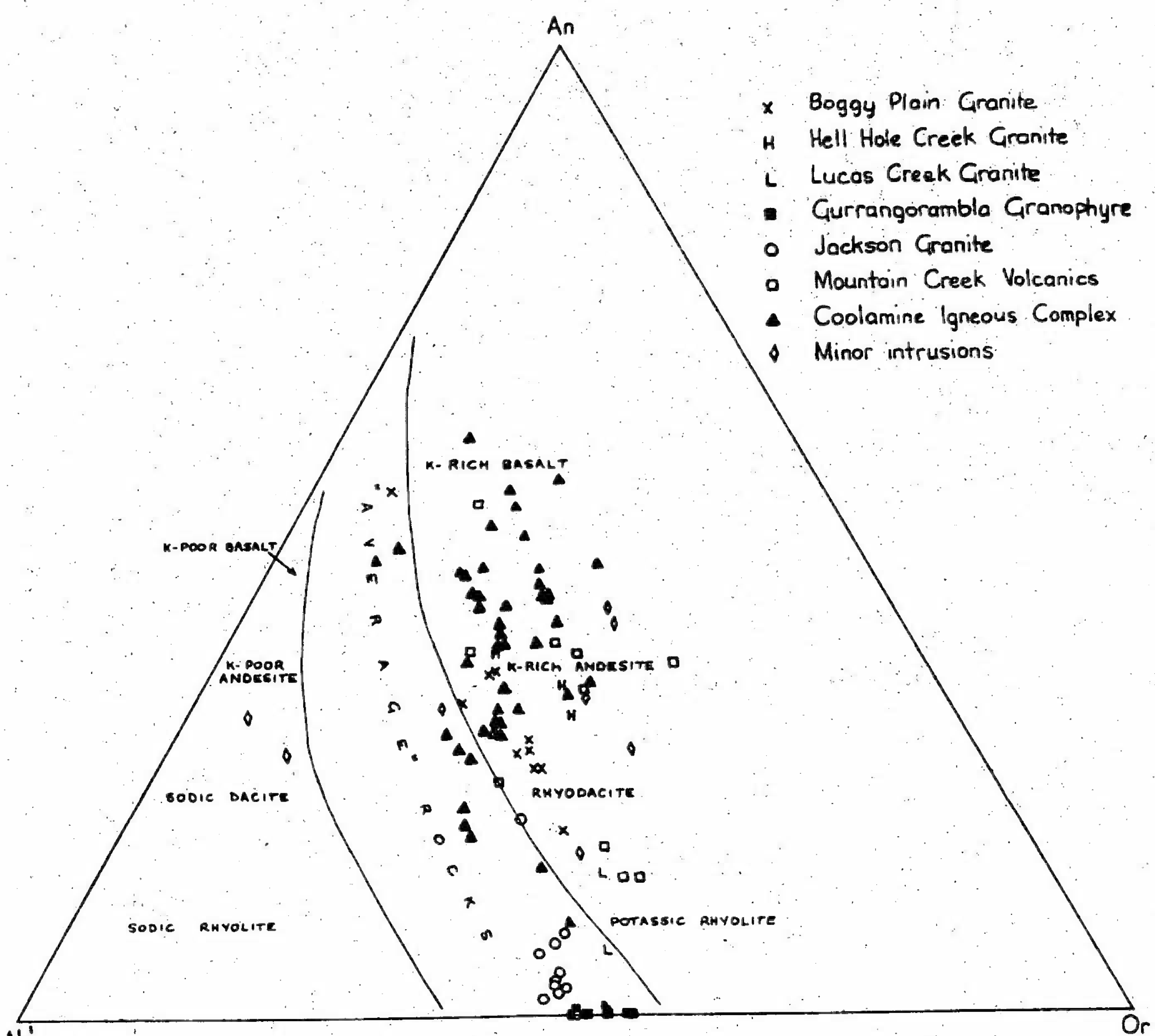


Fig. 42. An-Ab'-Or diagram for the Boggy Plain Granite and Cooleman area rock units.

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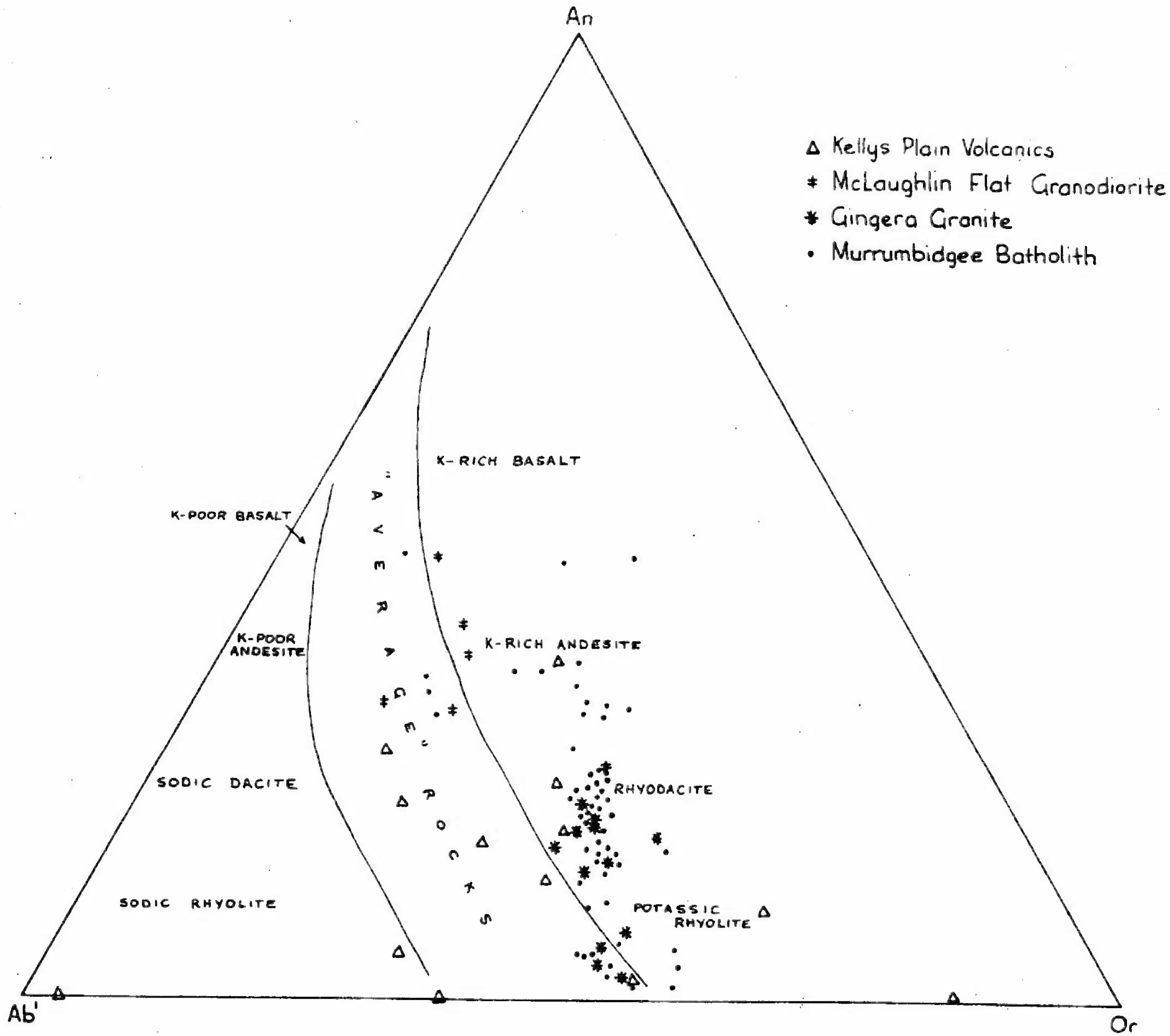


Fig. 43. An-Ab'-Or diagram for the Kellys Plain Volcanics, Gingera Granite, McLaughlin Flat Granodiorite and Murrumbidgee Batholith.

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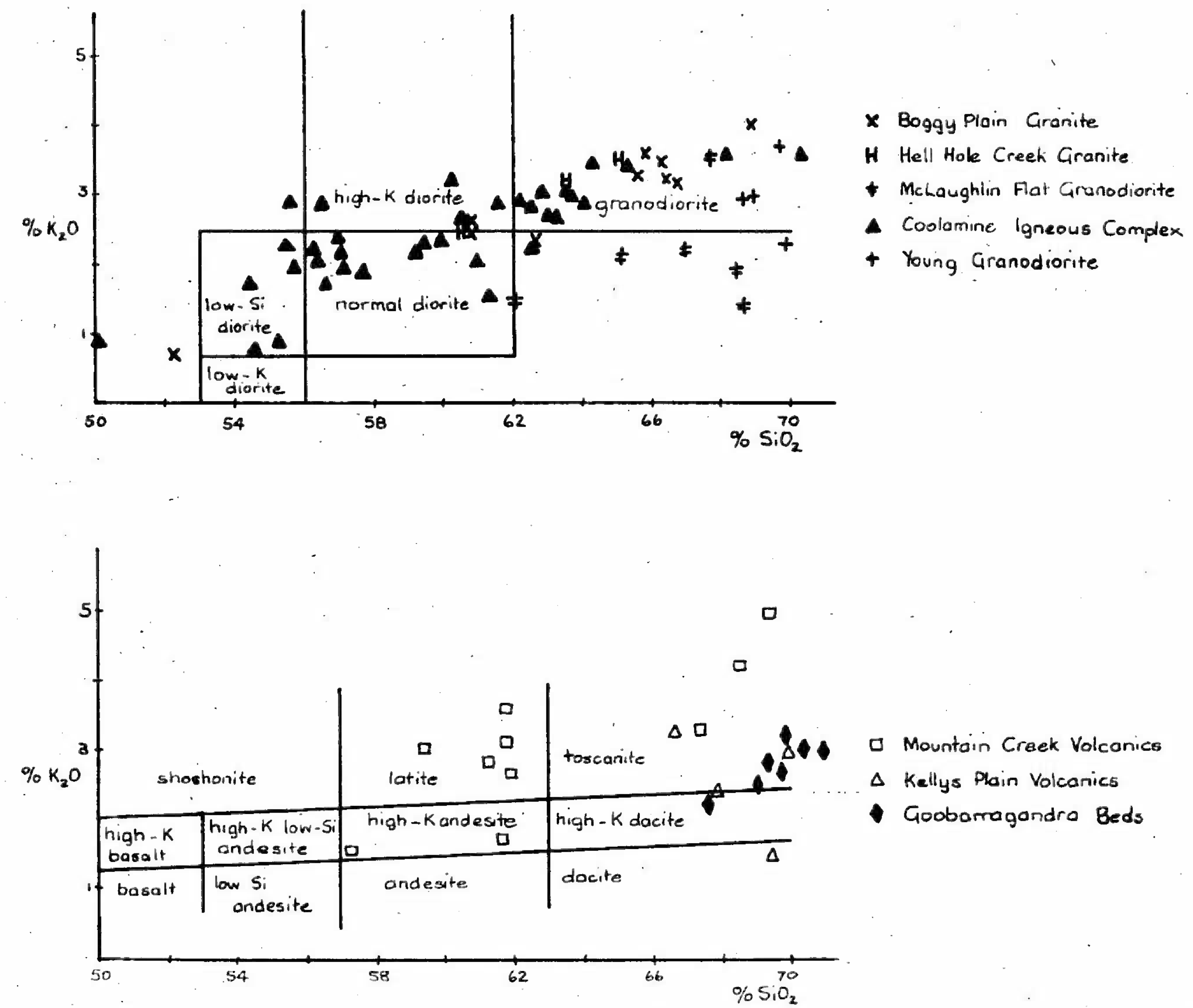


Fig. 44. Classification of the andesites (after Mackenzie & Chappell, 1972) and diorites (after Gulson, 1972).

The Gingera Granite and Murrumbidgee Batholith (Fig. 43) follow a similar trend to the Cooleman rocks, with the rocks of intermediate composition falling into the potassium-rich field and the acid rocks falling in the 'average' field. The Kellys Plain Volcanics samples of these rocks. The adamellite and leucogranite of the Gingera Granite and Murrumbidgee Batholith are clustered close together and are distinctly separated from the granodiorites, which tend to be more scattered in their distribution. This scatter is due to the fact that the granodiorites are contaminated rocks and contain varying amounts of sedimentary xenoliths (see earlier discussion, and Joyce, 1973). One McLaughlins Flat Granodiorite sample is more potassium-rich than the others - this rock is contaminated by sericite-rich xenoliths.

f) <u>Classification of the andesites and diorites.</u> The most common method of subdividing diorites and andesites is on the basis of their potassium and silica content. Mackenzie & Chappell's (1972) classification of andesites is used here (Fig. 44). The advantage of this diagram is that the natural increase of potash with silica is compensated for by the upward slope of the dividing lines. Gulson (1972) proposed a similar diagram for classification of diorites, although he used horizontal dividing lines (Fig. 44).

The main unit containing andesite is the Mountain Creek Volcanics (Rolling Grounds Latite), and these rocks fit in the potassium-rich fields of toscanites, latites, and high-K dacite and toscanite fields, with one exception.

Several of the intrusions contain diorites. The Coolamine Igneous Complex consists mainly of diorite and granodiorite, which fall in the low silica diorite, normal diorite, high-k diorite and granodiorite fields of Gulson's classification. Some samples from the Boggy Plain Granite and Hell Hole Creek Granite fall in the high-K diorite and granodiorite fields. Some of the McLaughlins Flat Granodiorite samples fall in the diorite field; samples containing less than 70% silica are plotted to show their comparatively low-K content.

According to this classification therefore, the Coolamine Igneous Complex and Rolling Grounds Latite are K-rich rocks. With the exception of the McLaughlins Flat Granodiorite, the other units plotted are K-rich at least in the diorite-granodiorite region.

g) <u>Conclusions</u>. The Coolamine Igneous Complex, Jackson Granite, Gurrangorambla Granophyre, Mountain Creek Volcanics, Boggy Plain Grainte, Hell Hole Creek Granite, Lucas Creek Granite, Kellys Plain Volcanics, Gingera Granite, McLaughlins Flat Granodiorite, Murrumbidgee Batholith, Goobarragandra Beds, and Young Granodiorite are all calcalkaline rocks, and are generally K-rich.

The alteration of the Nine Mile Volcanics makes it difficult to classify the rocks by variation diagrams. The Ol'-Ne'-Q' diagram suggests a tholeiitic composition, whilst the alkali-silica and alkali-alumina diagrams suggest an alkaline composition. However, the mineralogy and field associations support a tholeiitic composition.

## 2. Petrogenesis

The Gingera Granite, McLaughlin Flat Granodiorite, and intrusions of the Murrumbidgee Batholith are related and may be contemporaneous, as evidenced by their close chemical and mineralogical similarity and similar style of intrusion. The Kellys Plain Volcanics may be the extrusive equivalents of these rocks. It is difficult to tell the affinities of these volcanics from chemical evidence because the rocks are altered, but from geographic relations they are most likely to be related to the Gingera Granite. The Mountain Creek Volcanics (including the Rolling Grounds Latite) are the extrusive equivalents of the Jackson Granite, Gurrangorambla Granophyre, and Coolamine Igneous Complex. The Jackson Granite and Gurrangorambla Granophyre are almost identical in their chemical composition which is very restricted. However, they were intruded at different times as the Jackson Granite is the latest intrusion of the Cooleman area and the Gurrangorambla Granophyre is earlier than the Coolamine Igneous Complex.

The Coolamine Igneous Complex rocks are of hybrid origin, being derived from an acid and a basic magma. The acid parent was probably the magma that produced the Jackson Granite, because on the Harker and triangular variation diagrams the samples of Jackson Granite apparently terminate the Coolamine Igneous Complex trend. The identity of the basic parent is not so clear, but it may be related to basic rocks in the Micalong Swamp area of the Brindabella 1:100 000 Sheet area. The scatter of the Coolamine Igneous Complex samples on the variation diagrams indicates that they have not followed a simple fractionation trend but have been affected by some other process, which could be contamination, alteration, or hybridization. Other evidence for a hybrid origin of these rocks was discussed in the petrography of the Coolamine Igneous Complex. The Coolamine Igneous Complex is probably the northerly extension of the Boggy Plain Granite.

From chemical similarities and close field relations and Young Granodiorite appears to be the intrusive equivalent of the Goobarragandra Beds. These units are of calcalkaline composition as are the units already mentioned, but they are of probable Silurian age.

According to unpublished work on the Berridale Batholith in the Bega 1:250 000 Sheet area by the Australian National University (White, pers. comm.) and work on the Murrumbidgee Batholith by Joyce (1973), the granites are of two types, one derived from a magma (i.e. from a liquid), the other from incomplete melting of sedimentary rocks. The former is characterized by the presence of hornblende or possibly pyroxene as well as biotite, a massive texture, and few xenoliths which, if they are present, are of igneous origin. The latter type is characterized by biotite and/or muscovite, a foliation which is generally parallel to the regional strike although it may parallel the outlines of the intrusion, and an abundance of sedimentary xenoliths. The high-level Boggy Plain Granite is probably of the first type while the Gingera Granite and McLaughlins Flat Granodiorite and the Murrumbidgee Batholoth are the second type. According to Joyce (1973) the adamellites were derived from partial melting of sedimentary rocks, and fractional crystallization yielded leucogranites, whilst the granodiorites were derived by reaction of this adamellite magma with solid material, the remains of which is seen as xenoliths. A similar origin is probable for the Gingera Granite and McLaughlins Flat Granodiorite.

The Long Plain Fault is an important structural boundary in the Tantangara area. East of the Fault the Murrumbidgee Batholith and Gingera Granite show very little contact metamorphism whilst the Boggy Plain Granite, Coolamine Igneous Complex, and Jackson Granite have contact metamorphic aureoles. West of the fault is a similar situation where the Young Granodiorite shows little contact metamorphism whilst the Bogong Granite (in the Wagga Wagga 1:250 000 Sheet area) does. The granites with metamorphism aureoles are high-level bodies which were intruded into cold country rocks.

It is possible to relate the rocks of the Tantangara area to the overall tectonics of the Tasman Geosyncline (e.g. Solomon & Griffiths, 1972). The Ordovician Nine Mile Volcanics probably represent tholeiites of an early island arc which forms the basement for the calcalkaline igneous activity of the Silurian to Devonian. The marine origin of the Nine Mile Volcanics is indicated by their close association with chert and greywacke.

The Goobarragandra Beds and possibly the Kellys Plain Volcanics represented an island arc which was formed in the Silurian/Lower Devonian and extruded calcalkaline dacitic to rhyolitic rocks. The Kellys Plain Volcanics may be slightly younger than the Goobarragandra Beds and were extruded as the island arc moved eastward (Solomon & Griffiths, 1972). The Young Granodiorite is the intrusive equivalent of the Goobarrangandra Beds and the Murrumbidgee Batholith the equivalent of the Kellys Plain Volcanics, and the intrusion of these bodies marked the stabilization of the island arc and the cessation of this phase of volcanic activity. In the Early Devonian the eastern block collided with the island arc to the west, causing intrusion of the Coolac Serpentinite Belt (Wagga 1:250 000 Sheet area) and associated melting yielded the Micalong Swamp Igneous Complex (Brindabella Sheet area) and related basic intrusions (Solomon & Griffiths, 1972). Partial melting of the newly formed continental crust resulted in the formation of the Bogong Granite (Wagga 1:250 000 Sheet area), Jackson Granite Gurrangorambla Granophyre, and Mountain Creek Volcanics. Mixing of this acid melt and the basic magma which formed the Micalong Swamp Igneous Complex produced the hybrid Boggy Plain Granite and Coolamine Igneous Complex.

## 7. CAINOZOIC SEDIMENTS AND VOLCANIC ROCKS

### TERTIARY SEDIMENTS

(M.O.)

Tertiary sediments crop out in three areas in the Tantangara 1:100 000 Sheet area. The first area is on Bullock Hill where Miocene sub-basaltic sediments crop out; another area is on Cooleman Plain, where ferruginous gravels of presumed Tertiary age are present, and the third and largest area is occupied by the extensive gravels and sub-basaltic Tertiary sediments of the Yaouk/Shannons Flat area.

The Bullock Hill sediments are only part of much more extensive deposits to the west, outside the Tantangara 1:100 000 Sheet area, and have been described by Andrews (1901), and Gill & Sharp (1957). The only important deposits in the mapped area are at the Six Mile (or Gooandra) Diggings (G.R. 36355) at the southern end of the Bullock Hill basalts. These were briefly mentioned by Andrews (1901, p. 19, 26) and were said to be similar to the New Chum Hill deposits at Kiandra. Andrews presented a cross-section of the deposits which shows a basal bed of about 5 m of auriferous gravel and coarse sand, followed by about 1 to 2 m of clay; then about 4 m of lignite, and possibly 25 m of sand, sandy gravel, clay, and lignite forming the upper unit. At the present day little may be seen of the sediments, as float from the overlying basalt obscures them on natural hill-slopes, and vegetation regrowth or spoil from the diggings obscures them in the workings.

The age of the sediments based on work by Cookson (various papers from 1945 to 1954) on the microfloras was stated by Gill & Sharp (1957 p. 26) to be late Eocene or possibly early Oligocene. Earlier, Andrews (1901) had assumed a Miocene age, although firm evidence was lacking at that time. However, Wellman (1971) has dated the basalts at Kiandra as 18 to 22 m.y., early Miocene. Mrs J.A. Owen (pers. comm.) has recently been able to confirm this age for the sediments, after re-examination of the microfloras in the sediments at New Chum Hill, Kiandra.

The origin and age of the ferruginous gravels at Cooleman Plains is uncertain. They occur as thin patches overlying limestone, and are commonly formed of limonite, or hematite pebbles cemented by limonite. At some localities, such as near Blue Waterhole Saddle (G.R. 520536), the gravels are relatively uncemented, while at other localities (for example G.R. 519547) cementation of limonite pebbles by limonite is complete. Some of these massive limonite outcrops have developed gossanous weathered surfaces and it is uncertain if they are derived originally from cemented ferruginous gravels or if they are true gossans. A puzzling feature of these deposits is that they only overlie limestone and have not been found elsewhere. There are also small patches of stream gravel, preserved on interfluves between valleys. These gravels appear to be moderately well sorted, are well rounded, and are formed of vein quartz and locally derived igneous rocks.

The age of the deposits on Cooleman Plain is uncertain. They appear associated, from the presence of stream gravels on the interfluves of valleys, with the planation surface which exists on the limestone. This surface was suggested as Devonian in age by Stevens (1958b), but Jennings (1971) has argued for a late Tertiary age for this surface. A Miocene or Pliocene age is therefore thought likely for the Cooleman gravels.

Extensive areas of the Yaouk 1:50 000 Sheet area are covered by Tertiary sediments. They are divided into two groups for the purpose of description. The first is a series of siliceous and ferruginous gravel and sandstone apparently associated with the Tertiary basalts in the south and southeast of the area. The second group is the gravel, sand and clay forming high-level river terraces in the Murrumbidgee River valley.

Siliceous and ferruginous sand and gravel are common in the Shannons Flat area. They correspond to the 'grey billy' of W.R. Browne (1973), who has described many of the more important deposits both in the Shannons Flat/ Adaminaby area and in much of the remainder of eastern N.S.W.

Major outcrops of siliceous grey billy are at Adaminaby (G.R. 592163), Jones Plain (G.R. 738157), north of 'Bolairo' (G.R. 666186) and on the Callemondah road (G.R. 796197). The Callemondah outcrop is on top of a low ridge and is a hard white rock composed of coarse gravel to coarse sand cemented by silica. Pebbles are well rounded, generally composed of vein quartz, and poorly sorted. A crude bedding is visible in places, and the total thickness is about 5 m. There are 5 to 10 m of poorly exposed fine white sand and clay below the grey billy resting on Ordovician slate.

The outcrop of siliceous sandstone at Jones Plain is similar to that at Callemondah except that it is much finer-grained, most of the deposit being fine to medium sand, with some coarser. The rock is well sorted and cementation by silica is complete, leaving no pore space. Outcrops north of Bolairo and north of Adaminaby are similar in appearance to the Jones Plain occurrence.

Ferruginous sand and gravel are also common in the area. The main outcrop is on a basalt-topped hill north of the junction of the Shannons Flat/ Cooma road and the Callemondah road (G.R. 787183). The sediments underlie basalt and range from about 30 m thick at the northern end to about 45 m thick at the southern end of the hill. Interbedded slightly lithified coarse sand and fine gravel rests on leached Ordovician slate and become increasingly strongly cemented by limonite as the base of the overlying basalt is approached. At this locality fine-grained sediments are lacking, but at Jones Plain (G.R. 749159) a silt containing plant fragments has been completely cemented by limonite.

The origin of the grey billy association in N.S.W. is still uncertain. That there is a close relation between the overlying Tertiary basalts and the grey billy cannot be doubted from field evidence, but it seems certain that a contact metamorphic effect from the basalt at the time of extrusion is not involved, as many examples of basalt overlying unaltered sediments are known from the region. A more likely explanation is that the grey billy is formed by deposition of silica and limonite from circulating groundwater, the silica and iron being derived from weathering of the overlying basalt. Much more detailed work is needed to answer the many problems raised. In particular the detailed geochemistry of the process, the reasons why silica is deposited in preference to limonite at some but not other localities, and the reason why some flows (such as the Kiandra basalts) are never associated with grey billy are all unsolved problems.

There are widespread deposits of clay, sand, and gravel in the Yaouk area forming extensive river terraces of the Murrumbidgee River and apparently unrelated to the sub-basaltic sediments farther east. Several terrace levels are present. The highest is represented by a highly dissected gravel-covered surface about 75 m above the present river level, between Swamp Creek and Bog Plain Creek (G.R. 623307). A second terrace, 60 m above the river also highly dissectede, is present around Stuartfield homestead, and a third at 50 m is present north of Swamp Creek. The most extensive terrace is at the 40 m level and covers a large area north and west of the Murrumbidgee River at Yaouk. This level is almost completely undissected by the streams which drain it. Further terraces are present at various heights up to 10 m above river level but are small.

All of the terraces are covered by generally unknown thicknesses of gravel, sand, and clay. The gravels are usually poorly sorted, though well rounded, and may contain boulders up to 500 mm across. The composition of the boulders appears to remain constant on all terraces though no quantitative analysis was done. Granite and vein quartz dominate and quartzite, slate, sandstone, and rare acid porphyry rocks are also present. All of the rock types may be correlated with lithologies present in the upstream drainage area of the Murrumbidgee.

The only sections through the sediments are road cuttings at G.R. 618327 and G.R. 633340. Both show a series of interbedded gravels and sands, which are partly cemented by limonite, in beds from 0.5 to 2 m thick. At the locality south of Yaouk (G.R. 618327) a white silty clay is about 200 mm thick.

The Murrumbidgee valley near Yaouk has obviously had a complex history, the details of which are not known. Even the age of the various terraces is unknown. However it is likely that the higher levels are of Late Tertiary age, if not older. The extensive terrace at the 40 m level is probably Pleistocene as the streams which drain it have barely begun to dissect it. The lower terraces are probably late Pleistocene and Holocene.

## TERTIARY BASALTS

(M.O.)

Tertiary basalt is present in two areas in the Tantangara 1:100 000 Sheet area. The first is a zone extending from Tabletop Mountain in the southwest along the western edge of the area in a series of disconnected outcrops as far as Peppercorn Hill, together with isolated small areas in the northwest. The second is in the Alum Creek valley around Shannons Flat.

The Tertiary basalts of the Kiandra area occur as a series of disconnected outcrops forming small summit plateaux and ridges. The main areas within the Tantangara 1:100 000 Sheet area are Dunns Hill (southwest of Kiandra), Bullock Hill, and Peppercorn Hill. The Kiandra basalts (Dunns Hill and Bullock Hill basalts, with the New Chum Hill basalt which is just west of the map area), were once part of the same flow system (Gill & Sharp, 957; Moye et al., 1963; Mackenzie, 1968), now dissected by erosion. The relation of the Peppercorn Hill basalt to the Kiandra basalts is not known.

The basalts form poor outcrops in all areas, but boulders of basalt are common as float downslope from the outcrops. Individual flows are impossible to identify in the field owing to the poor outcrop, although drilling by the Snowy Mountain Authority at Eight Mile diggings between Kiandra and Cabbramurra has revealed at least four flows. The basalts vary in thickness from 100 m on New Chum Hill to about 20 m on Bullock Hill.

The petrography and geochemistry of the basalts has been discussed in detail by Mackenzie (1968) and Mackenzie & White (1970). The dominant rock type is a black fine-grained basalt with common olivine and rare titanaugite phenocrysts, and rare zeolite-filled vesicles. The groundmass is composed of small calcic plagioclase laths, subhedral to euhedral pyroxene, magnetite, rare nepheline and analcime, and interstitial sodic feldspar. The rock types vary from alkali basalt to basanite.

The basalt capping Peppercorn Hill covers an area of 2.5 $km^2$ at an altitude of 1550 m, and is about 60 m thick. It is similar to the Kiandra/Bullock Hill basalts but may be coarser-grained, and has a higher titanaugite content relative to olivine. Other basalts in the northwest part of the Tantangara Sheet area, at G.R. 385625, 371678, and 368702 are similar in composition to the Peppercorn Hill basalt but are very small in outcrop area.

The basalts at Kiandra were considered to be late Eocene or Oligocene by Gill & Sharp (1957). However K-Ar dating by Wellman (1971) gives an age of 18 to 22 m.y. for them (early Miocene), and more recent studies of the microflora in associated sediments also indicate an early Miocene age for the sediments (Mrs J.A. Owen, pers. comm.). The basalt at Peppercorn Hill has been dated by AMDEL for BMR at 23.2 $\pm$ 0.6 m.y. by

K-Ar on total rock. (see Appendix 1).

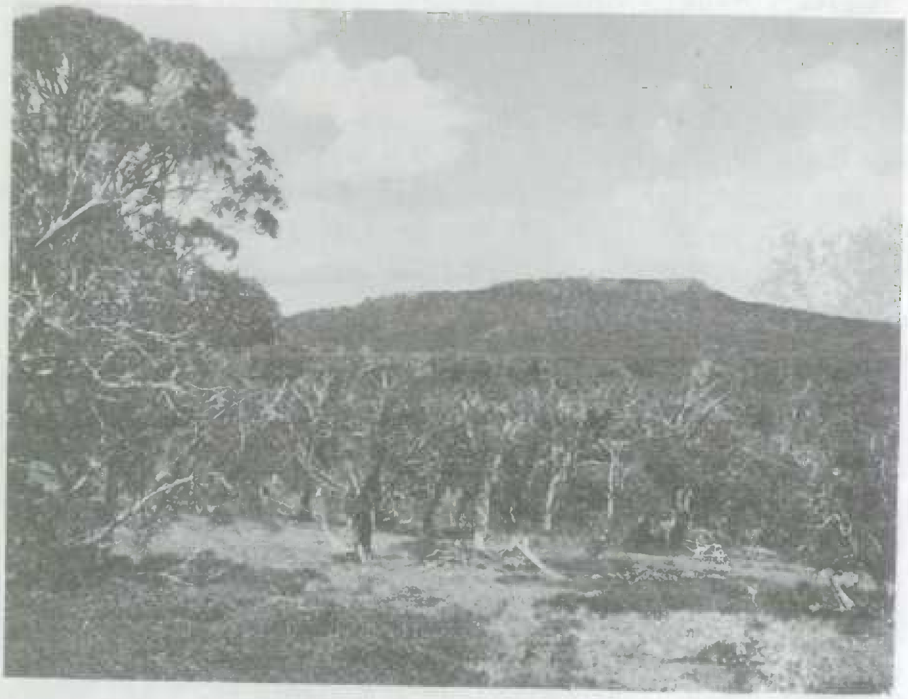

Fig. 71 Tabletop Mountain, a Tertiary basalt vent, from Four Mile Hill. (Neg. no. GA/6370).

The eruptive source of the Peppercorn Hill basalt is unknown, but the Kiandra basalts were said by Gill & Sharp (1957) and Moy et al. (1963) to have originated from Tabletop Mountain (Fig. 71), in the southwest corner of the Tantangara 1:100 000 Sheet area. Tabletop Mountain is therefore a volcanic plug about 700 m by 400 m, and formed of massive olivine basalt. Jointing is widespread, though irregular in direction, and tuff and breccia are absent.

Basalt is fairly common in the Shannons Flat area, the largest outcrop being on an unnamed hill at G.R. 723260 at an altitude of 1400 m. Other outcrops are at G.R. 767256 (altitude 1325 m), a series of small outcrops on a ridge from G.R. 763218 to 772209, (altitude 1100 m) and a large area centred on G.R. 786194 (altitude 1100 m). The present altitudes of the basalts indicate that they flowed from the northwest and it seems likely that the large, almost circular one at G.R. 723260 was the source of the flow.

The basalts are similar petrographically to those near Kiandra, except that nepheline appears to be absent. Rare subrounded phenocrysts of plagioclase and titanaugite up to 1 mm diameter, and abundant euhedral to subhedral phenocrysts of olivine up to 0.8 mm diameter lie in a groundmass of poorly aligned subhedral plagioclase laths up to 0.2 x 0.1 mm, and interstitial opaque minerals, titanaugite, and very pale brown devitrified glass. Quartz xenocrysts may be present, up to 3 mm diameter, and are surrounded by a reaction rim of euhedral augite with narrow margins of pale blue-green amphibole.

The age of the basalt in the Shannons Flat area is not known with certainty, but it seems likely that it is related to the basalt closer to Cooma, rather than those near Kiandra. Wellman (1971) has dated a basalt from south of Lake Eucumbene as 36 m.y. and one just east of Cooma as 39 m.y., so it may be assumed that the Shannons Flat basalts are of similar age.

## GEOCHEMISTRY (M.S.)

Only two rocks have been analysed for BMR, but in Table 54, five rocks are included from MacKenzie & White (1970), although these rocks outcrop just to the west of the Tantangara 1:100 000 Sheet area. Nockolds (1954) average alkali olivine basalt is also included.

All the samples are similar in composition with very little variation in silica content. The two BMR samples are slightly higher in alumina than MacKenzie & White's samples, and all seven samples are high in soda compared to the typical alkali olivine basalt. Although titania is high as is characteristic of alkali olivine basalt, Kiandra basalts are low in titania compared to Nockolds' average alkali olivine basalt. The low potash is a distinctive contrast to the K-rich Devonian igneous rocks of the area.

The presence of normative olivine is characteristic of alkali olivine basalts as typical tholeiitic and calcalkaline basalts contain 2 to 3% normative quartz (Nockolds, 1954). The high normative nepheline content of the Kiandra rocks compared to the average alkali olivine basalt reflects their high soda content.

TABLE 54. ANALYSES AND CIPW NORMS OF TERTIARY BASALTS

| Sample No. | 72840216 | 72840052 | 1* | 2* | 3* |
|---|---|---|---|---|---|
| Rock type | basalt | basalt | alkali basalt | basanite | basanite |
| G.R./ locality | 16256077 | 15375803 | 6.13 km W. of Kiandra | 6.45 km WSW of Kiandra | 3 km WNW of Kiandra |
| % | | | | | |
| $SiO_2$ | 45.2 | 45.3 | 47.02 | 45.43 | 44.48 |
| $Al_2O_3$ | 15.4 | 15.0 | 14.78 | 14.18 | 14.12 |
| $Fe_2O_3$ | 2.5 | 2.05 | 2.55 | 3.61 | 2.90 |
| FeO | 9.85 | 8.2 | 8.25 | 7.04 | 7.94 |
| MgO | 9.2 | 8.15 | 9.67 | 10.20 | 9.97 |
| CaO | 10.4 | 10.2 | 10.07 | 10.10 | 10.42 |
| $Na_2O$ | 3.2 | 3.05 | 3.49 | 3.85 | 3.93 |
| $K_2O$ | 0.86 | 1.36 | 1.23 | 1.08 | 1.40 |
| $H_2O+$ | 0.55 | 2.02 | 0.45 | 0.86 | 0.35 |
| $H_2O-$ | 0.21 | 0.90 | 0.42 | 0.59 | 0.32 |
| $CO_2$ | 0.05 | 0.10 | 0.01 | 0.01 | 0.02 |
| $TiO_2$ | 1.91 | 2.45 | 1.70 | 1.98 | 2.50 |
| $P_2O_5$ | 0.08 | 1.16 | 0.94 | 1.22 | 1.30 |
| MnO | 0.22 | 0.15 | 0.18 | 0.18 | 0.18 |
| | 99.63 | 100.09 | 100.76 | 100.34 | 99.83 |
| Qz | - | - | - | - | - |
| Or | 5.14 | 8.27 | 7.24 | 6.37 | 8.26 |
| Ab | 14.76 | 21.77 | 20.25 | 19.14 | 13.32 |
| An | 25.41 | 23.90 | 21.05 | 18.24 | 16.78 |
| Ne | 6.83 | 2.59 | 5.01 | 7.26 | 10.78 |
| Wo } Di | 10.82 | 8.23 | } 18.87 | } 18.70 | } 21.85 |
| En } Di | 6.49 | 5.23 | | | |
| Fs } Di | 3.76 | 2.48 | | | |
| Hy | - | - | - | - | - |
| Fo } Ol | 11.69 | 10.97 | 12.45 | 12.64 | 11.92 |
| Fa } Ol | 7.47 | 5.72 | 6.02 | 3.84 | 4.44 |
| Mt | 3.67 | 3.06 | 3.69 | 5.24 | 4.21 |
| Il | 3.67 | 4.79 | 3.24 | 3.77 | 4.74 |
| Ap | 0.19 | 2.83 | 2.05 | 2.67 | 2.85 |
| Cc | 0.12 | 0.23 | not given | not given | not given |
| others | | | 0.88 | 1.46 | 0.69 |

* MacKenzie & White (1970)

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TABLE 54 (Cont'd)

| Sample No. | 4* | 5* | ǂ |
|---|---|---|---|
| Rock type | basanite | basanite | Average alkali olivine basalt |
| Locality | 2 km WNW of Kiandra | 2.1 km SW of Kiandra | |
| % | | | |
| $SiO_2$ | 44.28 | 42.42 | 45.78 |
| $Al_2O_3$ | 14.07 | 13.60 | 14.64 |
| $Fe_2O_3$ | 3.38 | 4.74 | 3.16 |
| FeO | 7.48 | 6.70 | 8.73 |
| MgO | 10.32 | 8.73 | 9.39 |
| CaO | 10.50 | 11.07 | 10.74 |
| $Na_2O$ | 3.95 | 4.30 | 2.63 |
| $K_2O$ | 1.44 | 1.35 | 0.95 |
| $H_2O+$ | 0.30 | 1.15 | 0.76 |
| $H_2O-$ | 0.27 | 0.97 | - |
| $CO_2$ | 0.02 | 0.03 | - |
| $TiO_2$ | 2.47 | 2.79 | 2.63 |
| $P_2O_5$ | 1.34 | 1.85 | 0.39 |
| MnO | 0.18 | 0.19 | 0.20 |
| | 99.99 | 99.88 | 100.00 |
| Qz | - | - | - |
| Or | 8.48 | 7.97 | 6.1 |
| Ab | 12.45 | 12.48 | 18.3 |
| An | 16.42 | 13.82 | 24.7 |
| Ne | 11.37 | 12.95 | 2.3 |
| Wo) Di | 22.17 | 23.95 | 10.8 |
| En) Di | | | 7.1 |
| Fs) Di | | | 2.9 |
| Hy | - | - | - |
| Fo) Ol | 12.22 | 8.56 | 11.5 |
| Fa) Ol | 3.77 | 1.80 | 5.0 |
| Mt | 4.90 | 6.87 | 4.6 |
| Il | 4.68 | 5.29 | 5.0 |
| Ap | 2.93 | 4.05 | 1.0 |
| Others | 0.59 | 2.15 | - |

* MacKenzie & White (1970)

ǂ Nockolds (1954, 96 analyses)

## ALLUVIUM

(M.O.)

Small pockets of alluvium are present along most streams in the area, often covering less than 100 m$^2$. More rarely, extensive areas of alluvium have formed, particularly associated with the Murrumbidgee River at the northern end of Long Plain, Tantangara Dam, Yaouk, and Bolairo. Other rivers which have formed large alluvial deposits include the Eucumbene River at Providence Portal (now covered by Lake Eucumbene); Nungar Creek, particularly on Nungar Plain; Gurrangorambla Creek on Currango Plain; Yaouk Creek at Yaouk; and Little River at Adaminaby.

Exploration work for gravel by the Snowy Mountain Authority in many of these areas has revealed that the alluvium invariably consists of several metres of coarse, unsorted gravels which rest on bedrock and are overlain by a surface mantle of organic-rich silt up to 1 m thick. Up to 5 m of gravel was proved by the Authority at Providence on the Eucumbene River, and a similar thickness was considered to be present near Tantangara Dam.

The alluvial gravels deposited by the Murrumbidgee River near Bolairo are the most extensive in the area, and are presently being worked. They are similar to alluvial deposits elsewhere in the area, and at least 4 m of gravel are covered by up to 1 m of organic-rich silt. The total thickness of this deposit is unknown, though probably it is little more than already exposed, as a granite bar downstream has placed an effective base level to downcutting by the river.

## 8. STRUCTURE

(D.E.G.)

The map area (Fig. 45) is situated in the southern part of the Lachlan Fold Belt of the Tasman Geosyncline. Two synclinorial zones, the Bogan Gate zone and the Cowra - Yass zone approach from the north-northwest and north, and merge into one another in the northwest corner of the area. Most of the remainder of the area lies within the Molong/South Coast anticlinorial zone. Two sets of major faults, one of which strikes north-northeast and the other north-northwest to almost north, divide the area into several fault-blocks; a summary of the structure of these blocks is given in Table 55,

## TABLE 55. FAULT BLOCKS OF THE TANTANGARA SHEET AREA

| Name of block and bounding faults | Geological notes<br>Illustrated diagrammatically by vertical sections in Figs. 46-49, 51, 53-4; localities of sections are shown in Fig. 45. |
|---|---|
| Yarrangobilly<br><br>Long Plain Fault forms eastern boundary | Stratigraphy. Terrestrial volcanics, probably Middle Silurian, intruded by granite, gabbro and dolerite; Tertiary basalt (minor)<br><br>Regional Setting. At the junction of the Bogan Gate and Cowra-Yass synclinorial zones<br>Structure. (Figs. 46, 51) Possibly anticlinal in east, merging westward, outside the map area, into an open-folded syncline in which Devonian sediments and volcanics rest unconformably on Silurian sediments |
| Tantangara<br><br>Between Long Plain Fault and Tantangara Fault, south of Black Mountain Fault | Northeast and east<br><br>Stratigraphy. Middle to Late Silurian marine shelf clastic sediments and carbonate, and late Silurian to Early Devonian terrestrial volcanics; intruded by granite and diorite<br><br>Regional Setting. At southern end of Cowra-Yass Synclinorial Zone<br>Structure (Figs. 46, 47). Synclinal; open folds in Silurian, with small anticline in east; dips generally less than 45°, but range beyond 60°. Devonian volcanics gently folded; dips to the east, generally less than 30° |
| Tantangara<br>as above | West and south<br>Stratigraphy. Middle and Late Ordovician and Early Silurian turbidites, deep-water chemical deposits (chert), and submarine lava; intruded by granitic rocks, and minor acidic to basic intrusives<br><br>Regional Setting. In Molong/South Coast Anticlinorial Zone<br><br>Structure (Figs 48, 49, 51) Tightly folded overturned syncline with subsidiary anticline, or tightly folded overturned anticline with subsidiary syncline. Overturned cross-folds; axes strike northeast to east, and dip northwest to north |
| Cooleman<br><br>Between Long Plain Fault and Tantangara Fault, north of Black Mountain Fault | Stratigraphy<br>Regional Setting<br>Structure (Figs. 46, 47)<br>) Similar to 'Tantangara Block northeast and east'. Widespread intrusion of granitic and dioritic rocks, including Coolamine Igneous Complex |
| Bimberi<br><br>Between Goodradigbee Fault and Cotter Fault | Stratigraphy Late Ordovician turbidites, and major granitic intrusion<br>Regional Setting. Within Molong/South Coast anticlinorial zone<br>Structure (Fig. 47) Probably anticlinorial |

TABLE 55. (Continued)

| Name of block and bounding faults | Geological Notes<br>Illustrated diagrammatically in Figs. 46-49, 51, 53-4 |
|---|---|
| Nungar | Stratigraphy. Late Ordovician and Early Silurian turbidites, intruded by granite; small area of Late Silurian marine shelf deposits and Devonian subaerial volcanics in the north<br><br>Regional Setting. Within Molong/South Coast anticlinorial zone, and eastern fringe of southern part of Cowra-Yass synclinorial zone<br><br>Structure (Fig. 54). Anticline, with small infolded outliers of Early Silurian |
| Mount Kelly<br>East of Cotter Fault and north of Alum Creek Fault | Stratigraphy. Predominantly adamellite and grano-iorite in a batholithic intrusion; narrow belts of Late Ordovician turbidites at west and east margins<br><br>Regional Setting. Molong/South Coast anti-clinorial zone<br><br>Structure (Fig. 54) Possibly synclinal in west, anticlinal in east |
| Yaouk<br><br>East of Cotter Fault; between Alum Creek and Rosedale Faults | Stratigraphy. Late Ordovician turbidites intruded by granite and granodiorite<br><br>Regional Setting. Molong/South Coast anti-clinorial zone<br><br>Structure (Fig. 53) Probably synclinal, with subsidiary anticlines |
| Adaminaby<br><br>Between Rosedale and Cotter Faults. | Stratigraphy. Early Silurian turbidites<br><br>Regional Setting. Molong/South Coast anti-clinorial zone<br><br>Structure. Possibly synclinal, as in Nungar block. |

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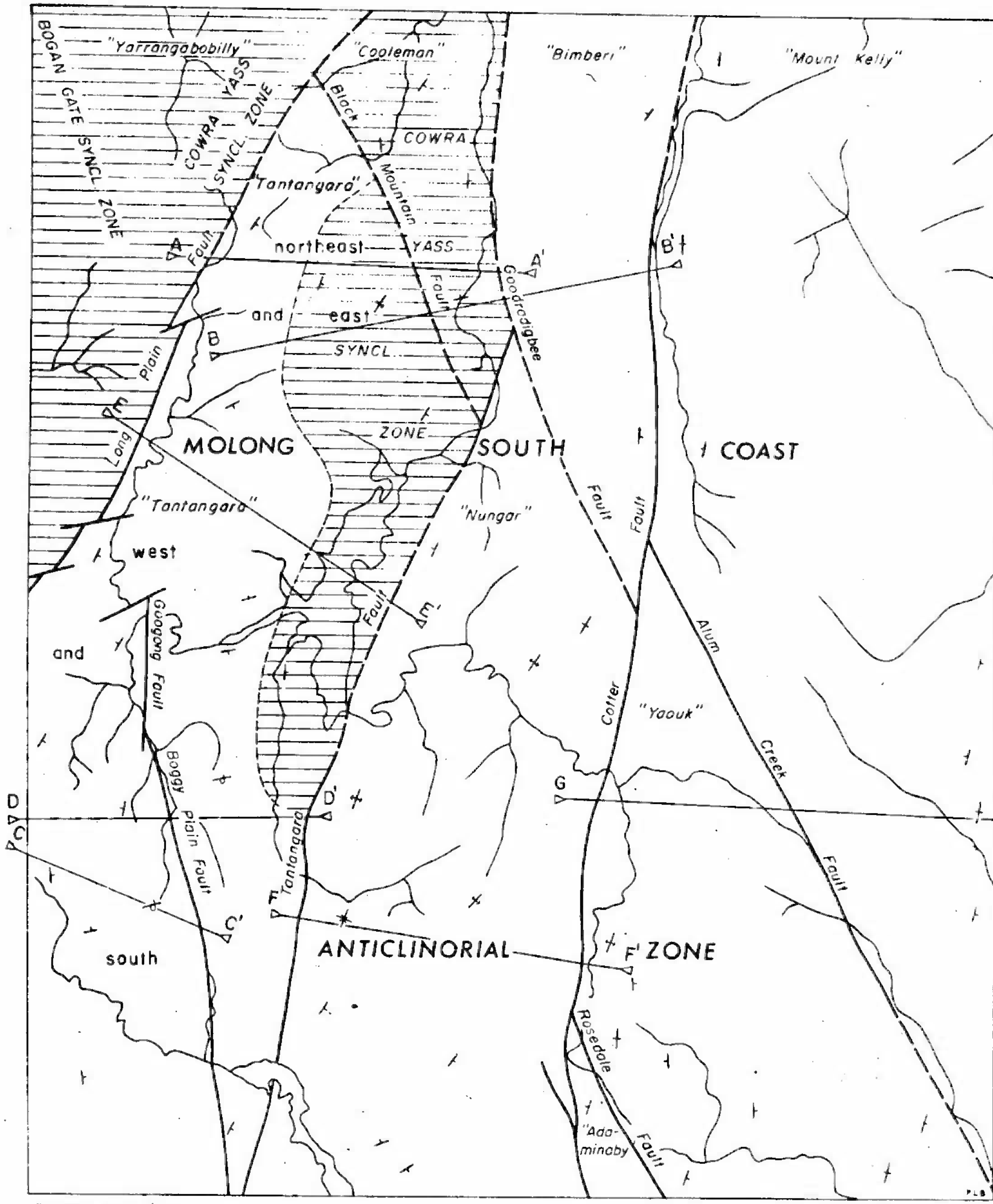
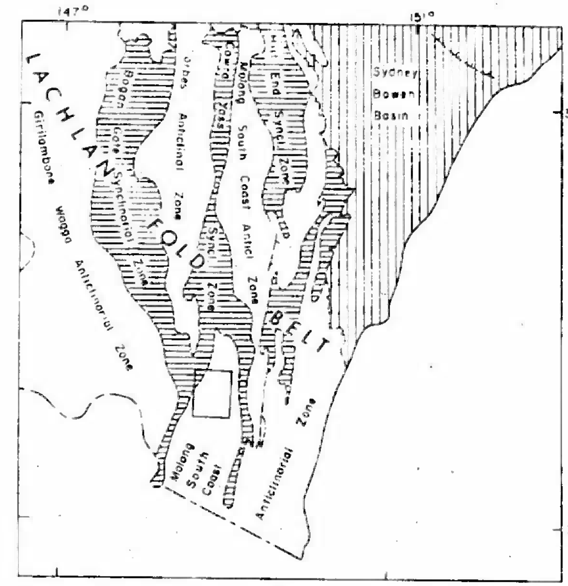



Inset: Location of Map Sheet in Lachlan Fold Belt
(Fold belt after Pogson, D. J., 1972. Geological Map of New South Wales, scale 1:1,000,000 Geol. Surv. N.S.W.

Area covered by map sheet

*Attitude of Bedding (Generalized)*

- Strike and direction of dip
- Vertical
- Strike and dip of overturned beds
- Anticline
- Syncline
- Fault

"Yarrangobilly" Yarrangobilly fault block

A — A' Section line

0 5 10 15 Kilometres

1: 250,000

**Fig.45. Major Faults and Regional Setting of the Tantangara Sheet area.**

I55/A16/1302

and is illustrated diagrammatically in the vertical sections of Figs. 46-49, 51, 53. The localities of the sections are shown in Fig. 45.

YARRANGOBILLY BLOCK (Fig. 46, 51)

Folding and faulting in Fiery Range. No evidence of the degree and type of folding was observed in the field. Cleavage where present is generally parallel to the Long Plain Fault or other faults. Should this cleavage prove to be axial plane cleavage, the fold axes are parallel to the Long Plain Fault.

Faulting is probably more complex than indicated on the geological map. A series of major faults including the Long Plain and Kennedy Range Fault strikes at 020° to 040°. The Long Plain Fault is a major shear zone up to 1600 m wide in the south, but to the north near Peppercorn Creek it breaks up into a series of parallel-trending faults. Minor cross faults and faults conjugate to the Long Plain Fault trend at 305°.

The Kennedy Range Fault is parallel to the Long Plain Fault in the south, but it diverges in the north, to strike at 340° along the Right Hand Branch of the Goobarragandra River. Other lineations in that area also tend to bend around towards 340°, giving rise to a fan-shaped pattern of lineaments. This 340° strike direction of the northern Kennedy Range Fault is approximately parallel to a major structural weakness east of Tumut, along which the Coolac Serpentine Belt was intruded, and to the general trend of the Bogan Gate Synclinorial Zone.

TANTANGARA BLOCK

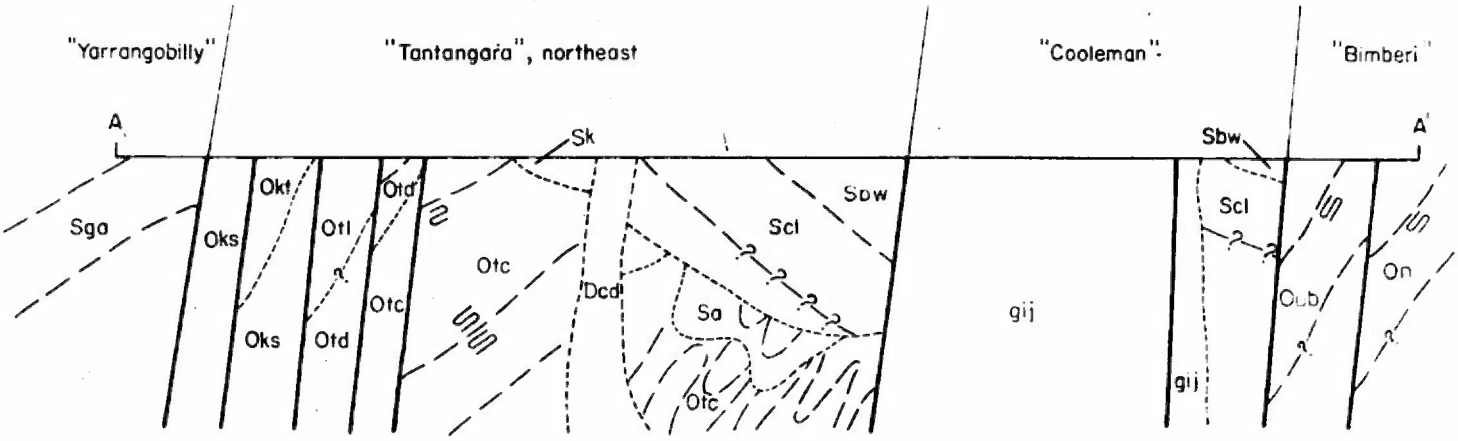
Faulting. The distribution of the rocktypes indicates that the area is intersected by numerous faults; few faults were seen, and most of those shown on the map are inferred.

Two faults that have fairly large displacements, the Black Mountain Fault and the Boggy Plain Fault, strike north-northwesterly through the northern and the southern parts of the block. The strike directions of the remaining faults fall into five groups. One is parallel to the Long Plain Fault (strike 030°), another to the Gooandra Fault (strike almost north) and a third group near Wild Horse Plain strikes about 070°; these faults dip westerly and northerly. Faults near Rules Point strike 290° to 300° and dip southerly; others near Zinc Ridge vary in strike from slightly south to slightly north of east.

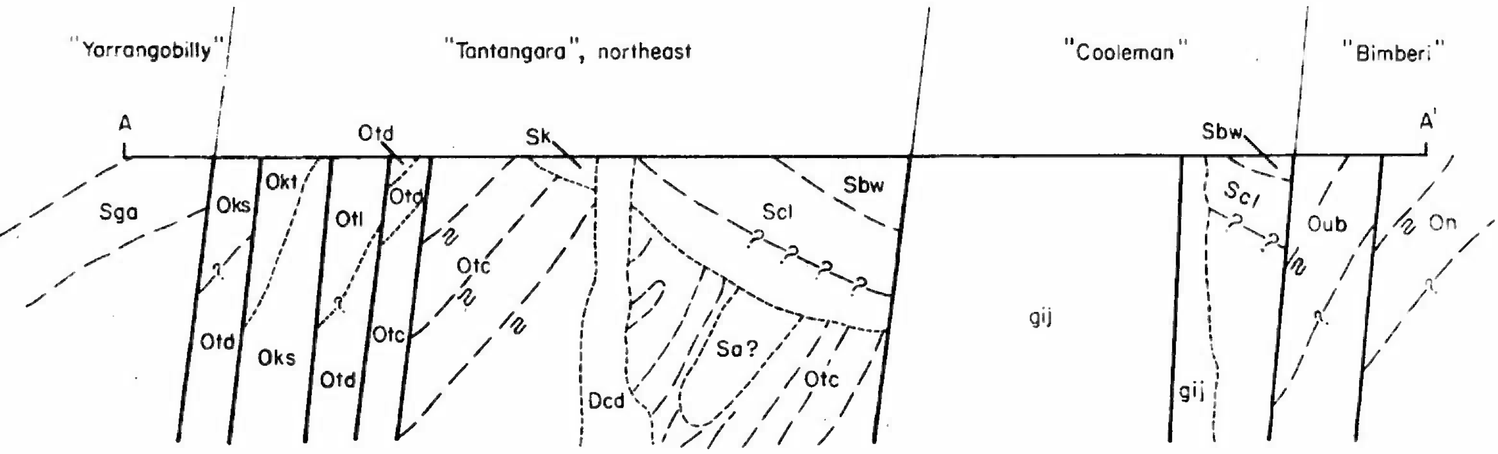
By photo-interpretation the Gooandra Fault can be followed northwards from an inferred cross-fault at about grid latitude 355, to a fault of the Rules Point group at about grid latitude 428. South of the inferred fault at latitude 355, a northerly-trending joint or fracture pattern on the aerial photographs suggests that the Gooandra Fault may continue along the south branch of Kiandra Creek at or a little west of meridian 400. The Gooandra Fault is apparently a normal fault, with interbedded chert and tuff on its western side faulted down against similar but older beds on its eastern side.

The Boggy Plain Fault strikes north-northwest along the western edge of Boggy Plain to Tantangara Creek, which it follows past the mouth of Blanket Plain Creek to end against the Gooandra Fault. At Blanket Plain Creek the boundary between the Tantangara Beds and Ordovician sediments trends east-northeast to Blanket Plain, beyond which it trends generally north-northwest in displaced segments, presumably along an extension of the Boggy Plain Fault, to end at a fault of the Long Plain group east of Rules Point. Along the Boggy Plain Fault and the apparent displaced northern extension of it, the spatial distribution of the rock types near their contact, and lineaments that can be seen in places on the aerial photographs suggest that the Tantangara Beds dip beneath the Temperance Chert; the fault is therefore interpreted as a reverse fault. If the eastern side of the Boggy Plain Fault were moved 4500 m south, the boundary between the granite and the Bolton Beds, on the opposite sides of the fault, would coincide. Similarly, if the eastern side of the apparent northern extension of the fault were moved in the same way, the chert north of Boundary Creek would be placed in contact with the chert near Tantangara Creek, and the upper boundary of the Temperance Chert Formation north of McPhersons Creek would be placed on strike with the upper boundary southeast of Rules Point. This suggests an apparent 4500-m component of movement along the fault. Southwards the Boggy Plain Fault extends down the Alpine Creek valley, crosses the Eucumbene River, and continues south along the upper part of Little Swamp Creek to join the Tantangara Fault just south of the Sheet area.

What appear to be the earliest faults, striking about 070°, are displaced by the Boggy Plain Fault, and that fault by the easterly-striking faults near Zinc Ridge; the sequence of faulting appears to continue with the Gooandra Fault, later faults that again strike about 070°, and then the faults near Rules Point that strike 290° to 300°. The sequence is probably complicated by repeated movements along older faults.




Current Interpretation (diagrammatic)




Alternative Interpretation (diagrammatic)


Vertical scale indefinite; sketched diagrammatically

| | | | | |
|---|---|---|---|---|
| Sk | *Kellys Plain Volcanics* | | | |
| Sbw | *Blue Waterhole Beds* | | ghj | *Jackson Granite* |
| Scl | *Cooleman Limestone* | | Dcd | *Cooleman Diorite* |
| Sga | *Goobarragandra Beds* | | | |
| Sa | *Tantangara Beds* | | | |
| On | *Nungar Beds* | | (drag fold symbol) | *Drag fold (diagrammatic)* |
| Oub | *Adaminaby Beds* | | (solid line) | *Fault* |
| | *Nine Mile Volcanics* | This sequence is reversed in the alternative interpretation | (dotted line) | *Geological boundary* |
| Okt | *Tuff* | | (dashed line) | *Trace of bedding (diagrammatic)* |
| Oks | *Sediment and tuff* | | "Cooleman" | *Fault block* |
| | *Temperance Chert* | | | |
| Otl | *Andesite lava* | | | |
| Otc | *Chert* | | | |
| Otd | *Chert and tuff interbedded* | | | |

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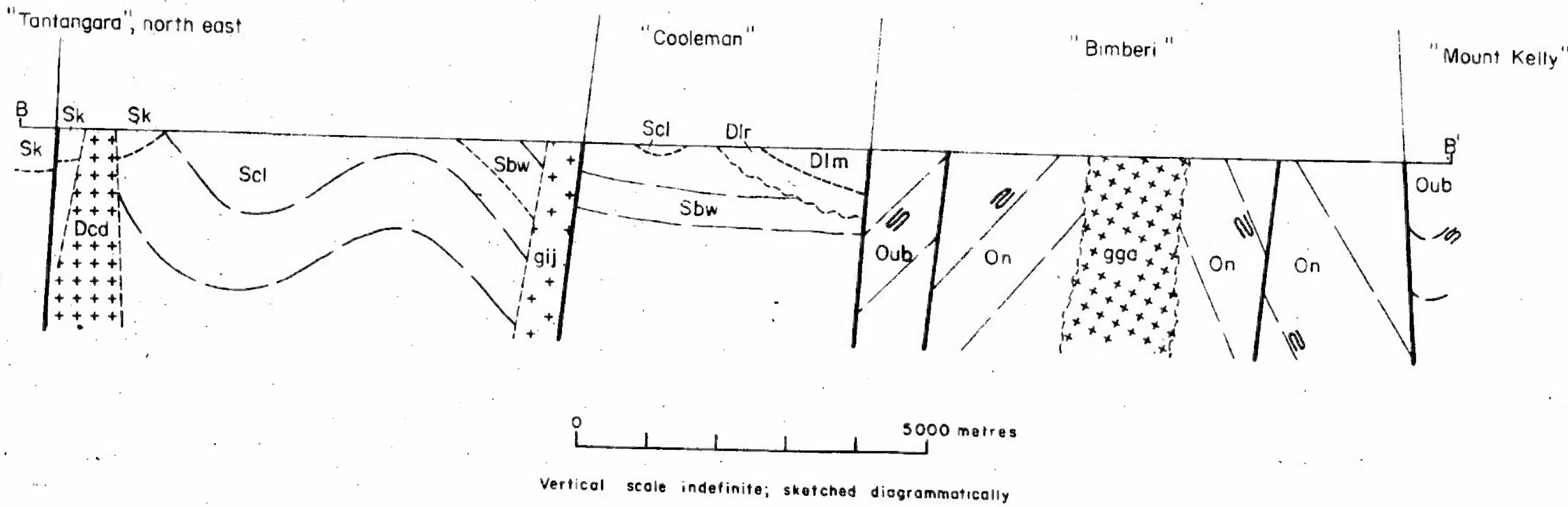
**Fig. 46. Section A–A' (diagrammatic).**




| | |
|---|---|
| Sk | *Kellys Plain Volcanics* |
| Dlm | *Mountain Creek Volcanics* |
| Dlr | *Rolling Grounds Latite* |
| Scl | *Cooleman Limestone* |
| Sbw | *Blue Waterhole Beds* |
| On | *Nungar Beds* |
| Oub | *Adaminaby Beds* |
| gij | *Jackson Granite* |
| gga | *Gingera Granite* |
| Dcd | *Cooleman Diorite* |
| - - - - | *Geological boundary* |
| (symbol) | *Drag fold (diagrammatic)* |
| ——— | *Fault* |
| — — | *Trace of bedding (diagrammatic)* |
| "Cooleman" | *Fault block* |

**Fig. 47. Section B—B' (diagrammatic).**

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Folding. In the western and southern part of the Tantangara block (Figs. 48, 49, 51), tightly folder Ordovician sedimentary strata occupy part of the east limb of a major syncline that has been disrupted by faulting and deformed by cross-folding. Minor tight folds are overturned at many localities, suggesting that the major structure is overturned. In the north and east, (Figs. 46, 47) moderately folded Middle and Late Silurian strata occupy a broad syncline that is strongly unconformable on the Ordovician. In the central part of the block, (Figs. 49, 51) strongly folded Early Silurian Tantangara Beds, sediments of flysch type, are unconformable on Ordovician sediments in two faulted synclines whose axes appear to strike east-northeast. In the western part of their outcrop area, the Tantangara Beds are almost as tightly folded as the Ordovician beneath them; dips commonly exceed 60° and 70°, and locally 80°; farther east, on the slopes leading down to Nungar Creek, the folding seems to be more moderate, and dips are commonly of the order of 45°. In the Nungar block, which is separated by a fault from the eastern side of the Tantangara block both the Tantangara Beds and the Late Ordovician Nungar Beds are tightly folded; dips in the anticlinal areas ranging between 80° and vertical in the Nungar Beds, and between 70° and vertical in the Tantangara Beds.

## Folding of the Ordovician strata

The Ordovician sedimentary rocks strike predominantly north-northeast and dip west; angles of dip commonly are steeper than 70°. West of Wild Horse Plain (Fig. 50) and north of MacPhersons Creek, the trend of the bedding appears to outline fold-structures that are presumably subsidiary to the major fold of the region. In several areas, the major fold appears to be deformed by easterly-trending cross-folds, in which the predominant strike is to the east-northeast and east, and the dip to the north. At many localities, both the westerly-dipping and the northerly-dipping beds form small, overturned, almost isoclinal folds, which have amplitudes of several metres.

The rocks commonly have at least two directions of fracture-cleavage; the cleavage is commonly obscured by shearing and close jointing, and was not systematically mapped. However, there are fracture cleavages which are similar in attitude to both the westerly and the northerly-dipping overturned folds. Westerly-dipping cleavage dips 70° towards 290° in outcrops of inter-bedded tuff and chert about 800 m west of the junction of Blanket Plain Creek with Tantangara Creek; northerly-dipping cleavages dip 65° towards 325° in thin-bedded quartz arenite about half-way between Sawyers Hill and Tantangara Mountain. The attitudes of the cleavages suggest overturning of the folds, so that the axes dip west in the major fold and north in the cross-folds.

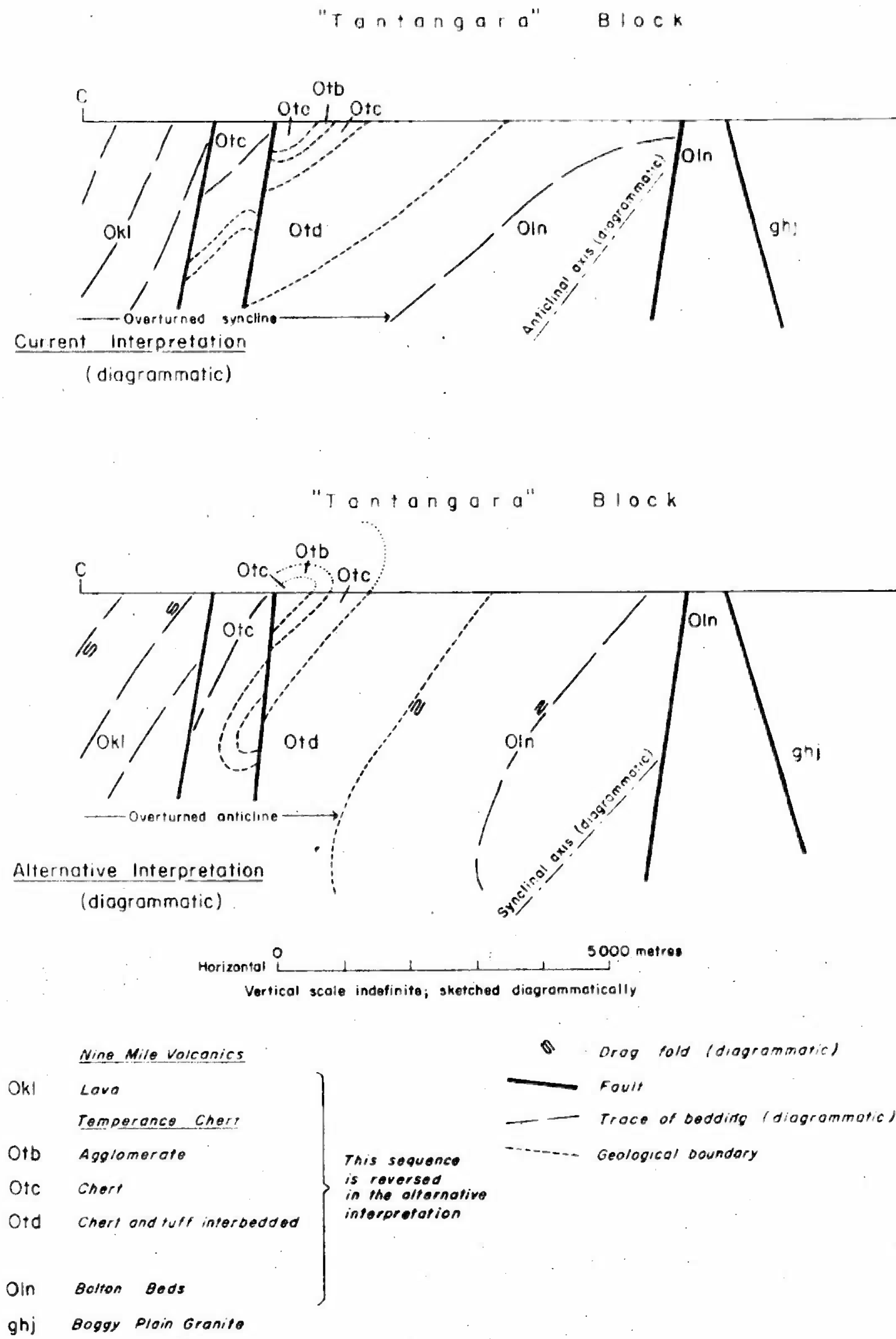


**Fig. 48. Section C—C' (diagrammatic).**

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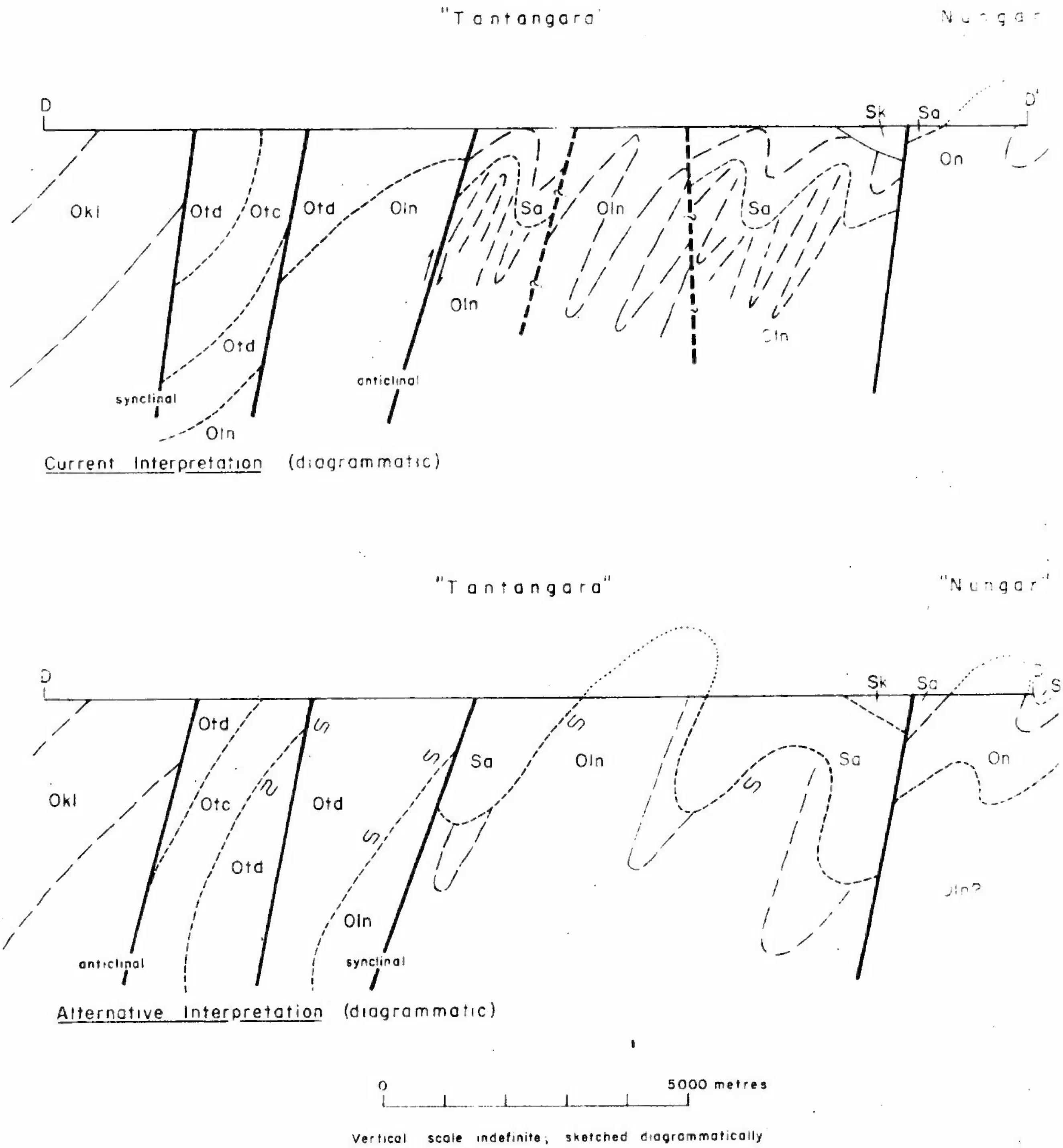


| | | |
|---|---|---|
| Sk | *Kellys Plain Volcanics* | |
| Sa | *Tantangara Beds* | |
| On | *Nungar Beds* | |
| Okl | *Lava* | *This sequence is reversed in the alternative interpretation* |
| Otc | *Chert* | |
| Otd | *Chert and tuff, interbedded* | |
| Oln | *Bolton Beds* | |

| | |
|---|---|
| – – – – – | *Geological boundary* |
| — — — | *Trace of bedding* |
| S | *Drag fold (diagrammatic)* |
| ▬▬ | *Fault* |
| "Tantangara" | *Fault block* |

**Fig. 49. Section D–D' (diagrammatic).**

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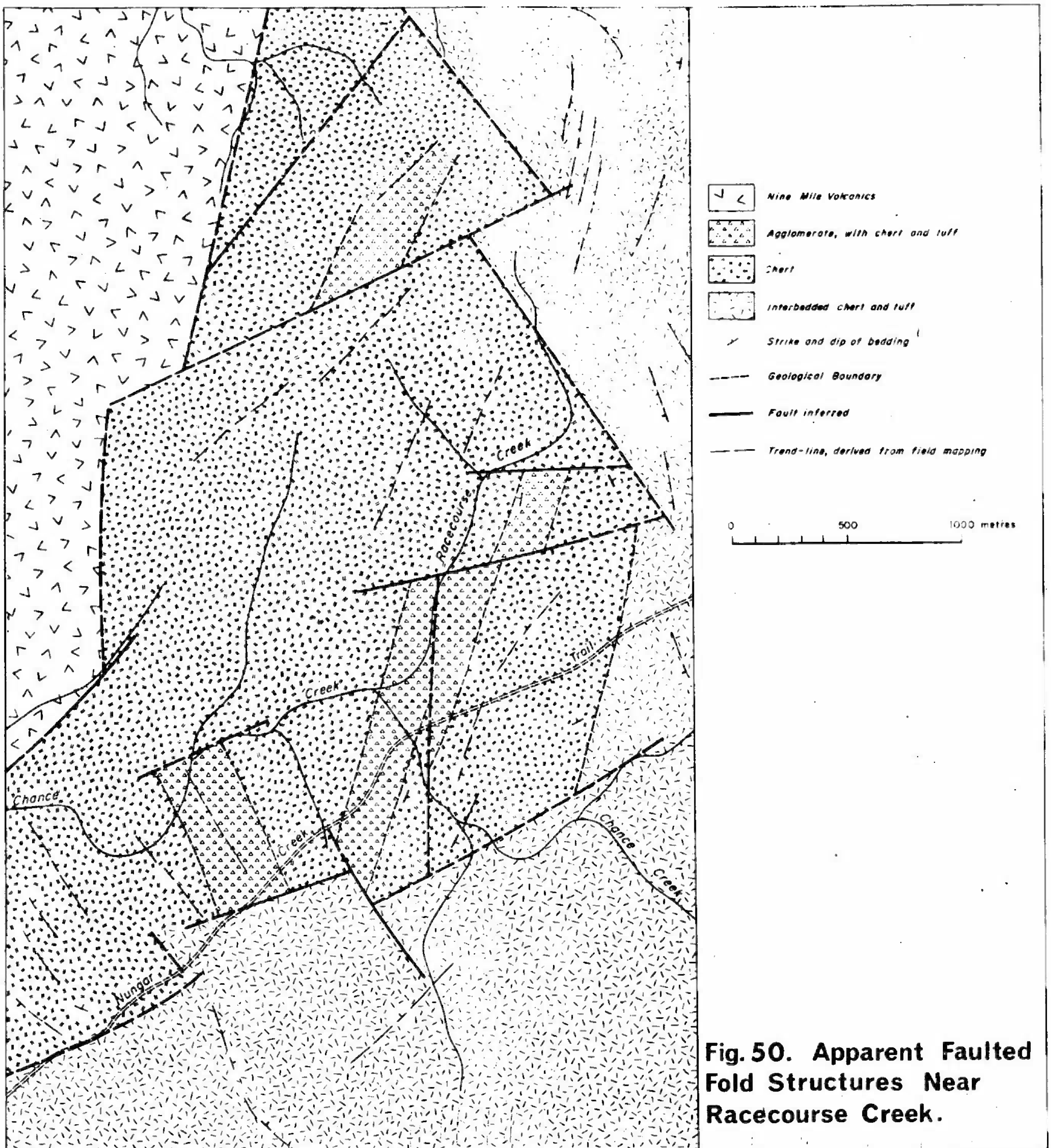
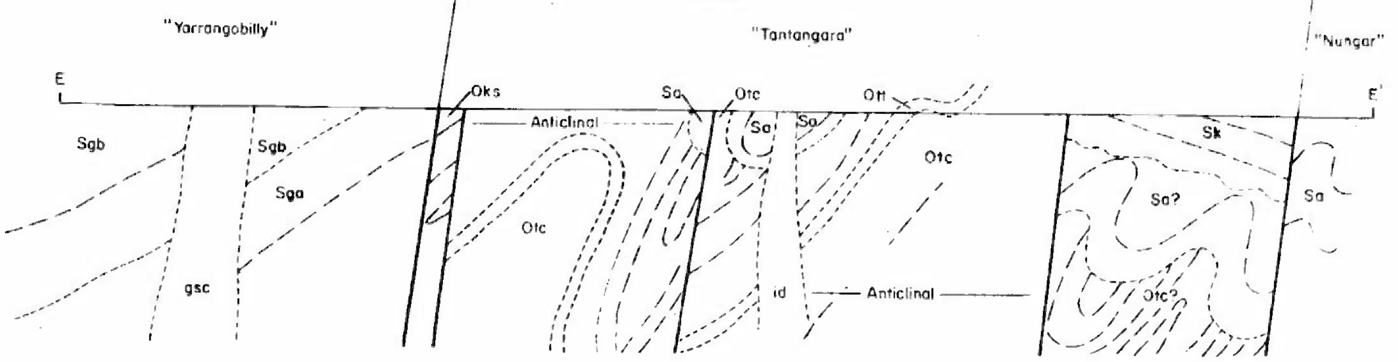
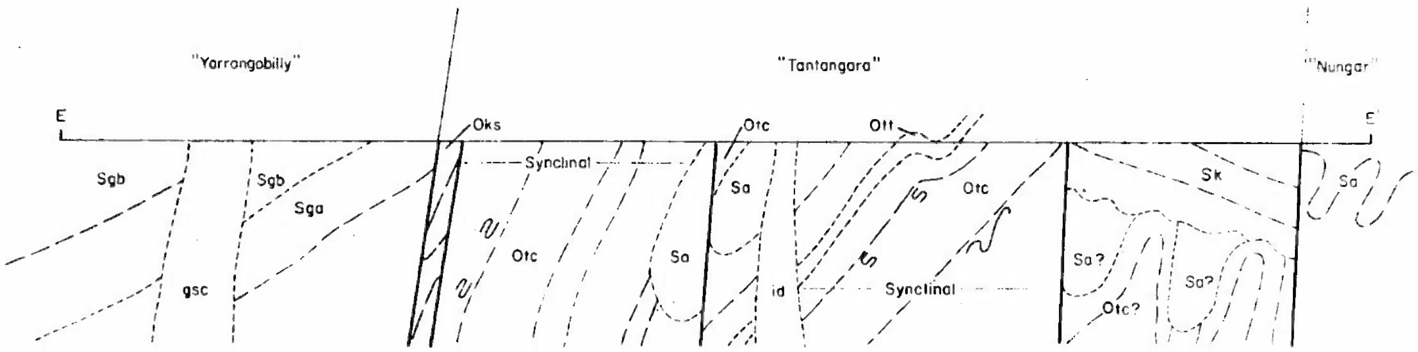



**Fig. 50. Apparent Faulted Fold Structures Near Racecourse Creek.**




Current Interpretation (diagrammatic)

Anticline with minor syncline




Alternative Interpretation (diagrammatic)

Syncline with minor anticline

| | | |
|---|---|---|
| Sk | *Kellys Plain Volcanics* | |
| Sgb<br>Sga | *Goobarragandra Beds* | |
| Sa | *Tantangara Beds* | |
| | *Nine Mile Volcanics* | This sequence is reversed in the alternative interpretation |
| Oks | *Sediment and tuff* | |
| | *Temperance Chert* | |
| Ott | *Tuff* | |
| Otc | *Chert* | |
| id | *Unnamed diorite intrusion* | |
| gsc | *Spicers Creek Granodiorite* | |

*Trace of bedding (diagrammatic)*

*Drag fold (diagrammatic)*

*Fault*

"Nungar" *Nungar block*

*Geological boundary*

Horizontal 0 — 5000 metres

Vertical scale indefinite; sketched diagrammatically

**Fig. 51. Section E – E'.**

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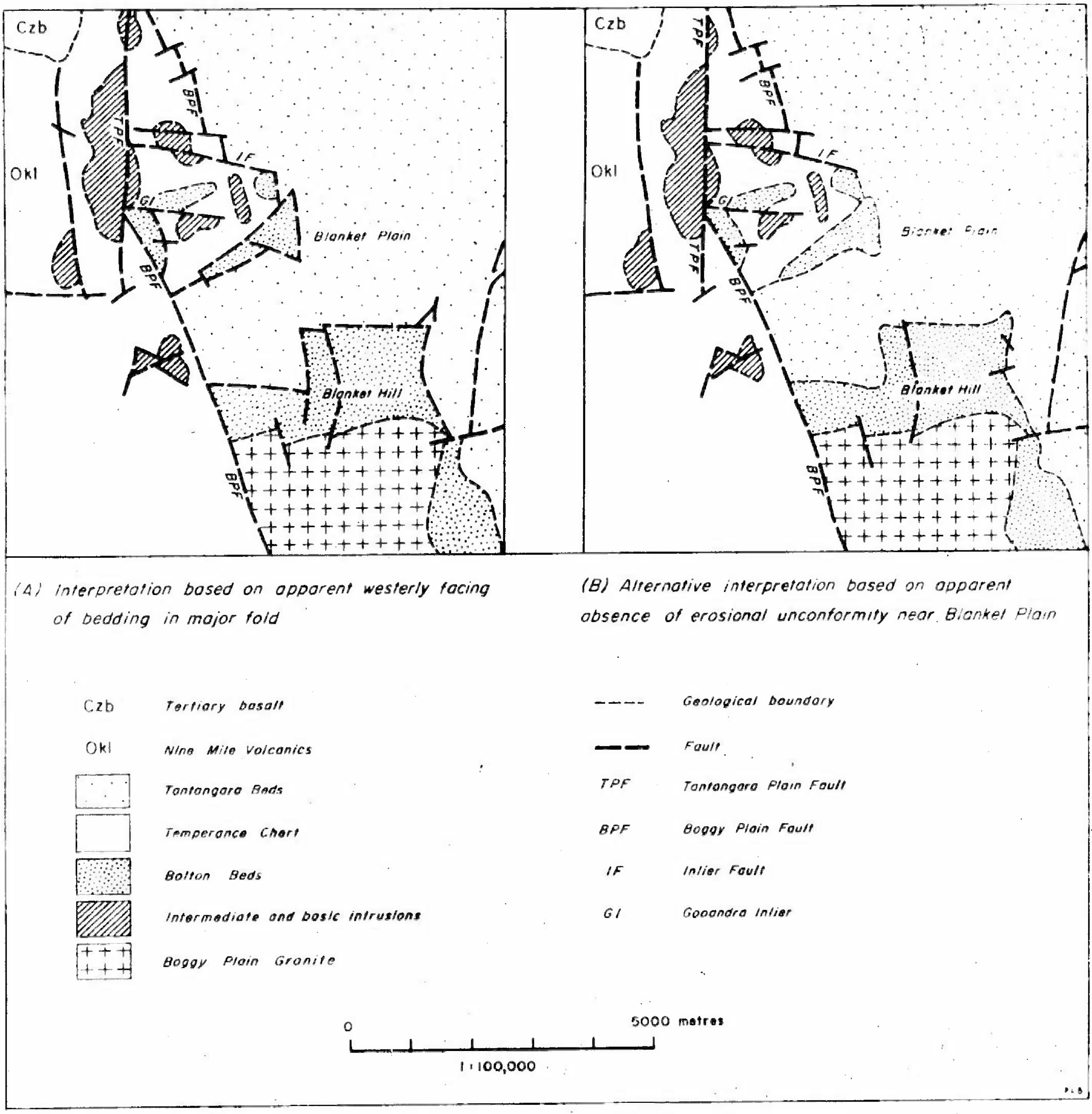


(A) Interpretation based on apparent westerly facing of bedding in major fold

(B) Alternative interpretation based on apparent absence of erosional unconformity near Blanket Plain

**Fig. 52. Alternative interpretations of structural and stratigraphic relations of Tantangara Beds and Bolton Beds near Blanket Hill and Blanket Plain.**

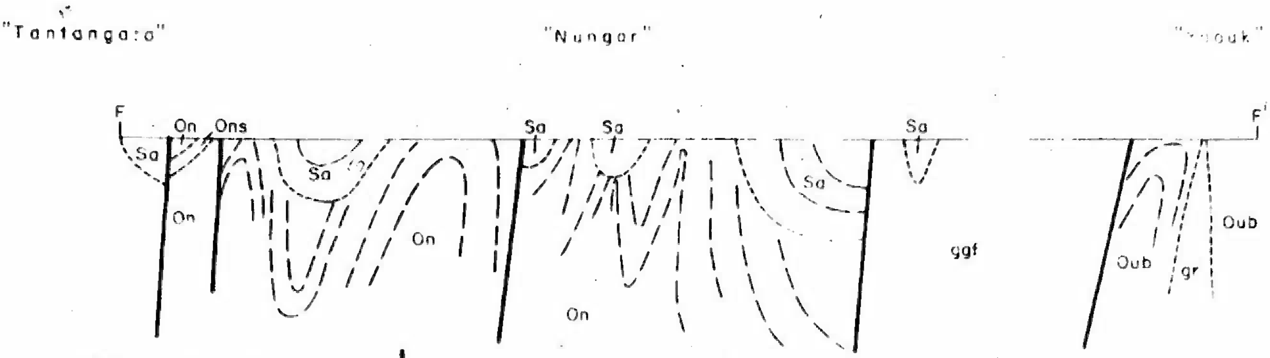


**Fig. 53. Section F—F'.**

M(S) 303

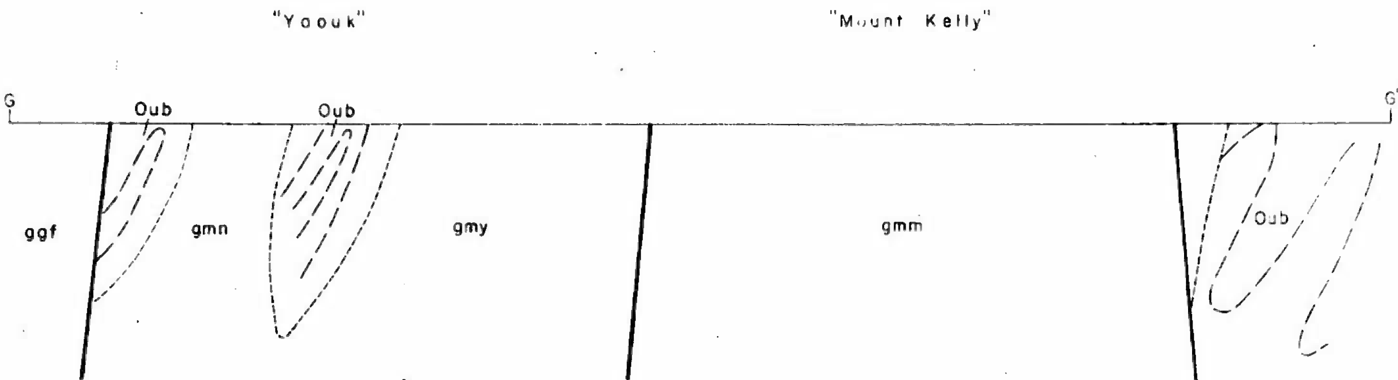


**Fig. 54. Section G—G'.**

0 5000 metres

Vertical Scale indefinite; sketched diagrammatically

| | | | |
|---|---|---|---|
| Sa | *Tantangara Beds* | -------- | *Geological boundary* |
| On | *Nungar Beds* | S | *Drag fold (diagrammatic)* |
| Ons | *Slate bed in Nungar Beds* | ——— | *Fault* |
| Oub | *"Adaminaby" Beds* | — — — | *Trace of bedding (diagrammatic)* |
| ggf | *McLaughlins Flat Granodiorite* | "Yaouk" | *Fault block* |
| gmn | *Shannons Flat Adamellite* | | |
| gmy | *Yaouk Leucogranite* | | |
| gr | *Unnamed granite intrusion* | | |

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Major fold (Figs. 48, 49, 51)

Fairbridge et al., (1951) mapped west-facing beds at several localities along Temperance Creek and the Tumut and Happy Jacks Rivers; they concluded that the area is situated on the eastern limb of a major syncline. In the present investigation, contemporaneously deformed beds in the highway cutting on Sawyers Hill were thought to be west-facing. An alternative interpretation, based on the apparent absence of an erosional unconformity between the Bolton Beds and the Tantangara Beds is given at the end of these notes on structure.

Subsidiary folds (Fig. 48)

If the major fold is synclinal, the subsidiary fold at Racecourse Creek must also be synclinal, even though the attitudes of the bedding suggest an anticline. It must be flanked by minor anticlines. Trend-lines that can be found on the aerial photographs of the area (Fig. 50) appear to outline the syncline and an anticline on its eastern side, both disrupted by faulting. The structure north of McPhersons Creek must be anticlinal.

In the Racecourse Creek syncline, foliation that could be axial cleavage dips 50° to 80° in a direction 315° to 320°. The apparent folding of the agglomerate bed at this locality was deduced from the structural interpretation of the surrounding area, and so depends on the accuracy of that interpretation; the stratigraphic boundaries were drawn to enclose scattered outcrops of agglomerate, taking account of the predominant strike of the bedding. The trough of the syncline can apparently be recognized in the attitude of the bedding south of the Wild Horse Plain Fault. Widening of the outcrop area towards the northwest, north, and north-northeast suggests that the presumed syncline plunges towards the north.

A fold structure at McPhersons Creek is suggested by a change in the strike of the bedding from about 030° near Long Plain to 060° near McPhersons Creek and, apparently around an anticlinal nose, to a direction of 170° to 190° near Nattung and Dairymans Plain. Cleavage and bedding near McPhersons Creek both dip southeasterly, which suggests overturning with the axis dipping in this direction. Widening of the outcrop area towards the south-southeast would indicate that the anticline, like the syncline of Racecourst Creek, is plunging northward.

Cross-folds

A northeasterly to easterly strike of the bedding suggests the presence of cross-folding in the area between Sawyers Hill and Tantangara Mountain, at Blanket Hill, at the Gooandra Inlier west of Blanket Plain, and south of the junction of Tantangara Creek and the Murrumbidgee River. The subsidiary fold near McPhersons Creek has a foliation close to that of the cross-folds. The fold near Tantangara Mountain and that near Blanket Hill are on opposite sides of the Boggy Plain Fault; if the apparent 4500 m horizontal component of movement suggested under Faulting be removed, the folding in the two areas merges into a single cross-fold. Similarly, the McPherson Creek subsidiary fold and the Tantangara Creek cross-fold, which are on opposite sides of the supposed displaced northern part of the same fault, would merge into a second cross-fold.

Sawyers Hill to Tantangara Mountain (Fig. 48). The strike of the bedding is northeast to east-northeast at Sawyers Hill and east to slightly south of east at Tantangara Mountain. Cleavage, and the attitudes of minor folds suggest that the cross-fold is overturned and dips northerly; northward-dipping cleavage was measured at two localities near Sawyers Hill and at another north of Tantangara Mountain; the bedding is tightly folded, presumably isoclinally, and dips are all to the north.

Blanket Hill (Fig. 49). The prevailing strike of the Bolton Beds on Blanket Hill, like that north of Tantangara Mountain, ranges from slightly south to slightly north of east; the beds dip to the north.

Gooandra Inlier. The bedding in the southern and eastern parts of the area around the Gooandra Inlier strikes east to northeast and dips north; a tight fold at GR420362 is overturned and dips slightly west of north. The attitude of the bedding and the overturned fold suggest a possible overturned anticlinal cross-fold, with the Bolton Beds exposed at the crest.

Near the mouth of Tantangara Creek. In the cross-folded area south of the mouth of Tantangara Creek, the chert unit is overlain by the upper part of the interbedded tuff and chert. Near the boundary, at least on the eastern side of the area, the structural pattern is similar to that near Tantangara Mountain. The chert is tightly folded and dips slightly east of north, indicating an overturned cross-fold.

Folding of the Silurian strata: Tantangara Beds (Fig. 49, 51). Tightly folded Tantangara Beds unconformably overlie the Bolton Beds and the Temperance Chert. They are bounded on the west by the Boggy Plain Fault. The northward elongation of the outcrop area suggests that the main syncline trends north; this accords with the general trend of the bedding in the Nungar block. West of Nungar Range Fault numerous easterly strikes suggest cross-folding of the Tantangara Beds, similar to that in the Ordovician beds.

Peppercorn Beds. South of the Murrumbidgee River, moderately folded Peppercorn Beds unconformably overlie the tightly folded Tantangara Beds along a boundary that is 2 to 4 km west of the Tantangara Fault. They were deposited in a sedimentary basin that occupied part of the site of the earlier syncline. Farther north, they rest directly on the Temperance Chert and the Nine Mile Volcanics. The Peppercorn Beds, unlike the Tantangara Beds, started with a basal conglomerate.

Silurian volcanics. The Silurian volcanics were extruded subaerially on an eroded surface that extended over all the earlier formations. They have been gently folded in a shallow syncline or basin that appears in this area to coincide approximately with the basin in which the Peppercorn Beds were deposited.

## ALTERNATIVE INTERPRETATION OF STRUCTURE IN THE TANTANGARA BLOCK (Fig. 52)

In the interpretation given in the preceding paragraphs, the Ordovician beds are thought to be facing west; if this is correct, the Bolton Beds must be the oldest beds in the area.

Along the boundary that runs south of and parallel to Blanket Plain Creek, and northwards through Blanket Plain Creek, and northwards through Blanket Plain to an easterly-striking fault, here termed the Inlier Fault, the Bolton Beds are in contact with beds that were mapped as Tantangara Beds. The boundary must be either a strong angular unconformity, or it must be faulted; it has been inferred to be faulted, and is shown as such on the geological map and in Fig. 52A. Its inferred position is based on slight lithological differences, principally the presence of small outcrops of chert and of argillitic arenite and argillite in a sequence of predominant arenite and quartzite.

Where the Tantangara Beds are in contact with the Temperance Chert along Tantangara Creek, and along a boundary that trends north-northeast from the Inlier Fault, a distinct lineament is visible on the aerial photographs, and is interpreted as the Boggy Plain Fault. Where the Tantangara Beds are in contact with the Bolton Beds there is little or no suggestion on the aerial photographs of a structural or depositional break. Similarly, on the northern and western sides of Blanket Hill, the aerial photographs give little sign of a break in the sedimentary sequence. In the field, there is no definite lithological change from the Bolton Beds to the Tantangara Beds; there is no suggestion of a basal conglomerate, or even of coarse sandstone. The apparent absence of structural and lithological breaks suggests that the succession upwards from the Temperance Chert through the Bolton Beds to the Tantangara Beds is interrupted only by a slight angular unconformity or a disconformity (Fig. 52B), a temporary cessation of deposition, but not by a subaerial erosional unconformity. The narrow outcrop areas of the Bolton Beds along Blanket Creek and on Blanket Hill are, it is suggested, an expression of this discontinuity. It could have been due to warping or tilting of the sea-floor. Exposures in the area are poor, and the boundaries that are shown are very approximate; possibly the Bolton beds are more extensive than they appear to be on the map. If the supposed 4500-m horizontal component of movement on the Boggy Plain Fault be removed by relative southern movement of the eastern side, the Bolton Beds on the western side would coincide roughly with the area on the eastern side that is occupied by the Bolton Beds and the Tantangara Beds.

This alternative interpretation implies that the major fold is an overturned anticline, not a syncline. The subordinate fold at Racecourse Creek would be anticlinal, and that McPhersons Creek would be synclinal. The cross-folds would be overturned anticlinal structures, except that at Gooandra Inlier where there would be a minor overturned syncline. Bedding in the major fold would be younging to the east. However, west-facing beds would be present in subordinate synclines, such as those that would flank the apparent anticline at Racecourse Creek.

In the north east of Rules Point, the Tantangara Beds are in contact with chert. The boundary strikes generally northeasterly to Nattung Hill, and then southwest and south-southwest to a fault that strikes east to Dairymans Plain. The general attitude of the bedding is the same on either side of the boundary, and there is no basal conglomerate. It is apparently similar to the boundary near Blanket Plain, and could be due to an extension of the supposed submarine tectonic disturbance; this could even involve faulting of the sea-bed along the straight north-northeasterly striking segments of the northern boundary.

NUNGAR BLOCK (Fig. 53)

The Nungar Block consists of Late Ordovician and Early Silurian strata that strike predominantly north and slightly east of north, and are folded together in a number of anticlines and synclines whose axes strike about north. A northeasterly strike suggests possible cross-folding in the southern part of the block. At the western boundary, the distribution of Silurian volcanics and Late Silurian sediments on either side of the Tantangara Fault indicates that the Nungar block was upthrown. As its Ordovician strata are younger than those in the Tantangara block, it must be synclinal with respect to that block.

Most of the Ordovician beds dip vertically or nearly so. Many of the Early Silurian beds are as steeply dipping, but others dip at 70° to 80°; this suggests a mild angular unconformity between the Late Ordovician and the Early Silurian.

The Synclinal relation of the Nungar Block to the Tantangara block is difficult to reconcile with the current interpretation (Fairbridge et al, 1951; Moye et al., 1963) that the Tantangara block is synclinal. It fits in naturally with the alternative interpretation that the Tantangara block is anticlinal. Following the alternative further, it is suggested that the Late Ordovician and the Early Silurian were deposited without any subaerial erosional unconformity, in the same geosynclinal trough; the mild angular unconformity represents a temporary cessation of deposition owing to warping and deformation of the sea-floor.

BIMBERI, MOUNT KELLEY, YAOUK, AND ADMINABY BLOCKS (Figs. 47, 53, 54)

Detailed information on the structure of these blocks is not available. The Bimberi, Mount Kelly, and Yaouk blocks consist of closely folded Late Ordovician sediments that strike nearly north; they are intruded by granitic rocks which occupy most of the Bimberi and Mount Kelly blocks. Dips in the sedimentary strata range commonly from about 60° to vertical, but lower dips are present; this suggests that the folding is slightly less intense than in the Nungar block.

The strata exposed in the Yaouk block are on the whole older than those in the Nungar block, yet the Yaouk block is on the downthrown side of the Cotter reverse fault; this suggests that the Yaouk block is anticlinally related to the Nungar block. Table 55B suggests that the Bimberi block is anticlinal, that the Mount Kelly block is synclinal in the west, changing to anticlinal in the east, and that the Yaouk block is probably synclinal. The Adaminaby block is possibly synclinal, and may be a displaced part of the Nungar block.

## 9. Mineral Deposits

(M.O. and D.W.)

The Tantangara area is typical of much of the Tasman Geosyncline in that, except for gold, known mineral deposits are small and mostly uneconomic.

The Kiandra goldfields at the time of their discovery were one of the richest in Australia, and a major goldrush developed. The field was discovered in November 1859, and the population rapidly rose to exceed 10 000 by April 1860, over 3000 of which remained in Kiandra over the winter. However by the end of 1860 the easily won gold had been worked out and the population had fallen to about 250 by March 1861. The total amount of gold production, according to official figures, from 1859 to the present is 172 000 oz, but it probably exceeds 200 000 oz, because much of the early production was not recorded. The history of the goldfields has been documented in detail by Andrews (1901) and Moye (1959).

The gold was initially found, and worked from recent alluvium, but most of the gold was won from Tertiary gravels preserved under the basalt capping of many hills around Kiandra. Many of the workings, and all the rich ones, are outside the Tantangara 1:100 000 Sheet area; those within the area are Basalt Claim (G.R. 355250) which yielded poor returns; and the Six Mile workings (G.R. 361357) which yielded good returns for a short time in 1860. Elsewhere in the area much prospecting was done in the 1860s, generally with limited or no success.

Sulphide orebodies have a limited occurrence in the area, the main one being at Mount Black Mine, about 200 m west of Spencers Hut on Cooleman Plain (G.R. 522556). Two shafts 13 m and 7 m deep were sunk in 1939, and a short horizontal drive was extended from the lower shaft. They proved an orebody of limited extent, which has recently been studied in detail by Ashley and Creelman (pers. comm.).

Ashley and Creelman consider that the deposit, which occurs in the Cooleman Limestone immediately below the contact with the overlying Blue Waterhole Beds, developed in a joint-controlled collapse breccia zone, which they interpret as a palaeokarst structure.

Limestone fragments in the breccia appear to have been replaced by a variety of minerals, including quartz, sphalerite, galena, and minor chalcopyrite, pyrite, marcasite, tetrahedrite, arsenopyrite, and mackinawite. Both Ashley &Creelman and Gilligan (1973) have recognized many similarities between the Mount Black deposits and Mississippi Valley-type ore deposits.

Extensive gossan is present at the southern end of Smiths Range (G.R. 483363) and a shaft was sunk in the early 1900s (T. Taylor, Currango, pers. comm.). The shaft is still in existence and is about 30 m deep, though in a very dangerous condition and should not be entered. It apparently failed to find an economic orebody. Evidence from the adjacent tip indicates that the dominant sulphide mineral was pyrite, with minor galena, sphalerite, chalcopyrite, and marcasite. The host rock is rhyodacite tuff, some of which may be reworked waterlain tuff, and the mineralization apparently occurs in veins, with quartz as gangue mineral.

Elsewhere, gossans are rare, possibly owing to the dominance of mechanical rather than chemical weathering in the area. A gossan of limited extent, 3 km south-southeast of Dennison Hill (G.R. 495168) has developed over black slate considered to be part of the Nungar Beds, and gave trace element values of Cu - 1195 ppm, Pb - 70 ppm, and Zn - 820 ppm. A gossan was also observed in the Peppercorn Creek valley (G.R. 482623), developed over black slate within the Nine Mile Volcanics.

Ironstone deposits are common on Cooleman Plain, and several of the largest are shown on the accompanying 1:1 000 000 map. Most apparently consist of limonite nodules, representing a ferruginized gravel, on top of limestone, though some may be true gossans.

A large magnetite deposit occurs just north of Jackson Trig. at G.R. 537619, in a joint which extends from within the Jackson Granite into the Mountain Creek Volcanics. Mineralization occurs over a total length of 1000 m, is up to 20 m wide, and the deposit was examined in some detail.

Petrography:

Samples from the deposit have a simple mineralogy of either one or two major phases and very small amounts of other phases. Assemblages present are:-

1. Monomineralic
   a) magnetite
   b) hydrogrossularite
   c) chlorite
   d) epidote

2. Two-phase assemblages
   a) magnetite - quartz
   b) magnetite - hydrogrossularite
   c) quartz-chlorite
   d) quartz - epidote

Sample 72841027 is a magnetite rock. It consists of about 90% red-brown magnetite partly altered to hematite along crystallographic planes. The magnetite has been shattered and the resulting cracks have been filled with limonite, chlorite, and minor quartz and epidote. One crack is up to 10 mm wide.

Sample 72841025 is a hydrogrossularite rock. It consists of about 95% strongly zoned euhedral to subhedral grains of hydrogrossularite up to 3 mm across. Much of the garnet is strongly anisotropic. A few patches of interstitial quartz up to 3 mm across contain rare magnetite octahedra up to 0.4 mm across. Also present are a few interstitial patches of hematite up to 0.8 mm across partly altered to goethite.

Sample 72841024 is a chlorite rock. It consist almost entirely of chlorite flakes about 0.05 mm across in random orientation. The chlorite is biaxial negative and pleochroic from green to pale yellow-brown. It probably contains interlayered biotite as many flakes have mottled birefringence. Patches of the chlorite have been iron-stained and these surround limonite veins less than 0.2 mm wide. Quartz is scattered throughout as anhedral grains and patches up to 2 mm across. Magnetite partly altered to hematite and goethite occurs as uncommon inclusions in the quartz grains. Pyrite and chalcopyrite occur as very rare inclusions up to 0.1 mm across in the quartz.

Sample 72841026 is an epidote rock. It contains 95% euhedral to subhedral crystals of epidote up to 2 mm x 0.3 mm. The epidote has $2V_x = 80^\circ$. Also present are a few grains of apatite up to 0.3 mm across. Quartz occurs as interstitial grains about 0.2 mm across and anhedral hematite occurs in rare composite patches up to 0.2 mm across.

Sample 72841039 is a quartz-magnetite rock. It contains about 45% magnetite as interconnected masses averaging 1 mm across. The magnetite is red-brown under reflected light but where crystal faces occur the rims are grey-brown. Hematite forms blades along crystallographic directions in the magnetite. A few patches of goethite are present and specular hematite crystals penetrate these from adjacent magnetite masses. The rest of the rock (50%) consists of patches of fine-grained vein quartz interstitial to the magnetite and about 1 mm across. The quartz grains are up to 1 mm across but most are about 0.1 mm across.

Sample 72840268 is a magnetite - hydrogrossularite rock. Magnetite (40%) consists of interconnected subhedral to anhedral grains and irregular masses up to 3 mm across. Two distinct phases of magnetite development have occurred. The first has resulted in the formation of red-brown magnetite, the second has produced a grey-brown magnetite rim around the red-brown cores. The boundary between the different coloured magnetites is very sharp. Hydrogrossularite (55%) and interstitial quartz (5%) make up the rest of the rock. The garnet occurs as strongly zoned euhedral to subhedral crystals up to 1 mm across. Some of the garnet grains cross cut the magnetite growth pattern. This indicates that either the garnet is a later phase that has partly replaced the magnetite or the garnet has been tectonically pushed into the magnetite grains.

Sample 72841031 is a quartz-chlorite-epidote rock. Unoriented flakes of chlorite (X=pale yellow brown, Y=Z=green, biaxial negative) averaging 0.05 mm across occur throughout (50%). Some green-brown biotite is interlayered with the chlorite and in a few areas biotite is in greater abundance than chlorite. Quartz (30%) occurs as anhedral grains up to 0.3 mm across scattered throughout. In some areas of the thin section the quartz grains are corroded where as in others they have undergone grain overgrowth. Anhedral epidote (10%) up to 0.1 mm across occurs in patches up to 2 mm across. Chlorite is absent in these patches but quartz is present.

Opaques present in sample 72841031 are magnetite, hematite, and geothite. Magnetite (5%) occurs as euhedral grains and clusters of grains up to 1 mm across embedded in chlorite. A few blades of specular hematite and highly martitized magnetite occur together. The hematite is partly altered to goethite.

Geochemistry:

Seventeen samples from the magnetite body were analysed by atomic absorption spectroscopy and emission spectroscopy. Results are shown in Table 56. In addition to these results, Y, Sc, Sr, Ba, Rb, Cs, Au, Th, Ru, Rh, Ir, and Nb were not detected by emmission spectroscopy, though detection limits were high.

Table 56 shows that Zn, Bi, W, and Sn are significantly enriched compared to normal crustal abundances. Considering the high concentrations of iron in these magnetite-rich rocks, the concentrations of Ni, Cd, V, and Ti are very low.

The Jackson Granite is a leucocratic rock low in MgO, FeO, and CaO. It is probable that these oxides, together with Zn, Bi, W, and Sn could not be accommodated into the granite and were expelled with the fluid phase when the granite magma crystallized. The Jackson Granite is a high-level granite that crystallized under very low load pressures so it is unlikely that the magnetite was caused to crystallize by a large decrease in pressure. Rather the magnetite was probably caused to precipitate from solution by a large decrease in temperature and wallrock reactions (chloritization and epidotization) decreasing the activity of elements in solution. It is not known whether the iron, magnesium, calcium, and various trace elements were original constituents of the hydrous magma or whether they were from the residues of partly assimilated xenoliths. Parts of the Jackson Granite contain abundant xenoliths (Figs. 69-70 and p. 299).

East of Seventeen Flat a magnetite-hematite deposit occurs along the Black Mountain Fault from G.R. 549536 to G.R. 558508 - a strike length of 3000 m. The deposit has not been studied in detail but it may have formed by a similar process to the Jackson Mountain deposit. An analysis of trace elemenus in a magnetite sample from this deposit gave Mn 2320 ppm, Cu 20 ppm, Pb 210 ppm, and Zn 225 ppm.

Thirty kilometres west of Jackson Mountain an iron and magnesium skarn occurs adjacent to the Bogong Granite. The skarn has developed in the northern end of the Late Silurian Yarrangobilly Limestone north of Yarrangobilly Village and at Black Perry Mountain (Yarrangobily 1:100 000 Sheet area). The Bogong Granite has a similar composition and age to the Jackson Granite. The iron and magnesium in this deposit was probably derived by a similar process to the Jackson Mountain deposit.

## 10. Geological History

(M.O. and D.W.)

An interpretation of the Ordovician geological history of the Tantangara area depends on the stratigraphic position assumed for the Bolton Beds.

TABLE 56. TRACE ELEMENT ANALYSES, JACKSON MOUNTAIN MAGNETITE DEPOSIT

| Sample | Cu | Pb | Zn | Co | Ni | Cd | Bi | Cr | Be | V | W | Mo | Ag | Ga | Ge | Sn | Li | Ti |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72841024 | 130 | 22 | 550 | 80 | 15 | 3 | X | X | 1 | 10 | X | 3 | X | 20 | 3 | 2000 | 25 | 800 |
| " 25 | 2 | 12 | 20 | 18 | 8 | 3 | 10 | X | X | 30 | 300 | X | X | 3 | 3 | 300 | 3 | 600 |
| " 26 | 2 | 20 | 120 | 18 | 22 | 1 | 10 | 5 | 1 | 50 | X | X | X | 15 | X | 200 | 25 | 3000 |
| " 27 | 38 | 100 | 110 | 70 | 22 | 3 | 1500 | 15 | X | 30 | 50 | 3 | 0.1 | 5 | 1 | 100 | 5 | 600 |
| " 28 | 12 | 20 | 60 | 55 | 20 | 4 | 70 | 10 | X | 30 | 50 | 5 | X | 3 | 1 | 120 | 5 | 600 |
| " 29 | 10 | X | 190 | 75 | 60 | 3 | 10 | 10 | X | 10 | X | X | 0.1 | 3 | X | 80 | 5 | 600 |
| " 30 | 55 | X | 120 | 50 | 18 | 4 | X | 10 | X | 20 | X | X | X | 3 | X | 120 | 15 | 600 |
| " 31 | 1250 | X | 330 | 50 | 18 | 4 | X | 28 | 3 | 10 | X | X | 0.1 | 5 | X | 100 | 30 | 2000 |
| " 32 | 55 | 10 | 160 | 80 | 22 | 3 | 40 | 15 | X | 30 | 50 | 3 | 1.0 | 5 | 1 | 150 | 10 | 800 |
| " 33 | 18 | X | 600 | 110 | 20 | 3 | X | X | 1 | 20 | 50 | X | X | 10 | 1 | 120 | 30 | 1500 |
| " 34 | 25 | 5 | 250 | 85 | 25 | 4 | X | 5 | 3 | 50 | X | X | X | 10 | 3 | 120 | 20 | 1500 |
| " 35 | 18 | 30 | 90 | 80 | 25 | 4 | 70 | 10 | 1 | 10 | 50 | X | X | 3 | X | 120 | 1 | 800 |
| " 36 | 25 | 40 | 75 | 110 | 20 | 4 | 120 | 8 | 3 | 1000 | 50 | X | X | 3 | 10 | 50 | 3 | 600 |
| " 37 | 15 | 5 | 65 | 70 | 35 | 1 | X | 10 | 1 | 20 | 50 | X | 0.1 | 3 | 3 | 100 | 5 | 600 |
| " 38 | 8 | X | 38 | 85 | 20 | 2 | 10 | 8 | 2 | 10 | 50 | X | X | 3 | 5 | 50 | 10 | 300 |
| " 39 | 20 | 25 | 60 | 120 | 22 | 3 | 90 | 5 | 3 | 50 | 80 | X | 1.0 | 3 | 10 | 80 | 30 | 1000 |
| " 40 | 100 | 10 | 65 | 60 | 22 | 4 | X | 10 | X | 10 | 50 | X | X | X | X | 80 | 8 | 1000 |

Results in ppm

X = not detected

Cu, Pb, Zn, Co, Ni, Cd, Bi, Cr, analysed by A.A.S.

Be, V, W, Mo, Ag, Ga, Ge, Sn, Li, Ti, analysed by E.S.

Traditionally they have been considered to be the oldest unit in the area and to have been overlain conformably by the Temperance Chert and Nine Mile Volcanics (Fairbridge et al., 1951; Moye et al., in Packham (ed.), 1969; Strusz, 1971). More recently Crook et al (1973) have suggested, mainly on the basis of a model for the evolution of the Lachlan Geosyncline, that the Bolton Beds may be younger than the Nine Mile Volcanics and Temperance Chert, and tentatively indicate that a minimum age of early Wenlockian is possible. We dispute the conclusions of Crook et al. (1973) as we consider that the passage from Bolton Beds to Temperance Chert in the Happy Jacks area is conformable (see p. 38).

Recent mapping by Williams (1974) has provided much additional evidence from southwest of the Happy Jacks area as far south as Jagungal and allows a new interpretation of the relation of the Bolton Beds to the other Ordovician units of the area. Williams presents compelling evidence that the basic rocks of the Jagungal area, previously considered to be intrusive (Hall & Lloyd, 1954, Joplin, 1958) in fact represent part of an ophiolite sequence and are abyssal tholeiitic basalts. Williams claims that pillow lava structures are present and gives trace element data for two samples, which, when plotted on the type of variation diagrams used by Pearce & Cann (1973) also suggest that the Jagungal rocks are abyssal tholeiites. These basalts are overlain by a thick chert sequence, with interbedded fine arenite and minor tuffaceous beds, continuous in outcrop with the Temperance Chert in the Happy Jacks area. The chert sequence passes up to the northwest and with apparent conformity into Nine Mile Volcanics, the Bolton Beds being absent.

William's mapping shows that the Bolton Beds do not extend farther south than the area of Far Balt Mountain (G.R. 314099, Kosciusko 1:100 000 Sheet area) being in part cut off by the Happy Jacks Granite complex and in part either lensing out into chert or being faulted out of the sequence. The former is considered more likely by us, and so the Bolton Beds may be considered as a thick wedge of fine clastic material developed to the north, as a unit within the Temperance Chert.

## Geological History

The history of the area throughout the Ordovician may therefore be as follows. Sometime during the Early or Middle Ordovician submarine eruption of tholeiitic abyssal basalt ceased in the area and chert sedimentation commenced. Chert formation (Temperance Chert) was interrupted for a time in the Happy Jacks area northweard by the deposition of fine sand and clay, presumably during the Darriwillian. These sediments (Bolton Beds) appear to represent a distal flysch sequence, presumably derived from the north, though the source area is unknown. A correlation seems likely with the Pittman Formation in the Canberra area, the lower part of which was dated by Opik (1958) from graptolite faunas as Darriwillian in age; it also represents a distal flysch facies (Crook et al., 1973, p. 123).

Within the Tantangara to Happy Jacks area chert-dominated sedimentation resumed after the clastic sediments (Bolton Beds) ceased to reach the area sometime in the Darriwillian. At about the same time tholeiitic volcanicity (related to the Nine Mile Volcanics) began in adjoining regions, although only a little tuffaceous material reached the Tantangara area initially. The cessation of sand deposition at this time could have been related to the development of the volcanic arc stopping turbidity currents reaching the area. Volcanic activity gradually increased in intensity and massive lava was extruded in the Peppercorn Creek area, where the sea shallowed sufficiently to allow corals to grow (Legg, 1968). Increasing volcancity in the region probably in the late Darriwillian led to tuffaceous beds dominating over chert, and to the development of the Nine Mile Volcanics. These Volcanics apparently represent a tholeiitic island arc complex which initially developed to the west and prograded eastwards over the earlier sediments.

Volcanism became dominant in late Darriwillian time (Nine Mile Volcanics) and eventually mainly lavas, some with pillows (Jeffrey, 1972) and flow breccias accumulated, together with clays, well into Gisbornian time (Opik, 1952, unpubl.).

Volcanic activity probably ceased in the area in the late Gisbornian or early Eastonian, and a return to flysch sedimentation (Nungar and Adaminaby Beds) took place in the Tantangara area, and over a large part of the Monaro area (the Monaro Slope and Basin of Scheibner (1973, p. 416). This continued into the Bolindian (Hopwood, in Packham (ed.), 1969, p. 94) and some of the sequence was eroded towards the close of the Ordovician as a result of slight folding (early phase of Benambran Orogeny), mainly inferred from the presence of the unconformity at the base of the Llandoverian Tantangara Beds. However, transposed bedding in the Nungar Beds may be related to this phase of folding, and Stauffer & Rickard (1966) have described very large recumbent folds of similar age east of Queanbeyan.

After this first phase of folding, flysch sedimentation resumed in the early Llandoverian (Tantangara Beds), some of the detritus being derived from older units within the area. Sedimentation was rapid but was soon brought to an end by a second, strong phase (equivalent to the Panuara phase of Packham, 1969) of folding which isoclinally folded the sediments in the mid-Llandoverian. Subsequent marine deposition in the Tantangara area was in a shallow shelf environment, and started in the late Llandoverian when pebbles, sand, silt, and some carbonate (Peppercorn Beds) accumulated. Parts of the shelf were virtually sediment-free, and conditions allowed carbonates (Cooleman Limestone) to accumulate from early Wenlockian to Pridolian time. A complex facies relation developed between the Cooleman Limestone and the chert and siltstone of the Blue Waterhole Beds during this period. While shallow water sediments were being deposited in the east calc-alkaline dacite, rhyodacite, and minor andesite (Goobarrangandra Beds) were being extruded in the west, mainly as extensive subaerial ignimbrite sheets with interbedded agglomerate and rare lava flows.

Folding in the Pridolian affected the Cooleman Plains sequence (broadly folded on east-northeast axes), and caused re-folding of the Ordovician and Early Silurian (Williams, 1974; den Tex, 1959).

Towards the end of the Pridolian calc-alkaline ignimbrite and agglomerate (Kellys Plain Volcanics) accumulated on an eroded and uplifted surface cut in the Cooleman Plains sequence, Tantangara Beds, and Ordovician rocks, and granitic bodies were intruded at depth (Murrumbidgee Batholith, Gingera Granite, McLaughlins Flat Granodiorite, Lucas Creek Granite, Happy Jacks Granite, and Young Granodiorite). Three varieties of Pridolian granites are recognized: contaminated granodiorite, uncontaminated adamellite, and leucogranite. The oldest is the foliated contaminated granodiorite (McLaughlins Flat Granoldiorite and Clear Range Granodiorite) which contains abundant metasedimentary xenoliths aligned along a primary foliation. It was probably intruded into regions of active meridional compression, initially by stoping and assimilation and finally by diapric rise. The contaminated granodiorite was followed by the intrusion of poorly foliated uncontaminated adamellite (Gingera Granite, Lucas Creek Granite, Happy Jacks Granite, and Shannons Flat Adamellite). It shows little evidence of assimilation and was most likely intruded by diapiric rise and minor stoping as the meridional compression decreased. When compression was minimal leucogranite (Yaouk leucogranite, Westerly Leucogranite) was able to rise diapirically.

After the Late Silurian acid volcanism (Kellys Plain Volcanics) there was a period of erosion before the extrusion of the Rolling Grounds Latite, (in the late Gedinnian) into valleys carved into the Kellys Plain Volcanic pile. The Rolling Grounds Latite is mineralogically, chemically and, spatially related to high-level intrusives of the Coolamine Igneous Complex intruded at the same time. These are in turn mineralogically chemically, and chronologically related to the Boggy Plain Granite, Hell Hole Creek Granite, and other minor intrusions which extend from Cooleman Plain in the north to 1 km west of Mount Jagungal (Kosciusko 1:100 000 Sheet area, G.R. 247986) in the south, a total distance of

75 km. Also associated with the Coolamine Igneous Complex and intruded at a similar time are high level acid intrusives, the Gurrangorambla Granophyre and Jackson Granite. The Rolling Grounds Latite is followed conformably by sub-aerial grey, blue, purple, and green banded rhyolite flows and rare rhyolitic tuff and reworked tuff. (Mountain Creek Volcanics).

The sequence was then strongly folded, probably in the Late Devonian, along north-south axes, particularly adjacent to the Long Plain Fault. There is no evidence of the history of the region from the Late Devonian to the Early Tertiary, and presumably it was being eroded.

Valley alluvium and lake deposits were present during the late Eocene and again in the early Miocene; both were covered by alkali olivine basalt of similar age to the sediments.

Uplift combined with movement along old faults in ?Miocene to Pliocene time (Kosciusko Uplift) caused rejuvernation of drainage. New stream patterns developed and near Yaouk extensive sheets of gravel west of the Cotter Fault were uplifted by about 60 m relative to those east of the fault. In the Pleistocene periglacial conditions existed, and erosion and solifluction resulted in extensive colluvial deposits masking slopes. In the Holocene the formation of alluvial deposits was widespread.

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## Appendix No. 1 Age Determinations

### 1. Potassium-Argon age determinations

Australian Mineral Development Laboratories (AMDEL) carried out K-Ar dating as summarized in Table 57.

Boggy Plain Granite. With the exception of the hornblende analysis of sample 73840170 very good agreement was obtained for K-Ar dating of the Boggy Plain Granite. The hornblendes in sample 73840170 have cores of augite and this resulted in an inhomogeneous concentrate being obtained. The age determination should be disregarded. The other Boggy Plain Granite samples give an age of 406 to 408 $\pm$ 10 m.y.

Peppercorn Hill basalt. The age of 23.2 $\pm$ 0.6 m.y. obtained for this basalt is slightly older than the ages of 18 to 22 m.y. obtained by Wellman (1971) for the Snowy Mountains Province basalts.

Micalong Swamp Basic Igneous Complex (unpublished name to be defined in the Brindabella 1:100 000 Sheet BMR Record). A good age determination of 387 $\pm$ 9 m.y. obtained for this sample indicates an Early to Mid-Devonian age. The Pigeon Square Gabbro is probably of similar age as it is mineralogically and chemically similar.

### 2. Rubidium-Strontium age determinations

Rb-Sr age determinations were carried out on the Goobarragandra Beds, Boggy Plain Granite, and Micalong Swamp Basic Igneous Complex by AMDEL.

Goobarragandra Beds. A suite of samples of volcanics from the Goobarragandra Beds was collected from the Snowy Mountains Highway northwest of Rules Point. Ten were selected for Rb-Sr analyses and the results are given in Table 58. The isochron is shown in Figure 72. It was fitted to seven points. Samples 71840569 and 71840546 have been rejected on geological grounds. Sample 71840569 comes from well to the north of the other samples, near known younger acid volcanics. Sample 71840546 comes from very close to the Long Plain Fault and is partly sheared. Sample 71840562 also lies off the isochron and has been rejected. The regression of the remaining seven samples gives an age of 438 $\pm$ 16 m.y. and an initial ratio of 0.7095 $\pm$ 0.0009. The initial ratio is intermediate between those of granites derived from sedimentary rocks such as the Cooma Gneiss and those derived from a more basic source. The magma that produced the Goobarragandra Beds volcanics probably originated at the base of the crust from both basic and sedimentary rocks.

Boggy Plain Granite. Nine samples of the Boggy Plain Granite, all from Boggy Plain, were collected for Rb-Sr age determination. Their approximate Rb and Sr contents are shown in Table 59. Six samples were selected for isotopic analyses. These results are shown in Table 60 and an isochron is shown in Figure 73. The slope of the isochron gives an age of 448 $\pm$ 130 m.y. and an initial ratio of 0.7042 $\pm$ 0.0010. The large error in the age is caused by a lack of sufficient spread in Rb-Sr for the total rock. The initial ratio is very low and indicates that the parent material was rather primitive. It is unlikely that the magma was derived from or contaminated by highly differentiated crustal material. In order to get a greater Rb-Sr spread the biotite concentrates from the K-Ar samples of the Boggy Plain Granite were analyses for Rb & Sr and an isochron constructed for each, using the initial ratio obtained from the whole-rock isochron. The results are shown in Table 61. The ages of 415 and 416 $\pm$ 5 m.y. are in good agreement with the K-Ar ages obtained.

Micalong Swamp Basic Igneous Complex. Thirteen samples of the Micalong Swamp Basic Igneous Complex collected for age determination all came from the slopes of Yankee Ned Hill (Brindabella 1:100 000 Sheet area, G.R. 382958) and both basic and more acid granophyric differentiates are present. It was hoped to get a good spread in Rb content by sampling a wide range of differentiates. The approximate Rb and Sr concentrations of the samples collected are shown in Table 62. Unfortunately the Rb content of the rocks is very low and a good spread in Rb-Sr is unattainable. Four samples were selected for isotopic analyses so at least an approximate idea of the age could be obtained. The results are shown in Table 63 and plotted in Figure 73 along with the samples from the Boggy Plain Granite. An isochron has not been fitted to the points because of the lack of sufficient Rb-Sr spread. From Figure 73 it can be seen that the points lie along a line approximately parallel with the Boggy Plain Granite isochron, thus the Micalong Swamp Basic Igneous Complex is fairly similar in age. The initial ratio of the complex is about 0.705 so it is unlikely that crustal contamination of the magma which produced the rocks has occurred.

TABLE 57. K-AR AGE DETERMINATIONS

| Sample No. | Grid Reference | Mineral analysed | K(%) | $\%Ar^{40}$ (atmos) | Radiogenic $Ar^{40}/K^{40}$ | Age & error m.y. | Rock type | Name |
|---|---|---|---|---|---|---|---|---|
| 73840170 | 386263 | biotite | 7.33<br>7.36 | 0.8 | 0.026585 | 408 ± 10 | adamellite | Boggy Plain Granite |
| 73840170 | 386263 | hornblende* | 0.554<br>0.553 | 9.5 | 0.024681 | 381 ± 15 | adamellite | Boggy Plain Granite |
| 73840175 | 440289 | biotite | 7.19<br>7.23 | 1.0 | 0.026451 | 406 ± 10 | granodiorite | Boggy Plain Granite |
| 73840175 | 440289 | hornblende | 0.389<br>0.392 | 5.3 | 0.026587 | 408 ± 10 | granodiorite | Boggy Plain Granite |
| 72840216 | 454637 | total rock | 0.707<br>0.709 | 9.1 | 0.0013657 | 23.2 ± 0.6 | alkali Olivine basalt | Pepperoorn Hill Basalt |
| 72840232 | 442961 ‡ | hornblende | 0.266<br>0.267 | 15.5 | 0.025085 | 387 ± 9 | hornblende gabbro | Mica-long Swamp Basic Igneous Complex |

constants used $\lambda\beta$ = $4.72 \times 10^{-10}$/year

$\lambda e$ = $0.584 \times 10^{-10}$/year

$K^{40}/K$ = 0.0119 atom %

* inhomogenous sample

‡ Brindabella 1:100 000 Sheet area

Note. Using the newly derived decay constant of Beckinsale and Gale (1969) these ages should be about 9 m.y. older except for sample 72840216

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TABLE 58. RB-SR ANALYSES GOOBARRAGANDRA BEDS

| Sample No. | Rb/Sr | $Rb^{87}/Sr^{86}$ | ‡$Sr^{87}/Sr^{86}$ |
|---|---|---|---|
| 7184-0546 | 0.869 | 2.5129 | 0.7223 |
| 7184-0547 | 0.692 | 2.0010 | 0.7219 |
| 7184-0548 | 1.275 | 3.6905 | 0.7323 |
| 7184-0549 | 0.616 | 1.7809 | 0.7203 |
| 7184-0554 | 1.092 | 3.1600 | 0.7295 |
| 7184-0557 | 0.981 | 2.8379 | 0.7264 |
| 7184-0560 | 1.519 | 4.3983 | 0.7359 |
| 7184-0562 | 2.818 | 8.1835 | 0.7659 |
| 7184-0563 | 3.050 | 8.8554 | 0.7637 |
| 7184-0569 | 0.866 | 2.5044 | 0.7229 |

‡ Ratios normalized to $Sr^{88}/Sr^{86} = 8.3752$

Constants Used: $Rb^{85}/Rb^{87} = 2.600$

$\lambda Rb^{87} = 1.39 \times 10^{-11}\ yr^{-1}$

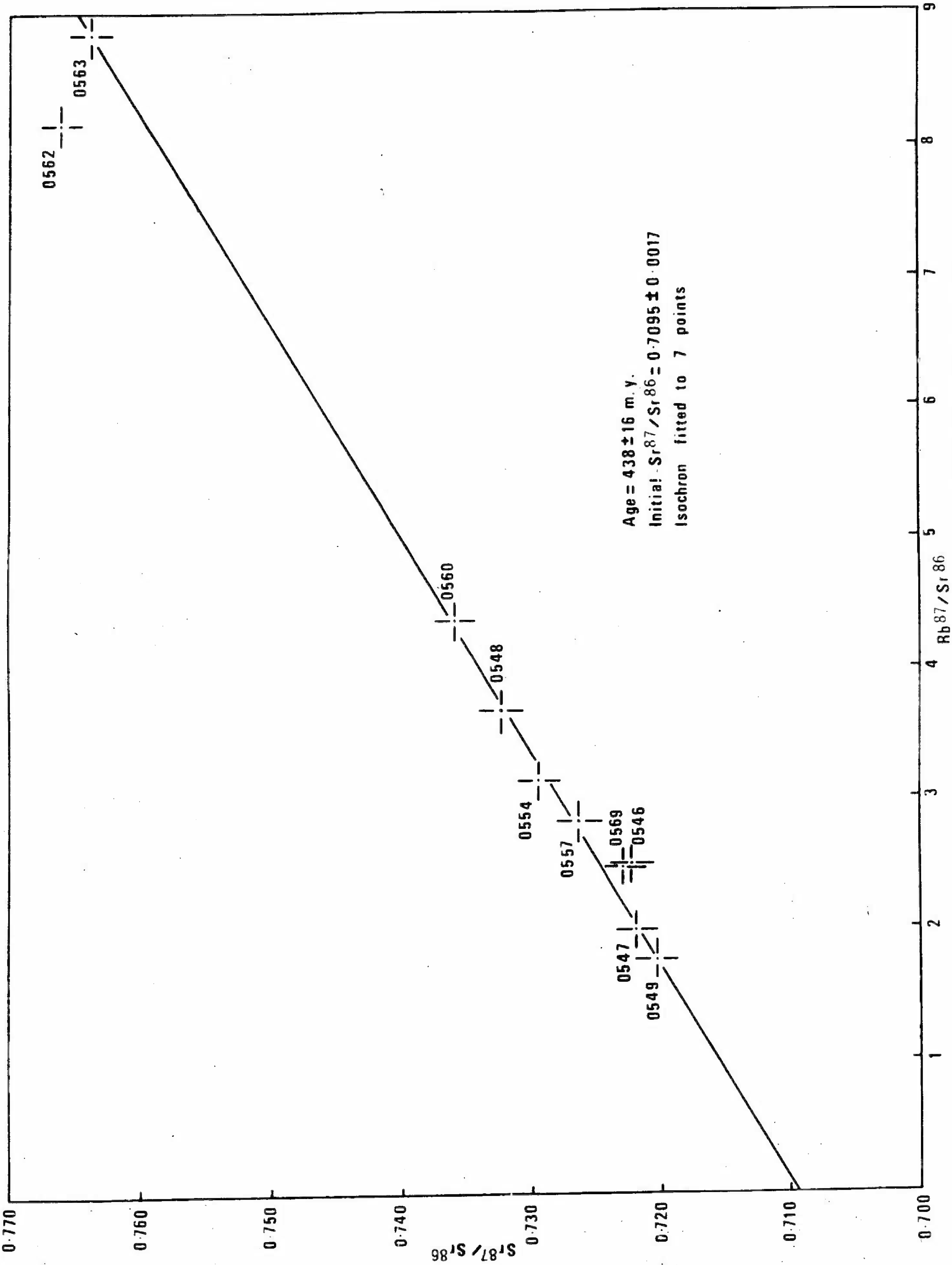


Fig 72 Rb-Sr+ ISOCHRON FOR GOOBARRAGANDRA BEDS.

M(G)523
R.F.

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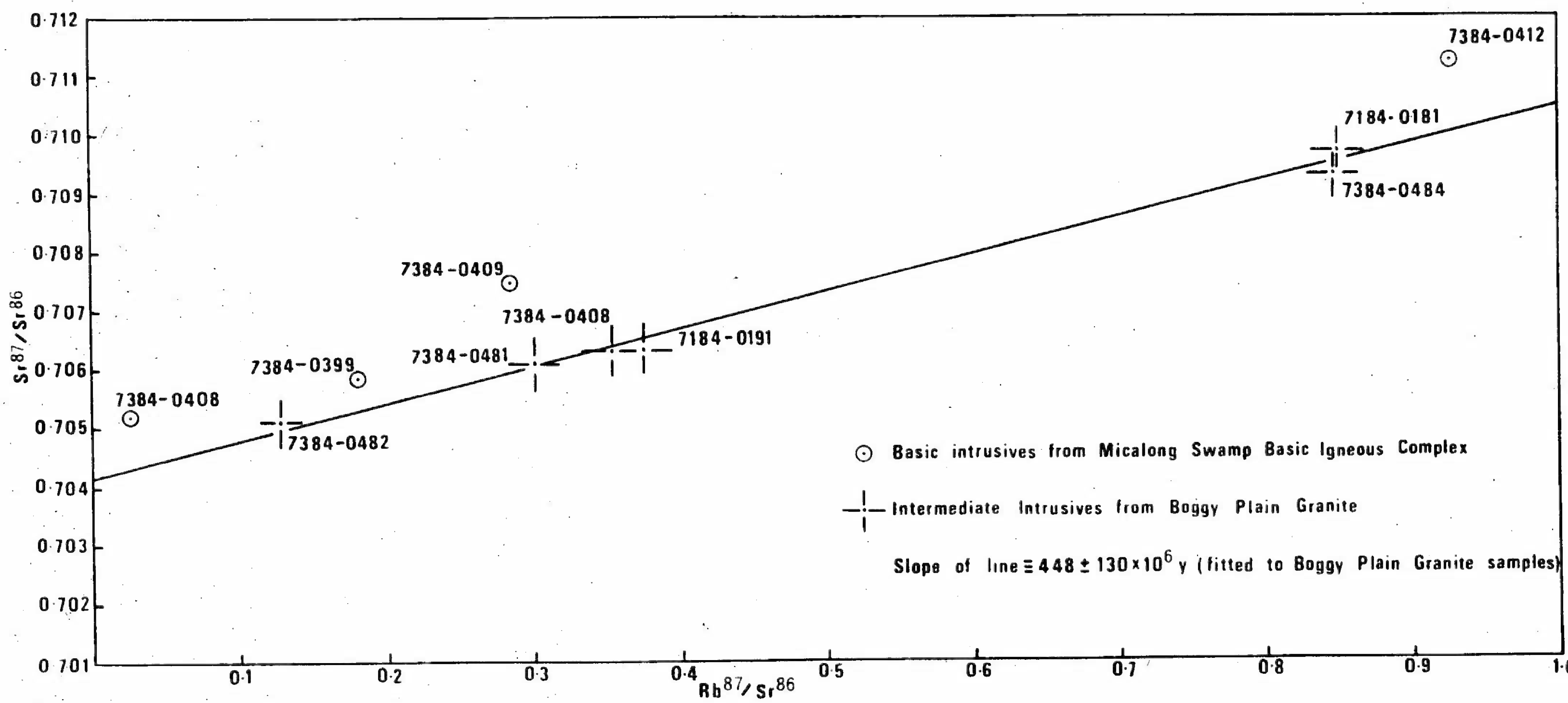


Fig. 73. Rb–Sr Isochron for Boggi Plain Granite; Rb–Sr anlyses of samples from the Micalong Swamp Basin Igneous Complex.

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## TABLE 59. APPROXIMATE RB AND SR CONCENTRATES, BOGGY PLAIN GRANITE SAMPLES

| Sample No. | Rb ppm | Sr ppm |
|---|---|---|
| 7184-0181 | 137 | 448 |
| 7184-0183 | 85 | 770 |
| 7184-0191 | 93 | 697 |
| 7384-0480 | 89 | 710 |
| 7384-0481 | 74 | 686 |
| 7384-0482 | 29 | 636 |
| 7384-0483 | 74 | 669 |
| 7384-0484 | 139 | 454 |
| 7384-0485 | 82 | 729 |

## TABLE 60. RB-SR ISOTOPIC ANALYSES, BOGGY PLAIN GRANITE

| Sample No. | Rb (ppm) | Sr (ppm) | $Rb^{87}/Sr^{86}$ | ‡$Sr^{87}/Sr^{86}$ |
|---|---|---|---|---|
| 7184-0181 Total rock | 130 | 442 | 0.8495 | 0.7097 |
| 7184-0191 Total rock | 88.8 | 684 | 0.3754 | 0.7063 |
| 7384-0480 Total rock | 86.0 | 701 | 0.3544 | 0.7063 |
| 7384-0481 Total rock | 70.4 | 674 | 0.3026 | 0.7061 |
| 7384-0482 Total rock | 28.0 | 627 | 0.1292 | 0.7051 |
| 7384-0484 Total rock | 132 | 448 | 0.8485 | 0.7093 |

‡ Normalized to $Sr^{88}/Sr^{86} = 8.3752$

Constants Used:

$Rb^{85}/Rb^{87} = 2.600$

$\lambda Rb^{87} = 1.39 \times 10^{-11}\ y^{-1}$

TABLE 61. RB-SR ISOTOPIC ANALYSES, BIOTITE CONCENTRATES, BOGGY PLAIN GRANITE

| Sample No. | Rb (ppm) | Sr (ppm) | $Rb^{87}/Sr^{86}$ | ‡$Sr^{87}/Sr^{86}$ | *Age ($x10^6$ y) |
|---|---|---|---|---|---|
| 7384-0170 Biotite | 593.0 | 5.3 | 399.65 | 3.0228 | 415 ± 5 |
| 7384-0175 Biotite | 483.7 | 26.5 | 54.353 | 1.0201 | 416 ± 5 |

‡ Ratios normalized to $Sr^{88}/Sr^{86}$ = 8.3752

* Age calculated assuming initial $Sr^{87}/Sr^{86}$ = 0.705

Constants used: $Rb^{85}/Rb^{87}$ = 2.600

$\lambda Rb^{87}$ = $1.39 \times 10^{-11}$ $y^{-1}$

## TABLE 62. APPROXIMATE RB & SR CONCENTRATES, MICALONG SWAMP BASIC IGNEOUS COMPLEX

| Sample No. | Rb ppm | Sr ppm |
|---|---|---|
| 73840398 | 3 | 180 |
| 73840399 | 12 | 165 |
| 73840400 | 2 | 215 |
| 73840401 | 2 | 195 |
| 73840402 | 3 | 240 |
| 73840403 | 7 | 165 |
| 73840404 | 8 | 170 |
| 73840405 | 1 | 170 |
| 73840407 | 4 | 140 |
| 73840408 | 2 | 225 |
| 73840409 | 22 | 185 |
| 73840410 | 7 | 205 |
| 73840412 | 45 | 125 |

## TABLE 63. RB-SR ISOTOPIC ANALYSES, SELECTED MICALONG SWAMP SAMPLES

| Sample | Rb (ppm) | Sr (ppm) | $Rb^{87}/Sr^{86}$ | ‡$Sr^{87}/Sr^{86}$ |
|---|---|---|---|---|
| 73840399 Total Rock | 11.3 | 181.2 | 0.1815 | 0.7058 |
| 73840408 Total Rock | 2.1 | 227.3 | 0.0272 | 0.7052 |
| 73840409 Total Rock | 18.5 | 186.2 | 0.2873 | 0.7074 |
| 73840412 Total Rock | 43.0 | 133.8 | 0.9286 | 0.7112 |

‡ Ratios normalized to $Sr^{88}/Sr^{86}$ = 8.3752

Constants used: $Rb^{85}/Rb^{87}$ = 2.600

$\lambda Rb^{87}$ = $1.39 \times 10^{-11}$ $y^{-1}$

## Appendix Two - Geochemical Methods

(M.O.)

All the BMR analyses were performed by AMDEL, about half on powders crushed in a chrome steel mill by members of the party and the remainder on powders prepared by AMDEL using a tungsten carbide mill. Wet-chemical methods were used to determine $SiO_2$, $Al_2O_3$, $TiO_2$, FeO, and $P_2O_5$, whilst MgO, CaO, MnO, $Na_2O$, $K_2O$, and trace elements were determined by atomic absorption spectrometry. The expected accuracies by AMDEL (in a letter dated 30.4.71 AMDEL reference AN2/1/0) are as follows:-

$SiO_2$ - $\pm$ 0.15%
$Al_2O_3$- $\pm$ 0.15%
$TiO_2$ - $\pm$ 0.01%
$Fe_2O_3$- $\pm$ 0.05%
FeO - $\pm$ 0.05%

| | | | | |
|---|---|---|---|---|
| MgO | ) Dependent on concentration | | | |
| CaO | ) from 0 to 2% | | accuracy | $\pm$ 0.01% |
| MnO | ) " | 2 to 10% | " | $\pm$ 0.05% |
| $Na_2O$ | ) | above 10% | " | $\pm$ 0.1% |
| $K_2O$ | ) | | | |

$P_2O_5$ - $\pm$ 0.01%
$H_2$)- - $\pm$ 0.01%
$H_2O$+ - $\pm$ 0.02%
$CO_2$ - $\pm$ 0.05%

As a check of the accuracy claimed by AMDEL, two samples were resubmitted for analysis. Sample number 71840447 was resubmitted as sample number 72840309, and is a granodiorite from the Coolamine Igneous Complex, while sample number 71840456, resubmitted as number 72840310, is a plagio-close porphyry, also from the Coolamine Igneous Complex. The analyses are compared in Table 64.

TABLE 64. RESULTS OF DUPLICATE ANALYSES BY AMDEL

| Sample Number | 71840447 | 72840309 | 71840456 | 72840310 |
|---|---|---|---|---|
| $SiO_2$ | 60.0 | 59.6 | 70.3 | 69.7 |
| $Al_2O_3$ | 14.5 | 14.8 | 13.9 | 13.9 |
| $Fe_2O_3$ | 1.85 | 1.8 | 0.50 | 0.25 |
| FeO | 4.90 | 4.95 | 3.20 | 3.30 |
| MgO | 4.45 | 4.3 | 1.60 | 1.60 |
| CaO | 6.55 | 6.85 | 1.93 | 2.25 |
| $Na_2O$ | 1.97 | 1.97 | 2.85 | 2.80 |
| $K_2O$ | 2.45 | 2.55 | 3.55 | 3.50 |
| $H_2O+$ | 1.95 | 1.93 | 1.38 | 1.27 |
| $H_2O-$ | 0.27 | 0.27 | 0.18 | 0.17 |
| $CO_2$ | 0.10 | 0.05 | 0.07 | 0.15 |
| $TiO_2$ | 0.74 | 0.74 | 0.56 | 0.56 |
| $P_2O_5$ | 0.12 | 0.23 | 0.12 | 0.12 |
| MnO | 0.23 | 0.11 | 0.05 | 0.05 |
| | 100.08 | 100.15 | 100.19 | 99.62 |

Examination of the above results shows that the differences between results is outside the limits of accuracy claimed by AMDEL in both sets of samples for $SiO_2$ and CaO; in one set of samples for $Fe_2O_3$, MgO, CaO, $H_2O+$, and $P_2O_5$. In many cases, however, the errors are close to the limits of accuracy claimed by AMDEL, and only the results for CaO give rise to concern. In contrast, the results for $Na_2O$, $K_2O$, and $TiO_2$ are closely similar if not identical.

As a further check on the accuracy of the AMDEL analyses, three powders analysed by Palmer (1972) were submitted to AMDEL. Palmer's

TABLE 65. COMPARISON OF ANALYSES ON IDENTICAL SAMPLES by K. PALMER (ANU) and AMDEL

| Sample Number | 7284C114 | C114 | 7284C149 | C149 | 7284C159 | C159 |
|---|---|---|---|---|---|---|
| Analyst | AMDEL | PALMER | AMDEL | PALMER | AMDEL | PALMER |
| Rock Type | Rolling Grounds Latite | | Coolamine Igneous Complex | | Gurrangorambla Granophyre | |
| $SiO_2$ | 61.2 | 61.62 | 55.5 | 55.13 | 74.4 | 73.95 |
| $Al_2O_3$ | 13.2 | 13.10 | 14.9 | 14.70 | 12.7 | 12.69 |
| $Fe_2O_3$ | 1.65 | 1.46 | 0.55 | 1.26 | 0.90 | 0.47 |
| FeO | 4.25 | 4.30 | 7.0 | 6.19 | 0.70 | 1.09 |
| MgO | 6.1 | 5.78 | 5.65 | 5.32 | 0.25 | 0.23 |
| CaO | 5.5 | 5.48 | 7.55 | 7.56 | 0.80 | 0.75 |
| $Na_2O$ | 2.4 | 2.40 | 2.35 | 2.36 | 3.70 | 3.53 |
| $K_2O$ | 2.85 | 1.90 | 2.00 | 1.87 | 5.00 | 5.02 |
| $H_2O+$ | 2.7 | 2.18 | 2.70 | 2.35 | 0.62 | 0.74 |
| $H_2O-$ | 0.22 | 0.13 | 0.13 | 0.19 | 0.17 | 0.14 |
| $CO_2$ | 0.15 | 0.08 | 0.45 | 1.60 | 0.15 | 0.47 |
| $TiO_2$ | 0.59 | 0.57 | 0.81 | 0.76 | 0.43 | 0.34 |
| $P_2O_5$ | 0.13 | 0.14 | 0.16 | 0.17 | 0.04 | 0.05 |
| MnO | 0.13 | 0.12 | 0.16 | 0.14 | 0.05 | 0.05 |
| | 100.07 | 99.26 | 99.91 | 99.60 | 99.91 | 99.52 |

samples were analysed by XRF, except for $Na_2O$ (by flame photometer) and ferrous iron (by wet-chemical methods), at the Geology Department, Australian National University, on an instrument which is regularly calibrated against international standards. The results are tabulated in Table 65.

Comparison of these results shows that in general, good agreement is present between the analyses. The main exception is ferric and ferrous iron, where significant differences are present in samples C149 and C159, though it should be noted that the values of total iron are closely comparable. Both analysts determine total iron (AMDEL colorimetrically and Palmer by XRF) and then ferrous iron by wet-chemical methods and obtain ferric iron by subtraction, so that error in determining ferrous iron by one of the analysts is the cause of error. Other oxides are generally in good agreement.

All the CIPW norms quoted in the text, including those of analyses by Palmer (1972), Joyce (1970) and other sources were calculated using a BMR program.

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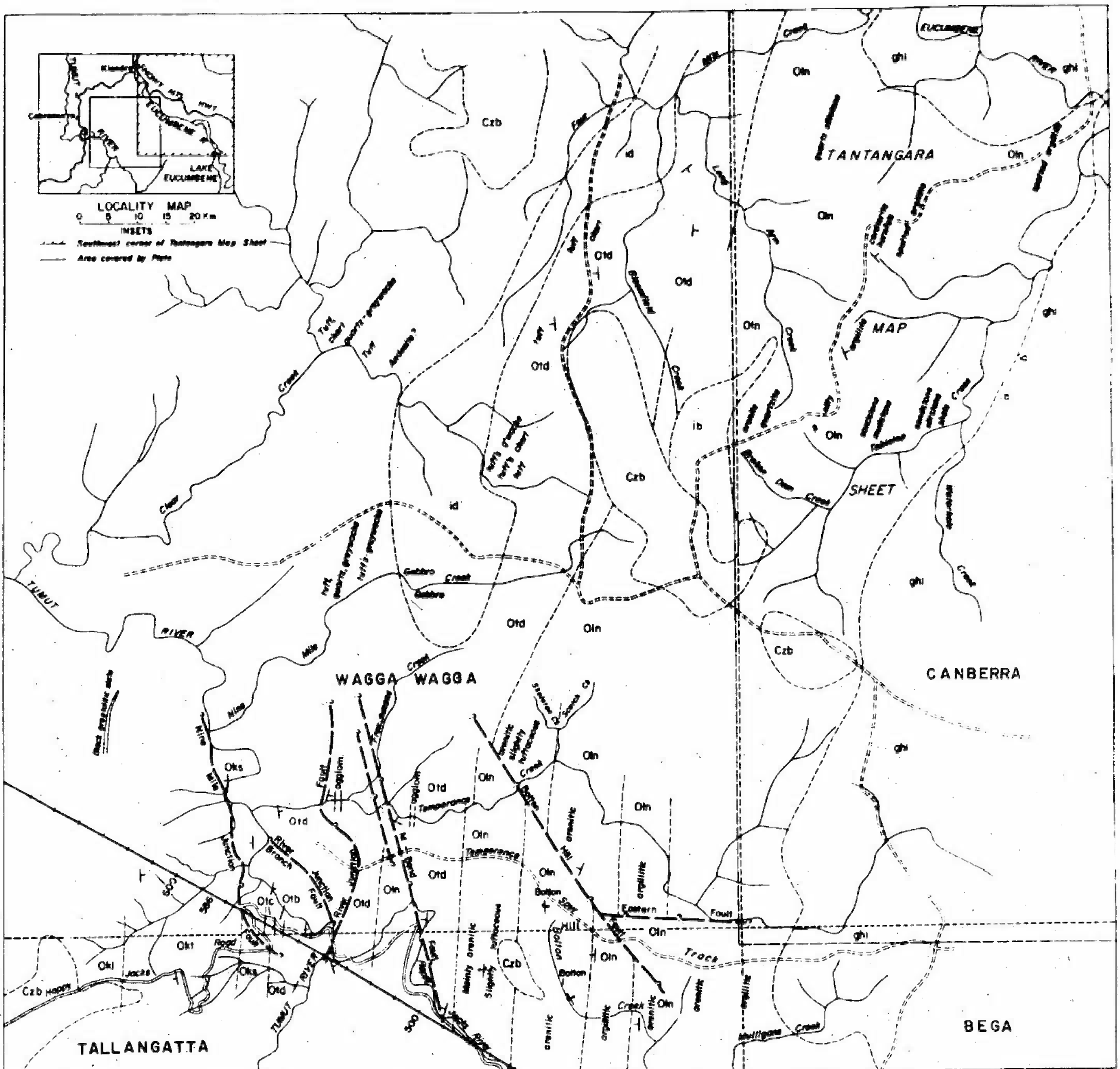



Record 1974/176

155/A/12

# Geological Sketch Map
## Happy Jacks Road to Tabletop Creek and Eucumbene River

**PLATE 1**

(Based on Snowy Mountains Authority topographic maps and in part on Moye, 1953: Report on geology of Upper Tumut Development)

0 500 1000 1500 2000 2500 metres
0 2000 4000 6000 8000 feet

Czb *Tertiary basalt*

*Nine Mile Volcanics*

Okl *Lava*

Okt *Tuff and minor sediment*

Oks *Sediment and tuff interbedded*

*Temperance Chert*

Otb *Agglomerate*

Otc *Chert*

Otd *Tuff and chert interbedded*

Oln *Bolton Beds*

ghl *Happy Jacks Granite*

ib *Diorite, gabbro, dolerite*

id *Intermediate and basic intrusive rocks*

*Strike and dip of bedding*

*Strike and dip of overturned bedding*

*Fault, inferred*

*Geological boundary*

*Vehicle track*

*Road*

*Eucumbene-Tumut tunnel line showing chainage station*

*Boundary of Tantangara 1:100 000 Sheet area*

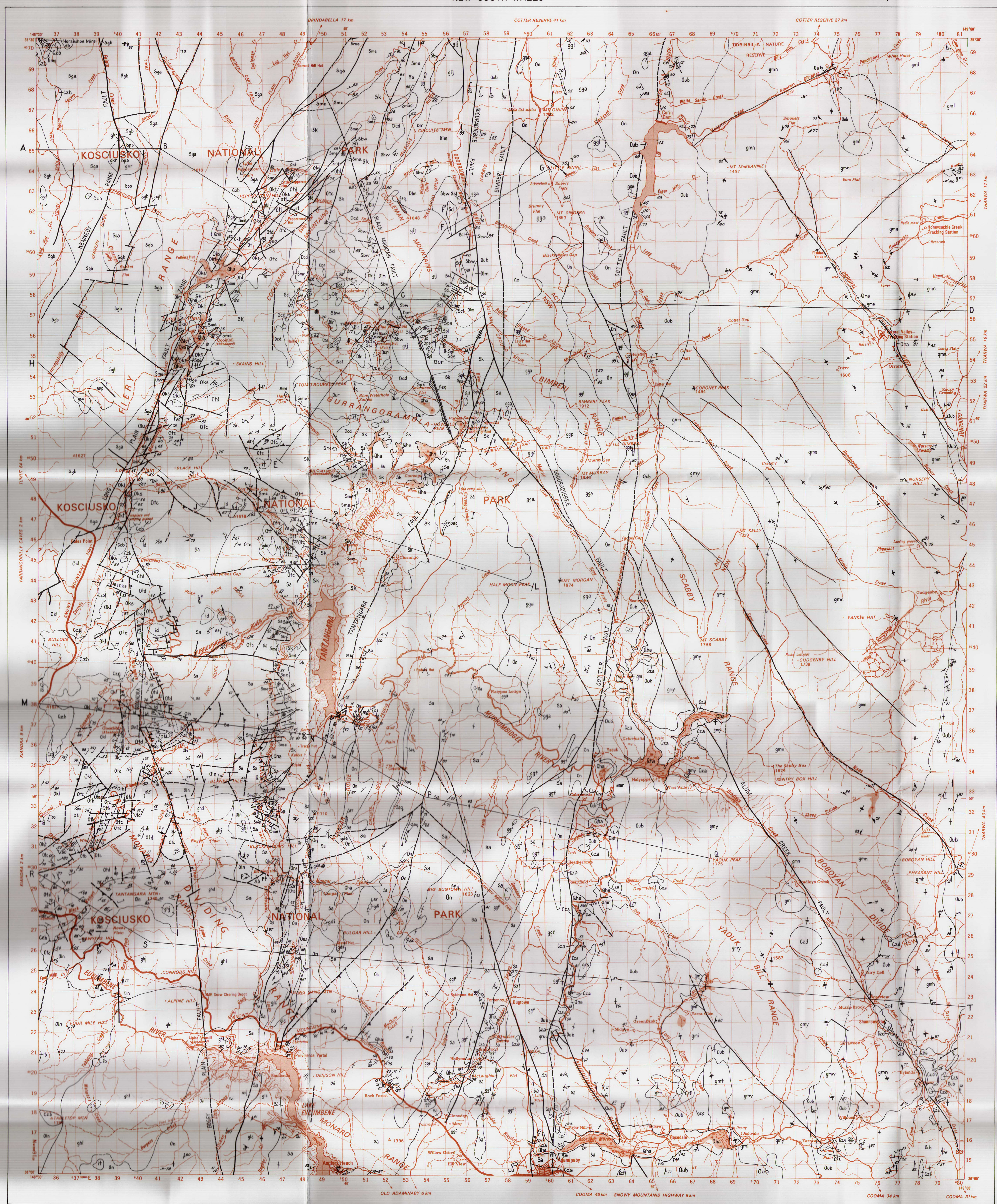
*Boundaries of 1:250 000 Sheet areas*

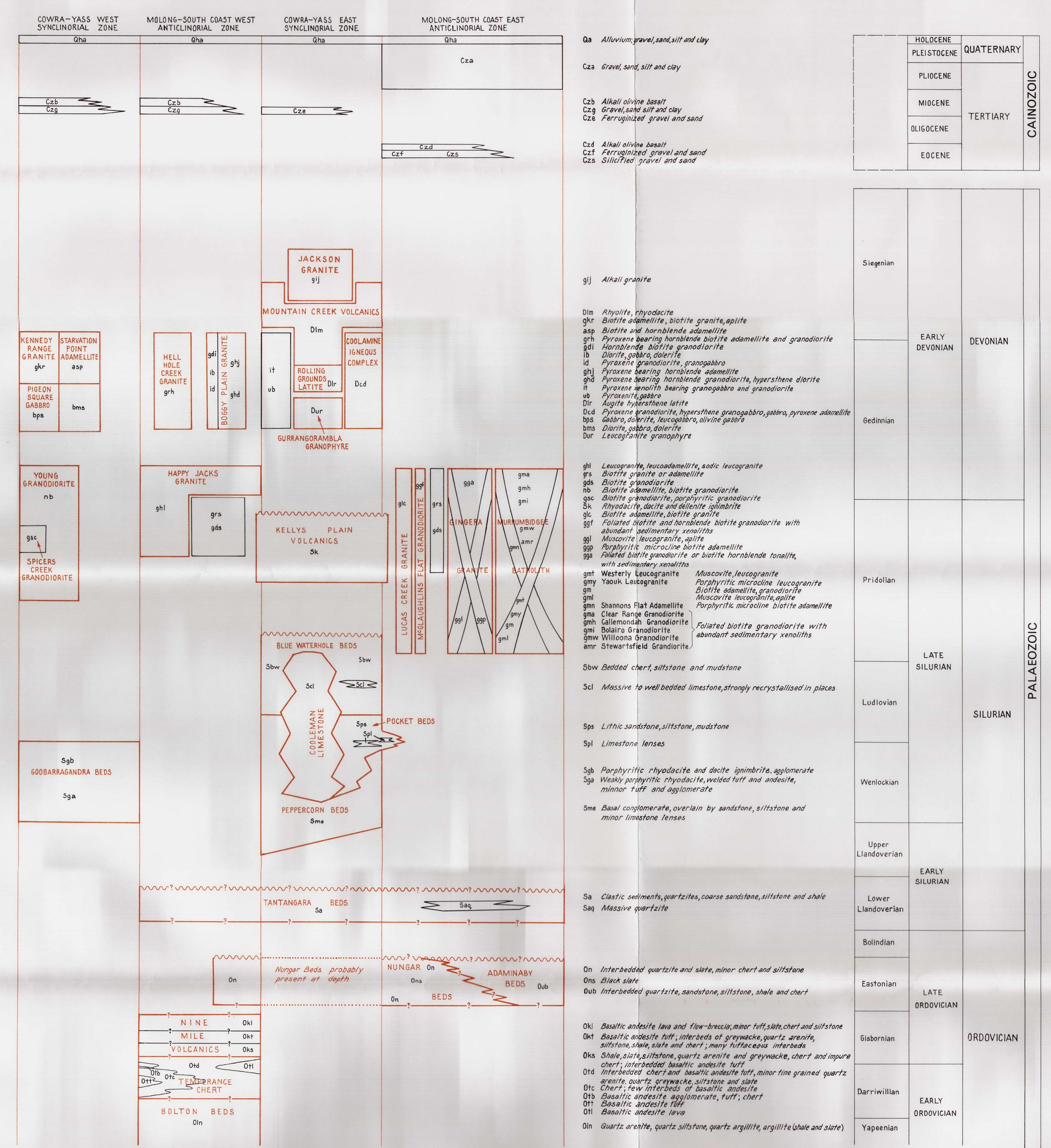
1:100 000 GEOLOGICAL SERIES

# TANTANGARA

NEW SOUTH WALES

AUSTRALIA, SHEET 8626




Geological boundary
Unconformity (u opens to younger formation) section only
Anticline
Syncline
Fault showing relative horizontal movement
Normal fault
High angle reverse fault
High angle reverse fault showing inclination
Where location of boundaries folds and faults is approximate line is broken, where inferred, querried; where concealed, boundaries and folds are dotted, faults are shown by short dashes
Plunge of minor syncline
Shear zone

Strike and dip of strata
Vertical strata
Strike and dip of strata, facing not known
Strike and dip of overturned strata
Lineament, airphoto interpretation

Strike and dip of joint
Strike and dip of joint; unmeasured
Vertical joint

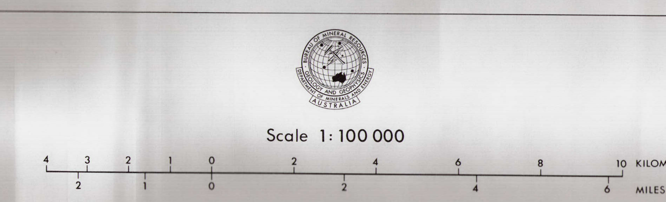
Strike and dip of foliation
Vertical foliation

Strike and dip of cleavage
Strike and dip of cleavage; unmeasured
Vertical cleavage

Platy flow; inclined
Macrofossil locality
Plant fossil locality

Dyke or vein; q-quartz, p-quartz feldspar porphyry, feq-haematite magnetite quartz, ap-aplite
Mine abandoned; Au-gold, Pb-Lead, Zn-zinc

Tank or small dam
Swamp
Escarpment
Highway
Road with gate and cattle grid
Vehicle track
Power transmission line
State boundary
Built up area
Building
Yard
Landmark object
Trigonometrical station
Elevation in metres



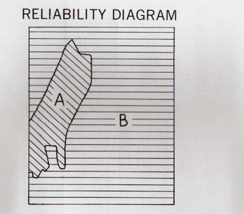
Scale 1:100 000

Compiled by the Bureau of Mineral Resources, Geology and Geophysics, Department of Minerals and Energy. Issued under the authority of the Hon. R.F.X. Connor, M.P., Minister for Minerals and Energy. Base map compiled by the Division of National Mapping from aerial photography at 1:50 000 scale. Transverse Mercator Projection

Geology 1971–73 by M. Owen, D.E. Gardener, A.L. Jaques, P.A. Langworthy, D. Wyborn, J. Saltet, P. Jell
Compiled 1973 by M. Owen, D.E. Gardener, D. Wyborn, J. Saltet, D.G. Walton, J.M. Mifsud, R.D. Cooper
Cartography by Geological Branch, B M R
Drawn by R.D. Cooper

Printed by: Mercury–Walch Pty Ltd., Hobart, Australia

## RELIABILITY DIAGRAM



Geology A Detailed mapping
B Detailed reconnaissance: numerous traverses

GRID REFERENCE

TO GIVE A UNIQUE REFERENCE ON THIS SHEET TO NEAREST 100 METRES

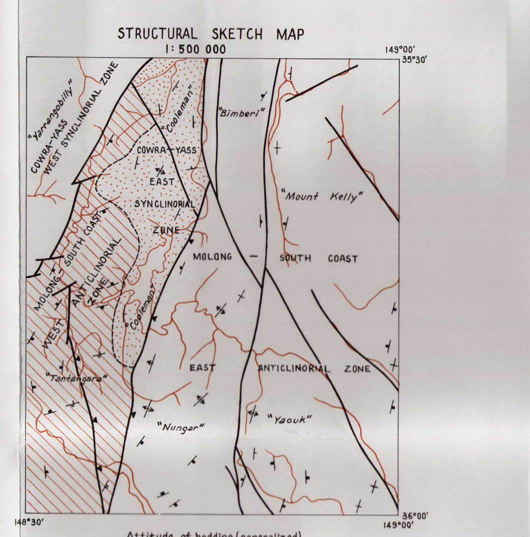
IGNORE the SMALLER figures of any grid number; these are for finding the full co-ordinates. Use ONLY the LARGER figures of the grid number, e.g. 637000

SAMPLE POINT: ·MT KELLY

1. Quote this 1:100 000 map sheet: 8626
2. Locate first VERTICAL grid line to LEFT of point and read LARGE figures labelling the line either in the top or bottom margin, or on the line itself: 69
3. Estimate tenths from grid line to point: 7
4. Locate first HORIZONTAL grid line BELOW point and read LARGE figures labelling the line in either the left or right margin, or on the line itself: 45
5. Estimate tenths from grid line to point: 8

## STRUCTURAL SKETCH MAP

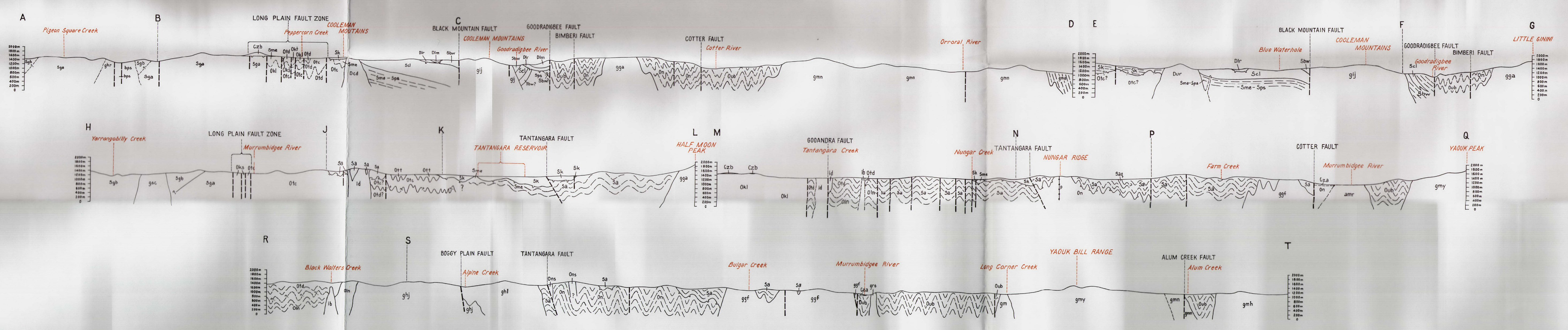
1:500 000




Attitude of bedding (generalized)

Direction of strike and dip of strata {Shallow, Steep}
Vertical strata
Strike and dip of overturned strata
Anticline
Fault
High angle reverse fault
"Yaouk" Fault block

Sections




PRELIMINARY EDITION 1974

SUBJECT TO AMENDMENT



INDEX TO ADJOINING SHEETS

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| HOLBROOK 8326 | ROSEWOOD 8426 | YARRANGOBILLY 8526 | TANTANGARA 8626 | MICHELAGO 8726 | ARALUEN 8826 |
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WAGGA WAGGA · CANBERRA · TALLANGATTA · BEGA
35°00' · 36°00' · 37°00' · 147°00' · 148°30' · 149°00'

TANTANGARA
8626