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GEOLOGY OF THE FORSAYTH 1:100 000 SHEET AREA (7660) NORTH QUEENSLAND

- Georgetown Project Progress Report

by

J.H.C. Bain[1], I.W. Withnall[2] and B.S. Oversby[1]

1 BMR
2 GSQ

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PLEASE NOTE

Owing to delays in the preparation of the photographs (Figs 4-27, 30-37, 40-43, 48-58, 60-63, 65-72) this record is issued without those figures. However copies of the figures will be sent to recipients of this Record later.

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SUMMARY

This report describes the geology of the Forsayth 1:100 000 Sheet area, north Queensland, as determined by recent Bureau of Mineral Resources (BMR) - Geological Survey of Queensland (GSQ) geological mapping (see Forsayth 1:100 000 Preliminary Edition in end pocket). The mines, mineral deposits and resource potential of the Sheet area, and the past exploration activity in the Georgetown Inlier, together with recommendations for future mineral exploration are covered in separate reports by Withnall, issued by the Geological Survey of Queensland.

Two major stratigraphic-structural units are recognized - (i) a basement of metamorphic and granitic rocks and in the central part of the Sheet area (ii) a cover of volcanic and sedimentary rocks.

The basement consists of multiply deformed, regionally metamorphosed Precambrian sediments (Robertson River Metamorphics and Einasleigh Metamorphics) and dolerite (Cobbold Metadolerite) and middle? Proterozoic and Lower Palaeozoic granites (Forsayth Granite, Oak River Granodiorite, Digger Creek Granite, Robin Hood Granodiorite).

The Robertson River Metamorphics, originally sandstone, siltstone, and shale with minor chert and marly beds, underwent low-pressure regional metamorphism about 1500 m.y. ago, and are now composed of schist, quartzite, and minor phyllite, graphitic schist, and calc-silicate rocks. Metamorphic grade ranges from greenschist to upper amphibolite. The Cobbold Metadolerite was metamorphosed together with the Robertson River Metamorphics. Five successive folding deformations have affected these rocks. The first two events each produced isoclinal folds, and most of the metamorphic minerals such as mica, hornblende, staurolite, sillimanite, and garnet crystallized during the second event. Subsequent deformations resulted in open folding of the metamorphic isograds.

The Einasleigh Metamorphics - biotite gneiss and subordinate schist, quartzite, calc-granofels, amphibolite, and migmatite - were probably feldspathic or marly sandstone, siltstone, and shale with dolerite intrusions prior to the dated metamorphism which appears to have occurred about 1700 m.y. ago. Metamorphic grade is mostly upper amphibolite, but granulite grades were attained in some areas, for example at Einasleigh. Like the Robertson River Metamorphics these rocks crystallized under conditions of low pressure and high temperature and have been deformed by five sets of folds. Although the same number of deformations effected both metamorphic formations, it is not yet established whether or not they are direct correlatives.

The Forsayth Granite, a Middle Proterozoic (1500 m.y.), multiphase, foliated biotite granite, intrudes Robertson River Metamorphics in the northwest quarter of the Sheet area. Distinctive alkali feldspar megacrysts 2-7 cm long characterise part of the granite. Contact metamorphic aureoles are absent or poorly developed. It appears that the granite was probably emplaced whilst the metamorphic country rocks were hot, i.e. during the regional metamorphism, probably during the third phase of folding immediately following the peak of metamorphism. Almost all of the numerous small gold-silver-quartz lodes in the Sheet area are within shears and fractures in either the granite or immediately adjacent metasediments.

The Oak River Granodiorite (locally foliated biotite granodiorite with potassium feldspar megacrysts, and foliated porphyroblastic hornblende biotite tonalite) intrudes Einasleigh Metamorphics to the southeast of the Newcastle Range. It was presumably emplaced during Middle Proterozoic time as it is older than the Digger Creek Granite but younger than the Einasleigh Metamorphics - it may have formed by anatexis of the latter. It was previously mapped as Forsayth Granite.

The Digger Creek Granite (muscovite leucogranite, aplite, and pegmatite ± garnet) intrudes the other Proterozoic units throughout all but the northeast corner of the Sheet area, although it seems to be restricted mainly to areas of middle amphibolite metamorphic grade. It was probably formed during the main Middle Proterozoic metamorphism which was at its peak during the second phase of isoclinal folding of the Robertson River Metamorphics. It was previously mapped as parts of the Robin Hood Granite and Forsayth Granite.

The Robin Hood Granodiorite (hornblende biotite granodiorite) crops out in the southern central part of the Sheet areas; it is a post-tectonic body which is not regionally foliated and clearly postdates the Digger Creek Granite; it is probably Siluro-Devonian (about 400 m.y.) in age.

The cover, which is mostly confined to the Newcastle Range in the central part of the Sheet area, consists predominantly of mid-Carboniferous Newcastle Range Volcanics (rhyolitic ignimbrite and subordinate rhyolitic lava, airfall tuff, and agglomerate; andesitic lava; and volcaniclastic and epiclastic sedimentary rocks). Two separate stratigraphic sequences are recognized, in the main and eastern parts of the Newcastle Range respectively. Most of the Newcastle Range Volcanics in the Sheet area are in the lower part of the main range sequence; some on the northern edge of the Sheet area north of Stockman Creek belong to a unit high in the eastern range sequence. Clastic sedimentary rocks crop out sporadically below the dominantly ignimbrite sequence of the main range. Numerous linear and curvilinear minor faults and fractures cut the volcanic rocks. Many faults, especially those in the basement adjacent to the volcanics, contain rhyolite and microgranite dykes. The volcanic rocks appear to have a basin-like structure, with concentrically distributed units dipping inwards at 20 degrees or less.

Permian Agate Creek Volcanics (epiclastic sedimentary rocks, rhyolite, basalt) crop out in the southwest. Rhyolite dykes here may be related to these volcanics rather than to the Newcastle Range Volcanics.

Remnants of thin, but once extensive, Mesozoic quartzose clastic sedimentary rocks form isolated mesas and cap parts of the Newcastle Range. The various Mesozoic units recognized by previous workers have been grouped together as they were not examined in sufficient detail to permit subdivision.

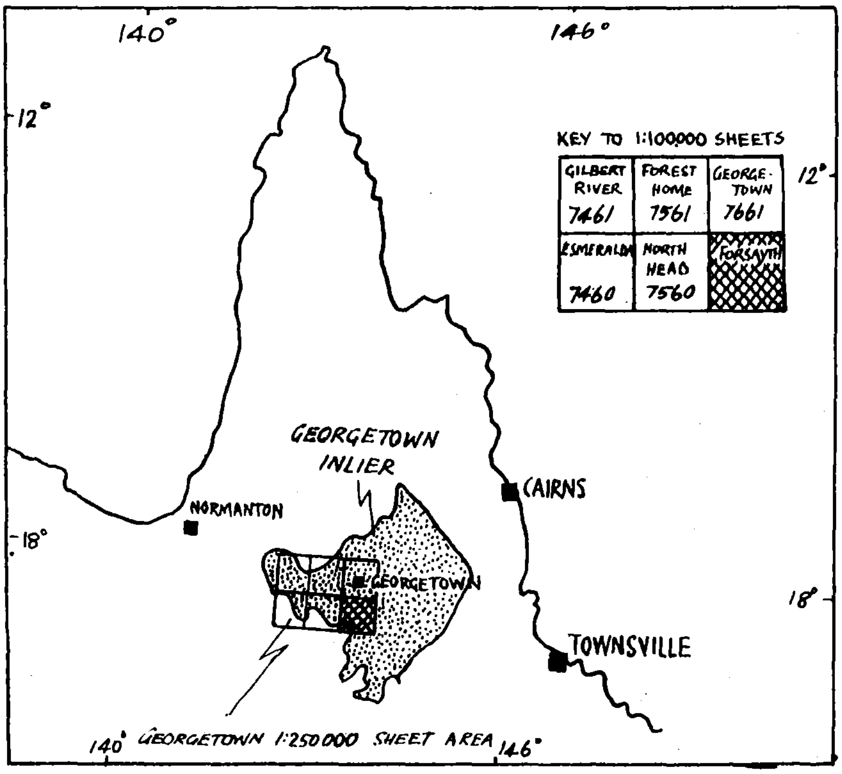
Three categories of Cainozoic sediment - soil and colluvium, inactive floodplain alluvium, and active stream bed sediments - have been mapped.

More than 7500 kg of gold and silver bullion and minor amounts of lead, zinc and copper have been obtained from fissure-vein deposits in the Forsayth Sheet area, mostly within the Forsayth Granite, but also in the Digger Creek Granite at Percyville and in adjacent metasedimentary rocks.

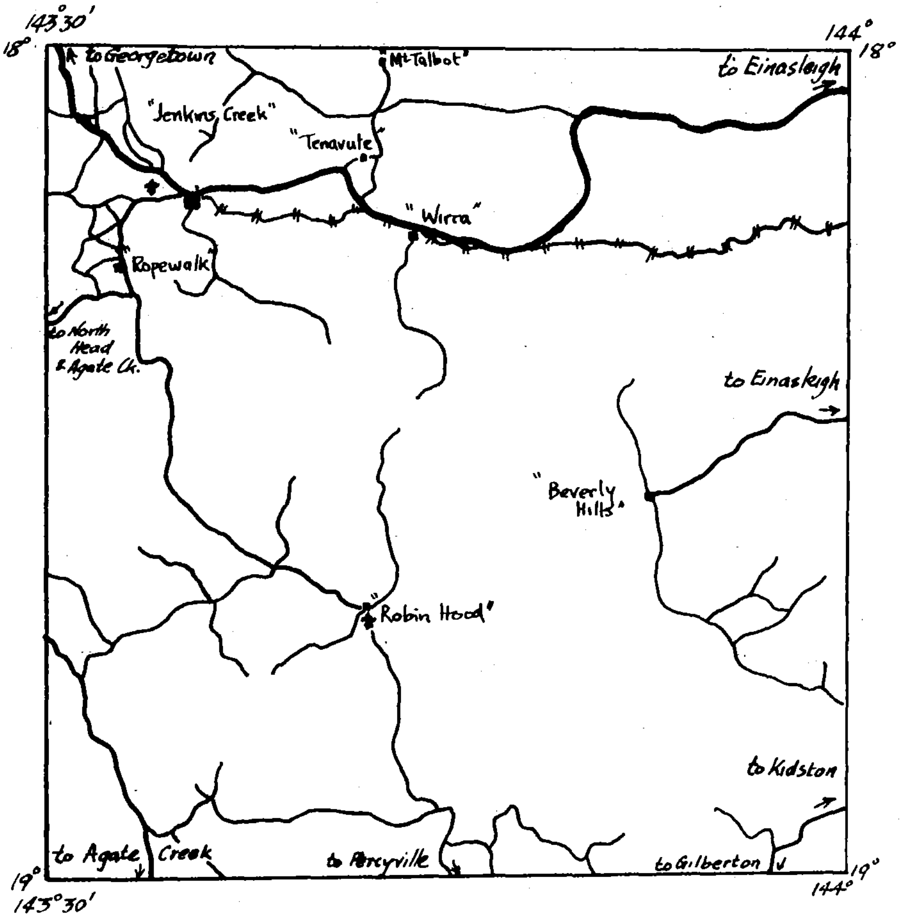
The Robin Hood Granodiorite contains several small Ag-Pb-Au fissure vein deposits, with associated extensive wallrock alteration, that have been worked to shallow depths. The largest - Jubilee Plunger - was the site of soil geochemical studies in 1973-74. The Granodiorite also contains a very small metatorbernite/autunite deposite - Limkins Prospect.

The Einasleigh Metamorphics in the northeast corner of the Sheet area contain several small copper and lead deposits, which have been prospected to shallow depths.

Apart from minor fluorspar occurrences the Newcastle Range Volcanics appear to be unmineralized.



LOCATION Fig. 1



SETTLEMENT & ACCESS Fig. 2.

▬ *Highway;* — *graded road;* — *vehicle track*

┼┼ *Railway;* ✢ *Airstrip*

■ *Settlement;* ▪"*Robin Hood*" *Homestead.*

INTRODUCTION

Area of investigation

The Forsayth 1:100 000 Sheet (7660) covers an area of 2915 km^2 bounded by latitudes $43^o30'$ and 144^oE, and longitudes $18^o30'$ and 19^oS. It lies within the Georgetown Inlier about 300 km southwest of Cairns (Fig. 1).

Object of investigation

The mapping of this area was part of the joint BMR-GSQ Georgetown Project which aims to revise the geological maps of the Georgetown Inlier and reassess the mineral resources of the region. Most of the area was mapped in June-September 1973 by Bain (BMR) and Withnall (GSQ); the area southeast of the Newcastle Range was completed in June 1974 by Bain, Oversby (BMR), and Withnall. Colour airphotos at about 1:25 000 scale were used for photo-interpretation and to locate and record field data. The data, on transparent overlays, were compiled at photoscale and the resulting twelve compilation sheets were reduced and redrawn at 1:100 000 scale to form the accompanying Preliminary Edition of the Forsayth 1:100 000 geological sheet. Forsayth is the first sheet area to be re-mapped and was chosen because, together with the Georgetown and Gilberton 1:100 000 Sheet areas, it contains most of the rock types, structures, and mineral deposits that characterize the Inlie, and is easily accessible.

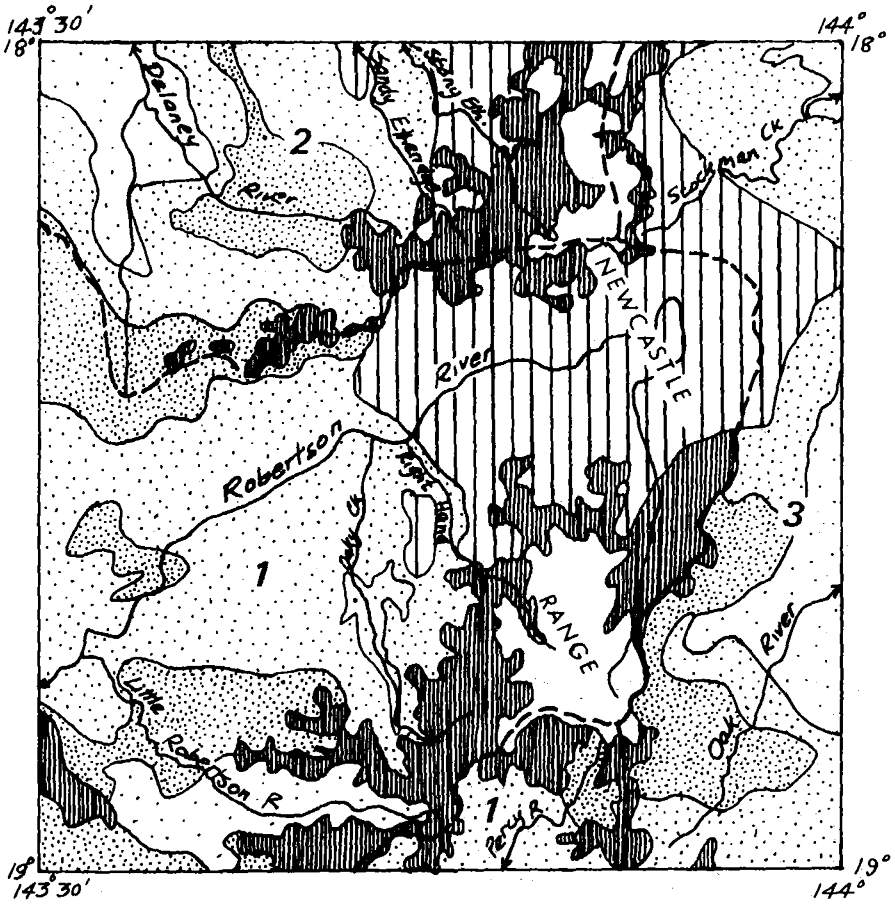
Geochemical and geophysical studies are also being carried out and will be reported on separately. Some preliminary results of extensive geochronoloical studies are incorporated in this report but most geochronological work will be reported on separately when the studies are more advanced. The mines and mineral deposits of the sheet area, and past exploration activity in the Inlier, are the subject of separate reports (Withnall, 1974 in press).

Access

Main access to the area is through Georgetown or Einasleigh; the former is 40 km north of Forsayth on the bitumenized Highway 1 from Cairns, the latter is about 70 km east by gravel road. There is also a rail link from Forsayth to Cairns via Mount Surprise and Almaden. Tracks and roads within the Sheet area are shown in Figure 2. Vehicular movement away from these tracks is hampered by the rough, commonly bouldery terrain, and long grass. During the wet season movement is severely restricted.

Settlement

Forsayth (pop. about 30) is the largest population centre, but its services are limited and its population and



▢	Undissected plateau
▥	Dissected plateau and mesas
⁘	Hills and ridges
▩	Rugged hills and ridges
∣∣∣	Rugged dissected plateau
·	Plains of erosion and flat-floored valleys
- - -	Boundary of major drainage system
1	Gilbert R. system
2	Etheridge R. "
3	Einasliegh R. "

Relief and Drainage **Fig 3**

importance declining. The main service centre for the district is Georgetown (pop. about 300). Only four pastoral leaseholders live on their properties within the Sheet area.

Relief and drainage (Fig. 3)

Most of the area is hilly and between 340 and 780 m above sea level. Although rugged in many parts, local relief rarely exceeds 150 m. The Robertson River and tributaries drain most of the area into the Gilbert River to the west. The northwest corner is drained by the Etheridge River system, and the area east of the Newcastle Range is drained by tributaries of the Einasleigh River (Fig. 3).

Climate

The climate is humid tropical to semi-arid with warm to hot humid summers and warm to cool dry winters. Annual rainfall is 600-800 mm; most falls between November and March but there are occassional falls in winter. For additional data refer to Perry (1964).

Previous geological investigations

A summary of previous geological work up to and including the BMR-GSQ 1:250 000 scale regional reconnaissance in 1956-59 is given by White (1965); Withnall (1974) has summarized exploration company activity in the area up to 1973. In 1970 Sheraton & Labonne (in press) collected and analysed specimens of some of the acid igneous rocks near Forsayth as part of a study of the geochemistry of the acid igneous rocks of north Queensland. Richards et al (1966) and Black (1973) dated specimens from the area isotopically; Black's work is continuing.

Glossary of terms used in this report

Amphibolite facies: Used in the sense of Winkler (1967) and Turner (1968) in preference to the 'almandine amphibolite facies' of Turner & Verhoogen (1960). Winkler (1967) subdivided his amphibolite facies into three subfacies which correspond with the lower, middle, and upper amphibolite facies used in this report.

Arterite: see migmatite

Calc-granofels: granoblastic metamorphic rock in which calc-silicates such as plagioclase, clinozoisite, epidote, hornblende, and diopside are present; in this area the rocks are generally laminated and are referred to as banded calc-granofels, (calc-silicate gneiss is a synonomous term for such banded rocks).

Epiclastic sedimentary rocks: are made up of fragments derived mainly from pre-existing basement rocks.

Granitoid: any light-coloured medium to coarse-grained plutonic rock containing quartz as an essential component along with feldspar and mafic numerals; used here in conjunction with pegmatoid.

Ignimbrite has the same meaning as 'ash-flow tuff' as defined by Ross & Smith (1961): The rocks are devitrified crystal-vitric tuffs containing pseudomorphs of glass shards and pumice which are commonly flattened: they were probably emplaced subaerially as turbid suspensions of crystals, shards, and pumice in hot gas.

Leucosome: see migmatite

Melanosome: see migmatite

Migmatite: 'A megascopically composite rock consisting of two or more petrographically different parts, one of which is the country rock, generally in a more or less metamorphic stage, the other is of pegmatitic, aplitic, granitic or generally plutonic appearance' (Mehnert, 1968, p.230). An arterite is a migmatite formed by injection of magma whereas a venite is a migmatite formed by in situ mobilization of vein material. The leucocratic part of a migmatite is referred to as a leucosome; where the migmatite has resulted from in situ mobilization, the leucosomes generally have a melanocratic rim or melanosome which is rich in mafic minerals. The unaltered or only slightly modified parent rock may be referred to as the palaeosome.

Mimetic growth: Recrystallization in metamorphism which reproduces any pre-existent anisotropy, bedding schistosity or other structures.

Mortar texture: A texture in which relatively large crystalline grains or groups of grains are separated by a microcrystalline mosaic formed by shearing.

Pegmatoid: An igneous rock that has the coarse-grained texture of a pegmatite but lacks graphic intergrowths and/or typical granite composition; used here particularly for coarse-grained dykes and veins in gneiss and migmatite.

Phenocryst: Large conspicuous crystals in porphyritic rock. Syn. megacryst. Some of the phenocrysts in the Proterozoic granites especially Forsayth Granite may be porphyroblasts - i.e. of metamorphic origin.

Plutonic rock nomenclature follows current IUGS recommendation (N.Jb. Miner. Mh, 44, 149-164, & Geotimes 1973, 26-30). Nomenclature of other igneous rocks is consistent with these recommendations.

Venite: See migmatite.

Vergence: The direction of overturning or of inclination of a fold indicated by the shape of parasitic folds viewed down their axes (synononous with fold sense); folds are described as having S, Z, or M vergence. In poorly exposed areas vergence is useful in indicating the location of regional fold hinges.

Volcaniclastic sedimentary rocks: are made up mainly of fragments from contemporaneous volcanic sources, mainly sand and silt-sized quartz and feldspar and local ignimbrite pebbles. They are distinguished arbitrarily from compositionally similar airfall tuffs, into which they grade, by being more regularly bedded and better sorted.

Acknowledgements

We gratefully acknowledge the advice, assistance, and contributions made by many BMR and GSQ colleagues, especially Lance Black and John Sheraton, and by Mike Rubenach of the James Cook University of North Queensland. K.J. (Tas.) Armstrong, Jim Pollard, and temporary field staff too numerous to mention individually, played an important part in the field operations; we extend out thanks to them all. We also wish to thank the local landholders for providing geographical information and access to their properties. We are especially grateful for the friendship and hospitality extended to us by Cob & Mary Terry of Robin Hood Station.

PROTEROZOIC METAMORPHIC ROCKS

Einasleigh Metamorphics

Introduction

The Einasleigh Metamorphics, named after the Einasleigh River which drains the eastern half of the Georgetown Inlier, were formally defined by White (1959b) who listed previous references to the unit.

The Einasleigh Metamorphics in the Forsayth 1:100 000 Sheet area consist of biotite gneiss, mica schist, basic amphibolite, and minor quartzite, calc-granofels and migmatite.

Because of the complex deformation the thickness of the unit cannot be determined. Pegmatoid dykes are common, and are an integral part of the unit, having formed in response to metamorphism. The Einasleigh Metamorphics are exposed in the Stockman Creek and 'Welfern' areas, in the northeast and southeast respectively. Probable Einasleigh Metamorphics occur below Mesozoic rocks about 6 km southeast of Robin Hood homestead. In the north, west of the Newcastle range, rocks mapped by White (1962d) as Einasleigh Metamorphics are assigned to the Robertson River Metamorphics.

In the Stockman Creek area the Einasleigh Metamorphics form hilly country with a dense drainage pattern. Outcrop is fair, particularly in the larger creeks and gullies. North of the Forsayth-Einasleigh road, strike ridges occur. Around Welfern homestead the topography is more subdued and outcrop is commonly poor, although there are some excellent exposures in Louis and W-tree Creeks.

Areas underlain by Einasleigh Metamorphics support a relatively high density of trees, mainly ironbank but also bloodwood and box species; small deciduous trees such as quinine bush, which are characteristic of some other parts of the Sheet area, are uncommon.

Lithology and petrography

(a) Biotite gneiss

Biotite gneiss is probably the most common rock in the Stockman Creek area and east of the Percy River in the Welfern area; many of the schistose rocks seen in creek banks and road cuttings are probably very weathered gneiss. Well-defined gneissic foliation is marked by alternate leucocratic and melanocratic bands, from a few millimetres to several centimetres wide (Figs 4 and 5). Within a single outcrop some of the banding may have a consistent dip and some may be intricately folded by one or two sets of folds; small crenulations are commonly associated with each fold set, and refolded folds are common. The banding was probably produced by the transposition of primary lithologic inhomogeneities (bedding?), and metamorphic differentiation. Small intrafolial folds occur locally within the banding; these represent the hinges of isoclinally folded quartzite laminae. The nature, origin, and relationships of the folds are discussed in more detail below (p.37).

Estimated modal compositions of eight specimens of gneiss from the Stockman Creek area and five from the Welfern area appear in Table 1. Quartz and plagioclase are granoblastic and usually less than 1 mm across. The grains are equant with curved to slightly sutured boundaries. Extinction angle

						Mineralogy					
		Q	Pl (composition)	M	Bi	Hbl	Mu	Chl	Sill	Ga	Accessories
GNEISS	1	50(25)*	30(5)(An_{37})	-	10(10)	-	0(50)	0(10)	Tr	5(5)	op
	2	35	15 (An_{35-40})	-	10	-	25	15	-	ca1	ap
	3	45	25 (An_{45})	-	10	-	10	10	-	5	ap, cz
	4	45	25 (An_{45})	-	10	-	5-10	5	5	5	op
	5	40	10 (An_{37})	-	-	-	25	15	-	10	ap
	6	30	20 (An_{35-40})	-	25	-	25	tr	-	-	ap, op
	7	15-20	5 (?)	35	20	-	10-15	5-10	-	5	ap, op, zr
	8	35	55 (An_{43})	-	10	-	5	tr	-	tr	ap, zr
	9	40	25 (An_{30})	tr	30	-	tr	tr	-	5	zr
	10	45(25)	45(35)(An_{40})	tr	5(25)	5(15)	-	-	-	-	sp
	11	30-35	45-50(An_{47})	-	10	5	-	-	-	-	zr, ap, op, cz
	12	10	30 (An_{32})	20	20	-	ca 1	-	-	-	zr
	13	45	40 (An_{33})	5	5-10	5	-	-	-	-	ap, zr, op, cz
SCHIST	14	40	-	-	10	-	30	20	tr	5	-
	15	25	-	-	25	-	40	10	-	tr	op
	16	40	-	-	20	-	25-30	5-10	-	5	-
	17	30	-	-	35	-	35	-	tr	-	-
	18	50	30(An_{25-30})	-	20	-	-	-	-	-	ap, op
	19	25	10-15 (?)	10-15	10	-	40	tr	-	-	op
QUARTZITE	20	55	40 (?)	-	-	-	-	-	-	-	zr, op
	21	65	30	-	2	-	5	-	-	-	op

* Figures inside bracket refer to mica-rich bands
" outside " " " mica-poor "

Q	quartz	op	opaques
Pl	plagioclase	ap	apatite
An	anorthite	cz	clinozoisite/epidote
M	microcline	zr	zircon
Bi	biotite		
Hbl	hornblende		
Mu	muscovite (mainly as sericite)		
Chl	chlorite		
Sill	sillimanite		
Ga	garnet		

Table 1 : Visually estimated modal compositions of gneiss, schist and quartzite in the Einasleigh Metamorphics.

Table 1 (continued)

GNEISS

1. Banded garnet-chlorite-muscovite-gneiss (6824/R5268*; F1/5642/3**). GR135509.
2. Garnet-biotite-chlorite-muscovite gneiss (6825/R5269; F15644/7). GR077495.
3. Garnet-chlorite-biotite-muscovite gneiss (6826/R5270; F1/5644/9A). GR078500.
4. Garnet-sillmanite-muscovite-biotite gneiss (6828/R5272; F2/5992/6). GR119482.
5. Garnet-chlorite-muscovite gneiss (6839/R5273; F2/5992/11). GR143453.
6. Muscovite-biotite gneiss (6831/R5275; F2/5992/19C). GR139463.
7. Garnet-chlorite-muscovite-biotite gneiss (6832/R5276; F2/5992/19G). GR139463.
8. Biotite gneiss (orthogneiss?) (6834/R5278; F3/4892/2B). GR165390.
9. Garnet-biotite gneiss (74300055; F12/4644/13B). GR129019.
10. Banded hornblende biotite gneiss (74300074; F12/4646/12B). GR085020.
11. Hornblende-biotite gneiss (74300075; F12/4646/13A) GR085012.
12. Biotite gneiss (74300083; F13/4726/6). GR991995.
13. Hornblende-biotite gneiss (74300086; F13/4732/11B). GR111984.

SCHIST

14. Garnet-biotite-chlorite-muscovite-quartz schist (6827/R5271; F2/5992/4).GR107484
15. Chlorite-quartz-biotite-sericite schist (6835/R5279;F3/4892/3A). GR155393.
16. Garnet-chlorite-biotite-sericite-quartz schist (74300058; F12/4646/7A). GR06827.
17. Quartz-sericite-biotite schist (74300078; F12/4646/3C). GR034022.
18. Biotite-plagioclase-quartz schist (74300079; F12/4652/10C). GR950015.
19. Biotite-plagioclase-microcline-quartz-sericite schist (74300080; F12/4652/2). GR955023.

QUARTZITE

20. Quartzite (74300077; F12/4652/10A).
21. Quartzite (74300089; F13/4732/6).

* GSQ slide and rock number

** Field number (photo run/photo number/observation point)

GR Grid reference

7430 BMR registered number

Numbers 1 to 8, 14 and 15 are from Stockman Creek area; remainder are from Welfern area.

measurements indicate that the plagioclase is andesine, in the range An_{30} to An_{45}; it is often slightly sericitized. Microcline is rare in the Stockman Creek area but more common in the Welfern area. The grains are usually clearer than plagioclase, and are from 0.5 to 2 mm across; some are poikiloblastic, enclosing quartz and biotite. Myrmekitic plagioclase and quartz occur adjacent to microcline. The main mafic mineral is biotite, which occurs as greenish-brown or reddish-brown flakes commonly parallel to the gneissic banding although a crosscutting generation occurs sporadically; zircon inclusions with pleochroic haloes are common. Biotite flakes are commonly slightly deformed and partly chloritized, particularly in the Stockman Creek area. Some melanocratic bands in the Welfern area contain up to 15 percent subequant to elongate hornblende grains, ranging in colour from brownish-green to bluish-green in the Z direction. Lenticular felted aggregates of sericite (shown as muscovite in Table 1) up to 1 cm across are common in gneiss in the Stockman Creek area. These aggregates are parallel to the foliation and have been folded with it; they have circular outlines parallel to the foliation. Muscovite occurs as flakes up to 0.3 mm across in patches within the aggregates, and as isolated, commonly randomly oriented, flakes up to 0.5 mm across. The sericite aggregates probably originated from the retrogressive metamorphism of sillimanite. Sericite aggregates are not present in the gneiss in the Welfern area. Garnet occurs as subequant, subidioblastic porphyroblasts up to 6 mm across which are commonly cracked. In the Stockman Creek area garnets are partly replaced along these cracks by chlorite and sericite (Fig. 6). Thin sillimanite fibres are present within some garnet grains. In general, however, sillimanite is rare - it is present in significant amounts in only one of the thin sections examined (Table 1, No. 4). There it forms bundles of fibres parallel to the foliation in bands rich in biotite, and it appears to have replaced biotite before the layers were deformed; the sillimanite is itself replaced locally by sericite.

(b) Mica schist

Mica schist also occurs in both the Stockman Creek and Welfern areas, although gneiss and schist are rarely both present in the one outcrop. In the headwaters of the Percy River, however, outcrops of interlayered schist, quartzite, and gneiss occur. The foliation of the schist is apparently roughly parallel to that of the gneiss, but the complex folds developed in the latter do not occur to the same extent in the schist although crenulations and some small folds are present. The schistose foliation has apparently been derived by transposition of an earlier foliation, as suggested by small biotite 'hooks' and very tight crenulations in some specimens. In the headwaters of Diggings Creek, and farther

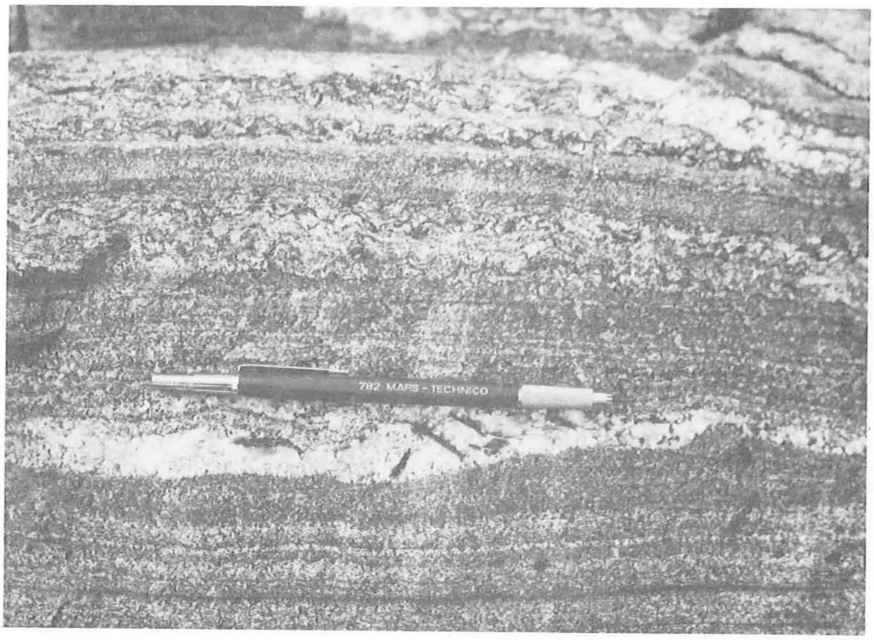


Fig 4: Typical banded gneiss of the Einasleigh Metamorphics, showing a small pegmatoid pod and crenulations within the more micaceous bands.

Fig. 5: Einasleigh Metamorphics exposed on the bank of Stockman Creek near the Einasleigh-Forsayth, road crossing, showing banded gneiss (grey) concordant and slightly crosscutting pegmatoid veins (white), and amphibolite (dark grey). GA9462 (I.W.W.).

Fig. 6: Photomicrograph of garnet in gneiss of the Einasleigh Metamorphics, showing alteration to chlorite along cracks. GSQ Slide No. 6832. Magnification X25 (plane polarized light). M 1921/13A. (I.W.W.).

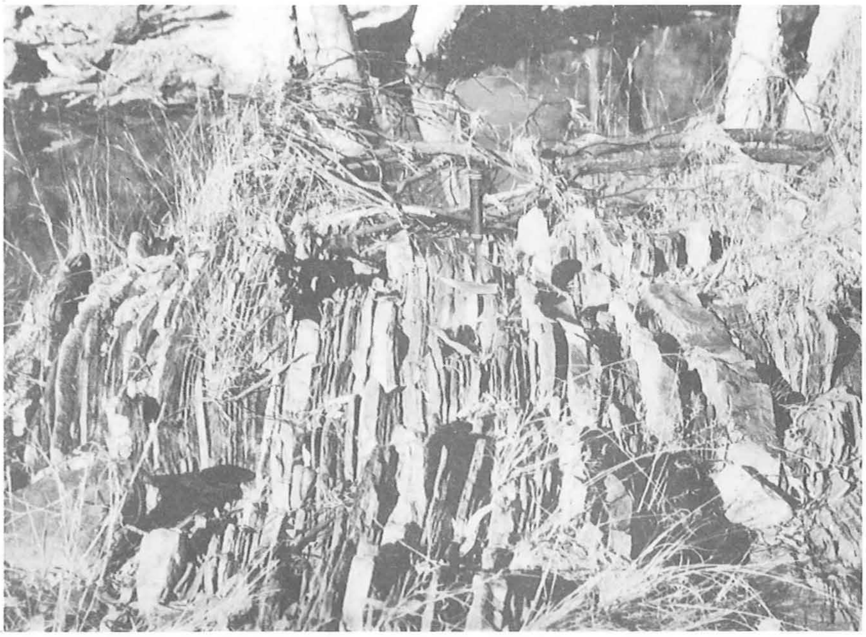


Fig. 7: Interlayered quartzite and schist of the Einasleigh Metamorphics in Fraser's Creek near Fraser's Well. GB144. (I.W.W.).

west, near Fraser's Well, quartzite and schist appear to predominate in the Einasleigh Metamorphics. In outcrop at least (Fig. 7), these rocks are similar to some of the Robertson River Metamorphics (Fig. 24) and they may mark a gradation between Einasleigh Metamorphics and the more peletic Robertson River Metamorphics.

The schists are fine- to medium-grained and commonly consist of quartz, biotite, chlorite, muscovite, sericite, and garnet. Estimated modal analyses of six specimens are given in Table 1. Quartz occurs as equant to subelongate grains up to 1.0 mm in maximum dimension. Biotite and chlorite form ragged parallel flakes up to 1.5 mm long (generally 0.5 mm or less). The chlorite, which has replaced biotite, is colourless to pale green when fresh but is often oxidized and brown; it cuts across the schistosity locally. Muscovite (sericite) occurs as aggregates which form lenses and discontinuous bands parallel to the foliation. Traces of sillimanite occur in some of these aggregates. A schist from near Fraser's Well (BMR registered No. 74300079) contains a similar mineral assemblage to gneiss farther east (Table 1).

Another schist (BMR registered No. 74300080) from about 1 km northeast of Fraser's Well contains lenticular aggregates up to several centimetres long of sericite and minor quartz sheathed by muscovite associated with quartz, plus sericitized feldspar and biotite; the aggregates probably consisted originally of sillimanite and quartz, like ones common in the high-grade parts of the Robertson River Metamorphics (see p.19).

(c) Quartzite

Quartzite is a comparatively minor rock type in the Stockman Creek and eastern Welfern areas, where it generally occurs as thin bands. It is more common in the headwaters of the Percy River and in the vicinity of Fraser's Well (Fig. 7), where it is interlayered with schist.

The quartzites consist of 55 to 70 percent equant to subequant granoblastic quartz and 30 to 40 percent plagioclase; accessory minerals include muscovite and biotite (Table 1). The quartzites in the Percy River also contain small grains of calc-silicate minerals (garnet and hornblende) and are like some quartzite bands in the Robertson River Metamorphics.

(d) Calc-granofels (or calc-silicate gneiss)

These rocks are more common in the Welfern area, than in the Stockman Creek area. In the former area they crop out in a discontinuous belt from the Einasleigh-Gilberton road to

Number	Q	Pl (composition)	M	Di	Hbl	Ep	Access-ories.	Name	Location (Grid Ref.)
6830/R5274*	10–80	0–80 (altered)	0–80	0–5	0–10	10–70	ap,sp,op	calc-granofels	140437
6833/R5277	15–20	40 (altered)	0–40	–	15–50	10–60	ap,sp,op	calc-granofels	845395 (Einasleigh)
6836/R5280	20	–	–	10	–	70	sp,ap	diopside-quartz-epidote granofels	159395
74300053**	10–40	40–70 (An$_{40}$)	10–20	0–5	0–10	5	sp	diopside-hornblende-microcline-quartz-plagioclase granofels	140000
74300057	10–20	25–30	10–25	0–10	5–50	0–20	sp	diopside-hornblende-epidote-quartz-microcline-plagioclase granofels	075012
74300059	10–15	30 (altered)	10	15	10	5	sp,ap,op, ca	hornblende-microcline-quartz-diopside-plagioclase granofels	068018
74300061	5	15–25 (andesine)	30–40	30	5	tr	sp,ap,op	hornblende-plagioclase-diopside-microcline granofels	078004
74300088	25	50	tr	10–15	5	5	sp,ap,op	hornblende-diopside-quartz-plagioclase granofels	119988

* numbers in GSQ slide and rock collection (collected from Stockman Creek area)

** BMR registered number (collected from Welfern area)

percentages show range in various bands

Q	quartz	sp	sphene
Pl	plagioclase	ap	apatite
An	anorthite	op	opaques
M	microcline	ca	calcite
Di	diopside		
Hbl	hornblende		
Ep	epidote		

Table 2 : Visually estimated modal compositions of calc-granofels in the Einasleigh Metamorphics.

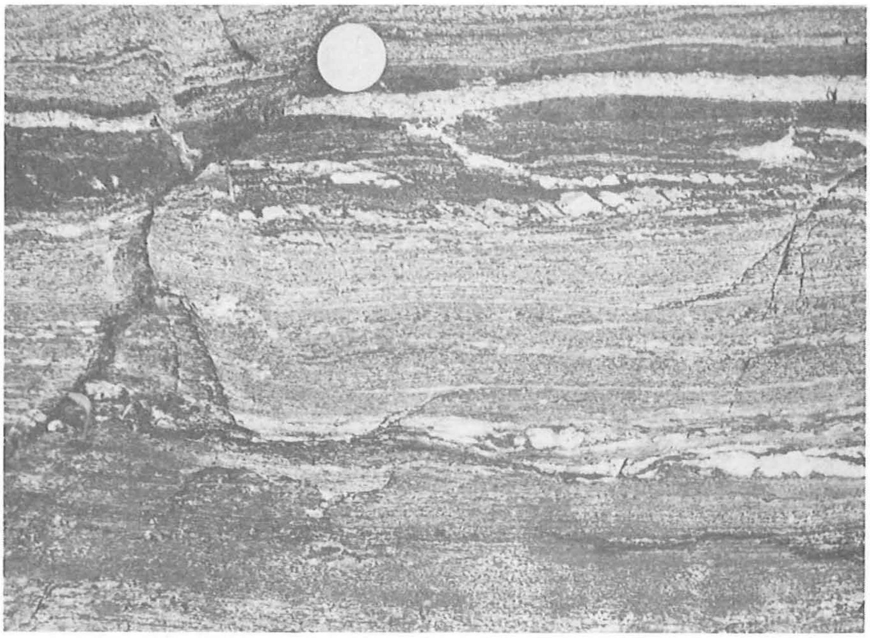


Fig. 8: Para-amphibolite bands (dark) in calc-granofels; Einasleigh Metamorphics at GR068018 2.2 km northwest of Fernhill outstation. GB142 (I.W.W.).

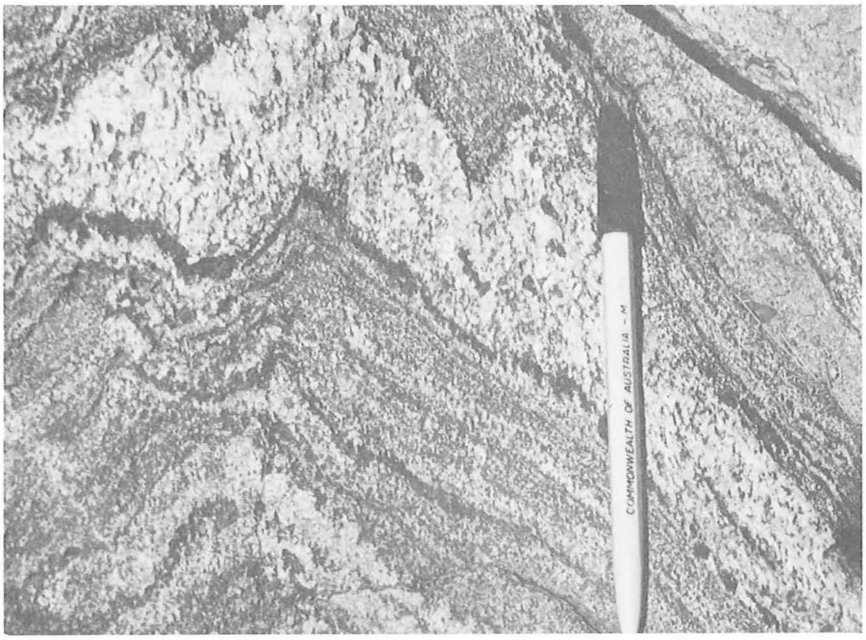


Fig. 9: Folded calc-granofels or calc-silicate gneiss showing weak axial plane foliation; Einasleigh Metamorphics in Louis Creek at GR129019. GB156 (I.W.W.).

about four kilometres northwest of Fernhill outstation. Some also occur in the headwaters of the Percy River. In the Stockman Creek area, calc-granofels occurs near the track between the Teasdale mine and Mount Misery prospect and in a belt trending east-northeast from about 2.5 km south of the Stockman Creek crossing on the Forsayth- Einasleigh road.

The calc-granofels is usually banded (Figs 8 & 9), the bands being probably primary, although they may have been accentuated by minor metamorphic differentiation. No intrafolial folds were recognized in the bands although the calc-granofels has undoubtedly been isoclinally folded as it is part of the same sequence as the gneiss. The banding has been deformed by at least two later sets of folds, and a mineral lineation is well developed parallel to the axes of some of the tighter folds. A belt of calc-granofels forms a ridge trending northwest from Fernhill outstation for about 2.5 km; at GR 069019 (where a tributary of W-tree Creek cuts the ridge) small-scale faults that are probably syn-depositional occur (Fig. 35). This is the only locality where any probable primary sedimentary structures other than the banding were observed. Some hornblende-rich calc-granofels bands and pods (Fig. 8) are mineralogically identical to basic amphibolites in the Einasleigh Metamorphics (see p. 23 and Table 3). These bands and pods are relatively thin and their margins tend to be gradational with the surrounding calc-granofels; they are considered to be true para-amphibolites whereas the thicker, more widespread basic amphibolite bands are probably ortho-amphibolites.

Typical calc-granofels consists of alternating light and dark bands from less than 1 mm to 4 cm thick. The texture is granoblastic and equigranular; grain boundaries, particularly of quartz, are curved and commonly sutured. Estimated modal analyses are given in Table 2.

The light-coloured bands contain various proportions of quartz and feldspar grains up to 1.0 mm across. Sericitized plagioclase (andesine when fresh) is commonly the dominant feldspar, although some microcline is present in most specimens and is locally more abundant than plagioclase. Accessory epidote and small amounts of other mafic minerals are also present . In the dark bands, diopside is usually the most abundant mafic mineral. It occurs as slightly pleochroic, pale green subequant grains up to 1.5 mm in maximum dimension, partly replaced along their margins and cleavage planes by hornblende. Bluish-green hornblende grains up to 1 mm long are also present; they define a b-lineation in some rocks. Quartz, plagioclase, and epidote also occur in the dark bands. Sphene (up to 2 percent) is common throughout all bands as small rounded grains about 0.1 mm across. Opaque grains up to

1 mm across, rimmed by sphene, epidote, or actinolite, are present in all bands; apatite is a minor accessory.

The calc-granofels from the Stockman Creek area consists of alternating pink and green bands. The green bands contain mainly xenoblastic epidote and quartz grains up to 0.5 mm across, with some actinolite. The pink bands contain quartz, microcline, and saussuritized plagioclase, with up to 15 percent amphiboles (both deep bluish-green hornblende and pale green actinolite). Near Mount Misery prospect a fine-grained banded granofels containing diopside (10 percent), quartz (20 percent), and epidote (70 percent) crops out.

The abundance of epidote in the calc-granofels of the Stockman Creek area suggests extensive metamorphic retrogression from amphibolite facies to greenschist facies; only slight retrogression has occurred in the Welfern area. The calc-granofels, particularly the more Ca-rich bands, seem to have been more susceptible to retrogression than the surrounding gneiss, in which plagioclase is sometimes sericitized but never extensively replaced by epidote. The mineral assemblages suggest that the rocks were originally calcareous or dolomitic sediments.

(e) Basic amphibolite

Small, generally tabular, bodies of basic amphibolite are ubiquitous in the Einasleigh Metamorphics. They vary from less than 1 metre to more than 100 metres wide, and are invariably concordant with the banding of the gneiss; they are foliated and commonly strongly lineated. Foliation is parallel to that in the enclosing gneiss and has been folded locally; contacts with the gneiss are sharp. The amphibolites were probably basic sills and dykes originally; their concordant nature suggests that they were emplaced before deformation and metamorphism had transposed the host rocks and produced the gneissic foliation. White (1962 b, d) assigned the amphibolites in the Einasleigh Metamorphics to the Cobbold Dolerite (herein called the Cobbold Metadolerite) which intrudes the Etheridge Formation, which is the greenschist facies equivalent of the Robertson River Metamorphics, although he considered the Einasleigh Metamorphics to be Archaean, and to have been metamorphosed before deposition of the Etheridge Formation. Until relations between these units are known for certain we prefer not to correlate the amphibolites within the Einasleigh Metamorphics with the Cobbold Metadolerite. Small dykes of uralitized dolerite or andesite cutting the Einasleigh Metamorphics near Mount Misery and in places in the Welfern area are probably related to minor basic or intermediate lavas near the base of the Newcastle Range Volcanics (see below, p. 165), and not to the Cobbold Metadolerite.

	MINERALOGY								
Number	Q	Pl (composition)	Hbl	Ga	Op	Ep	Accessories	Name	Location (Grid Ref.)
6837/R5281*	5–10	20–25 (An$_{55-60}$)	70	–	5	–	zr	quartz-plagioclase-hornblende amphibolite	079505
6838/R5282*	10	40 (An$_{65}$)	50	–	ca 1	tr	sp, ap	quartz-plagioclase-hornblende amphibolite	109476
6839/R5283*	30	20 (labradorite)	30	15	5	tr	bi, chl, ap	garnet-plagioclase-quartz-hornblende amphibolite	143456
6840/R5284*	15	15 (An$_{65-70}$)	70	–	ca 1	–	bi, chl	quartz-plagioclase-hornblende amphibolite	139463
6841/R5285*	5	20–30 (An$_{40}$)	70	–	tr	tr	ap	plagioclase-hornblende amphibolite	836396 (Einasleigh)
6842/R5286*	5	30 (An$_{57}$)	65	–	ca 1	tr	chl, ap, sp	plagioclase-hornblende amphibolite	138406
6843/R5287*	5	25 (An$_{57-60}$)	70	–	tr	tr	ap	plagioclase-hornblende amphibolite	138406
74300054**	10	10 (altered)	75	–	5	tr	–	quartz-plagioclase-hornblende amphibolite	129019
74300060	10	30 (")	60	–	tr	tr	–	quartz-plagioclase-hornblende amphibolite	057016
74300062	5	40–45 (An$_{40}$)	50	–	tr	5	sp	quartz-plagioclase-hornblende amphibolite	082025
74300066	5–10	35 (altered)	50	–	ca 1	5	sp, chl	altered quartz-plagioclase-hornblende amphibolite	077032
74300082	5–10	35 (An$_{65-70}$)	55	–	ca 2	–	bi, ap	quartz-plagioclase-hornblende amphibolite	982995
74300087	–	40 (An$_{40}$)	60	–	ca 1	tr	sp, chl	plagioclase-hornblende amphibolite	115988

* GSQ slide and rock collection
** BMR registered number

Q	quartz	Hbl	hornblende	Zr	zircon
Pl	plagioclase	Ga	garnet	Sp	sphene
An	anorthite	Op	opaques	Ap	apatite
		Ep	epidote/ clinozoisite	Bi	biotite
				Chl	chlorite

Table 3 : Visually estimated modal compositions of amphibolites in the Einasleigh Metamorphics.

The amphibolite is black and fine- to medium-grained, and consists of hornblende, plagioclase, and quartz, it was a granoblastic polygonal to lepidoblastic texture. Estimated modal analyses of thirteen specimens are given in Table 3. Hornblende grains are subequant to elongate and rarely more than 1.5 mm in longest dimension, and commonly have smooth, straight boundaries. The colour in the Z direction is usually brownish-green, but along grain boundaries and cracks it is often slightly bluish. The plagioclase forms subequant to equant xenoblastic grains up to 1 mm long but commonly less than 0.5 mm. The grains are commonly partly sericitized or saussuritized, either uniformly throughout, or along cracks and margins. Compositions, determined by extinction angle measurement on fresh plagioclases, are labradorite in the range An_{55} to An_{70}; some altered plagioclase may be andesine. Quartz commonly has a similar habit to plagioclase but also occurs as small rounded inclusions in hornblende. Garnet is uncommon. However, a quartz-rich amphibolite exposed at GR143456 contains large highly poikiloblastic porphyroblasts of garnet up to 2 cm in diameter (Fig. 10). Similar garnetiferous quartz-rich amphibolites have also been observed in the Robertson River Metamorphics. The deficiency of plagioclase in such rocks may be due to the incorporation of the Ca and Al in hornblende and garnet respectively (cf. Joplin, 1968, p. 213). Opaque grains, mostly magnetite or ilmentite, constitute 1 to 5 percent of the rocks; traces of sphene, apatite, zircon, chlorite, and epidote also occur.

The average quartz content (Table 3) suggests that the rocks were originally quartz-dolerite or andesite; an overabundance of quartz in some specimens may be due to the introduction of silica during metamorphism and deformation.

(f) Metasomatized and altered gneiss and amphibolite

Zones of altered and metasomatized gneiss and amphibolite more than 100 m wide crop out in the Welfern area; the zones are of unknown length. Typical altered rocks are banded, and cream and pink, or green, in colour. The fluids which presumably caused the alteration and metasomatism were apparently introduced along fractures parallel to the foliation. In the amphibolite there is a distinct colour contrast between the black unaltered amphibolite and the pink quartzo-feldspathic bands which are parallel to the foliation; the bands commonly have relatively sharp edges, although they are gradational locally; on first impressions this gradation suggests that the rocks are para-amphibolites. However, a metasomatic origin for the bands is considered more likely because adjacent gneiss shows similar alteration effects.

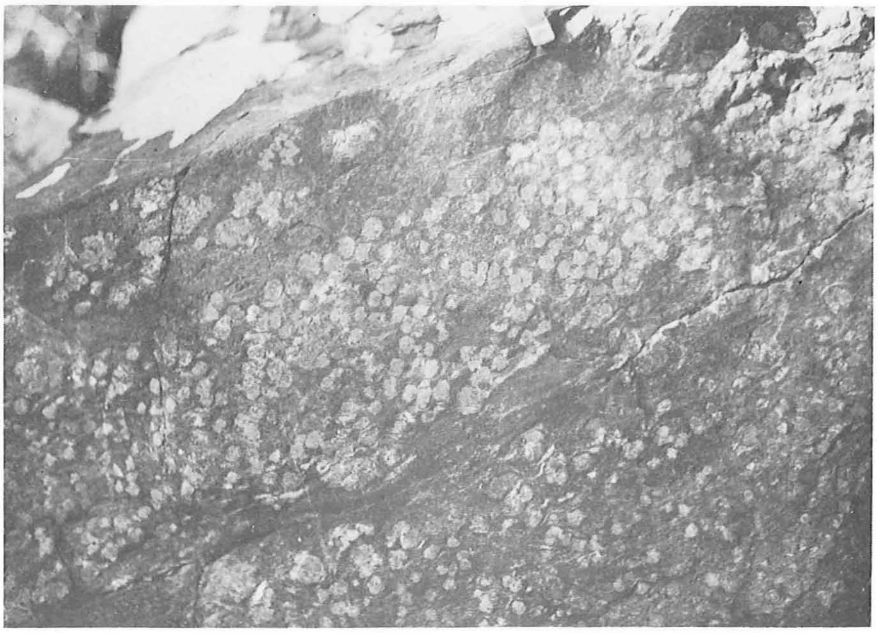


Fig. 10: Garnet porphyroblasts in amphibolite; Einasleigh Metamorphics about 1 km south-southeast of where the Einasleigh-Forsayth road crosses Stockman Creek. GA 9566. (I.W.W.).

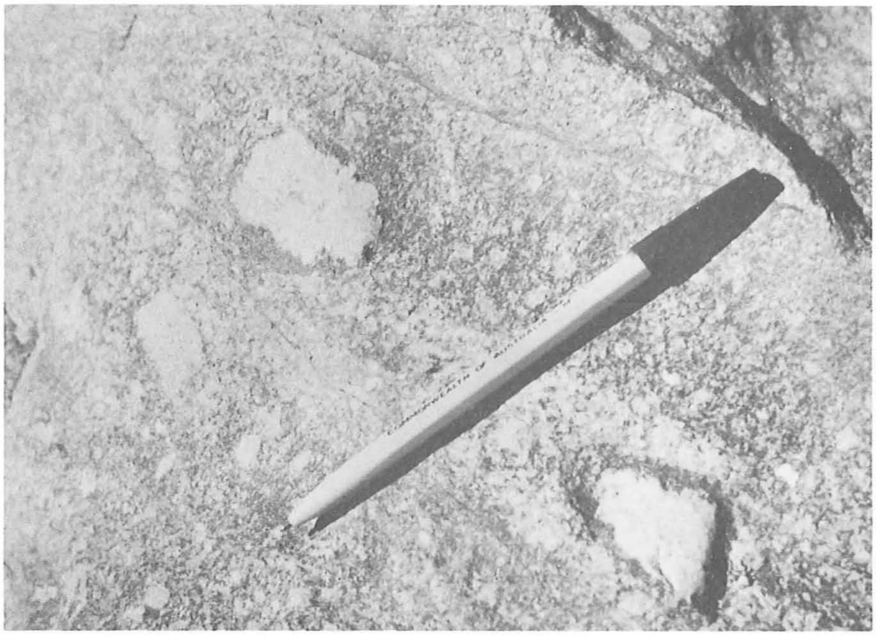


Fig. 11: K-feldspar porphyroblasts in metasomatized gneiss; Einasleigh Metamorphics in Louis Creek at GR 115977. GB 136 (I.W.W.).

Fig. 12: Migmatite consisting of white quartzo-feldspathic bands (leucosomes) and dark mafic-rich bands (melanosomes); Einasleigh Metamorphics in W-tree Creek at Fernhill outstation. GB150 (I.W.W.)

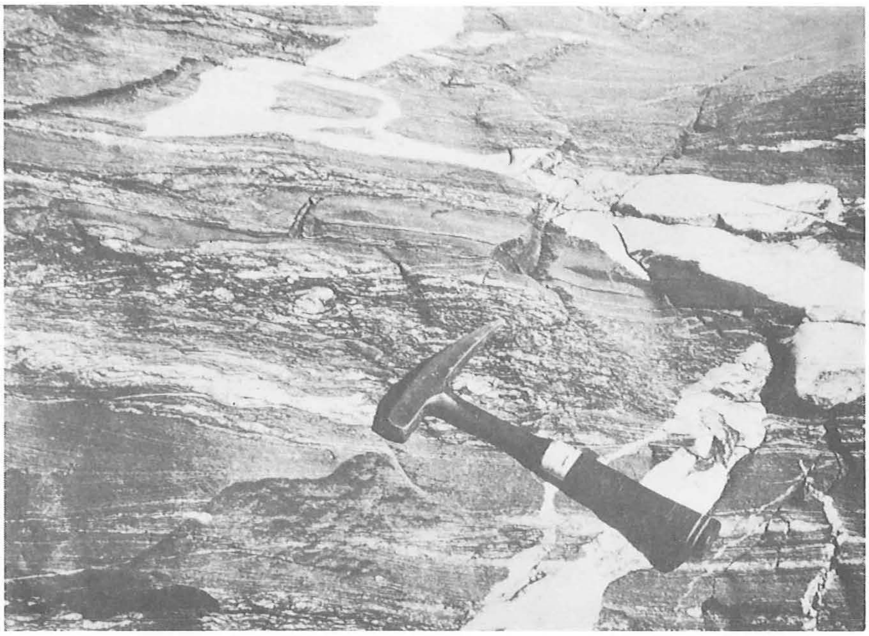


Fig. 13: Migmatite band in gneiss with crosscutting aplite vein; Einasleigh Metamorphics in Louis Creek at GR127018. GB148 (I.W.W.).

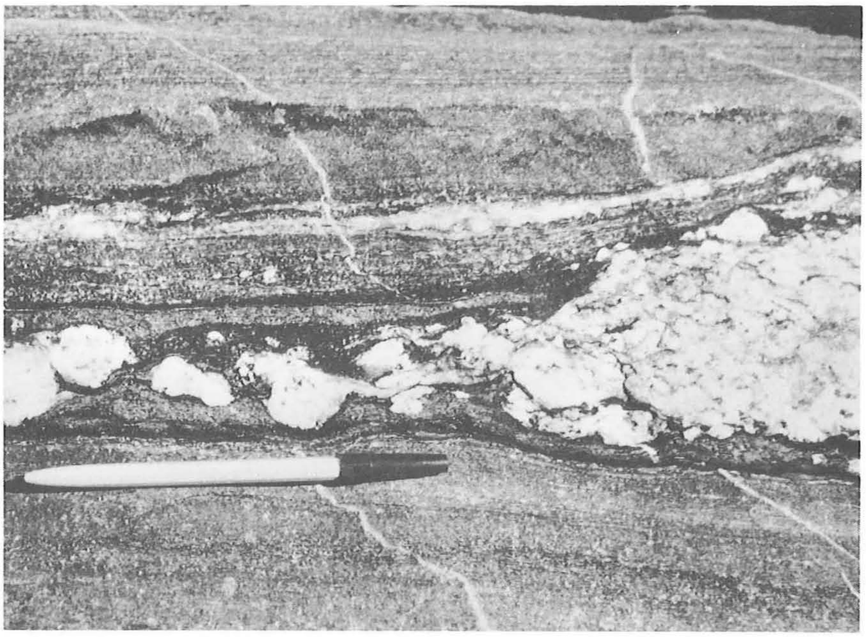


Fig. 14: Pegmatoid leucosome with thin biotite melanosome in banded biotite gneiss; Einasleigh Metamorphics in Louis Creek at GR127018. GB152 (I.W.W.).

The bands in the amphibolite consist of quartz, sericitized and saussuritized plagioclase with albite rims, epidote, and hornblende. They are fine- to medium-grained, and in places distinctly granite-like in appearance; a finer-grained margin occurs locally. Alteration of biotite to chlorite, sericitization and saussuritization of plagioclase, and formation of epidote in most of the rocks, are obvious changes in the altered gneiss. In hand specimen or outcrop the most obvious indication of alteration is that feldspar is commonly cream or white, rather than grey as in fresh gneiss. Microcline, when present, is clear and unaltered, however, suggesting that it may have been introduced by K-metasomatism. At GR115977 gneiss appears to have been selectively 'granitized' along certain bands by K-metasomatism (Fig. 11). The gneiss is of the normal banded type; one band about 0.5 m wide grades laterally into massive granite which contains scattered, irregular pink microcline porphyroblasts up to 2 cm long. The origin of the metasomatizing fluids is unknown, although the Digger Creek Granite, which is associated with extensive swarms of pegmatite and aplite dykes.

(g) Migmatite

The rocks described in this section show definite separation of leucocratic and melanocratic components, consistent with their having been derived by in situ mobilization of country rock, probably as a result of partial anatexis. Migmatites are best developed in the Welfern area, where they are interlayered with gneiss. A typical migmatite band is up to one metre wide and consists of thin discontinuous bands, pods, and augen of quartz and feldspar (leucosomes) with intervening bands rich in biotite (melanosomes) (Figs. 12-14). The adjacent gneiss (palaeosome), although banded, does not have a separate granitic phase. Where migmatization has proceeded to an advanced stage the migmatite bands resemble the granite-gneiss described under (h) below.

Leucosomes are fine- to medium-grained with a hypidiomorphic granular texture. They consist mainly of anhedral quartz with interlocking margins, subequant tabular plagioclase (An_{40-50}) with myrmekite, and microcline grains which are commonly perthitic. Minor biotite, hornblende, and garnet are also present. Melanosomes also contain quartz and feldspar but have up to 40 percent mafic minerals; they are well foliated. Biotite occurs as clusters of subparallel reddish-brown flakes. Hornblende, when present, occurs as subidioblastic elongate bluish-green grains up to 1.5 mm long. Garnet forms subequant xenoblastic grains up to 3 mm across. Accessory zircon occurs in both melanosomes and leucosomes. Estimated modal analyses of two migmatite specimens are given below (Table 4).

Table 4

	1		2	
	Leucosome	Melanosome	Leucosome	Melanosome
Quartz	25	45	30	30
Microcline	40	< 5	< 5	tr
Plagioclase	30	25	60	30
Biotite	5	25	5	15-20
Hornblende	-	-	< 5	10
Muscovite	1	< 5	-	-
Garnet	-	-	tr	10-15

1. BMR registered No. 74300072; Migmatite or augen gneiss (Fig. 12)
2. BMR registered No. 74300073; Banded migmatite

(h) Granite-gneiss

These rocks crop out in a poorly exposed belt 4 km wide between 6 and 17 km south of Beverley Hills homestead. In hand specimen they resemble strongly foliated granodiorite but many outcrops have a gneissic appearance and are characterized by bands containing up to 20 percent of large K-feldspar porphyroblasts (Fig. 15). The K-feldspar porphyroblasts are subhedral and up to 5 cm long. The 'groundmass' consists of 30 percent quartz, 50 percent plagioclase (An$_{40}$) and 20 percent biotite. Accessory minerals include zircon and apatite. The average grain size is 1.5 mm. A mortar texture is commonly developed.

Although the rocks have the bulk composition of granodiorites, the groundmass has the composition of tonalite, as has the biotite gneiss. The granite gneiss may have been derived by anatexis of the biotite gneiss and K-feldspar porphyroblasts introduced by later K-metasomatism from an unknown source.

(i) Pegmatoid and granitoid veins

Pegmatoid and granitoid dykes and veins are common in many parts of the Einasleigh Metamorphics; they range in width from less than a centimetre to several metres and are

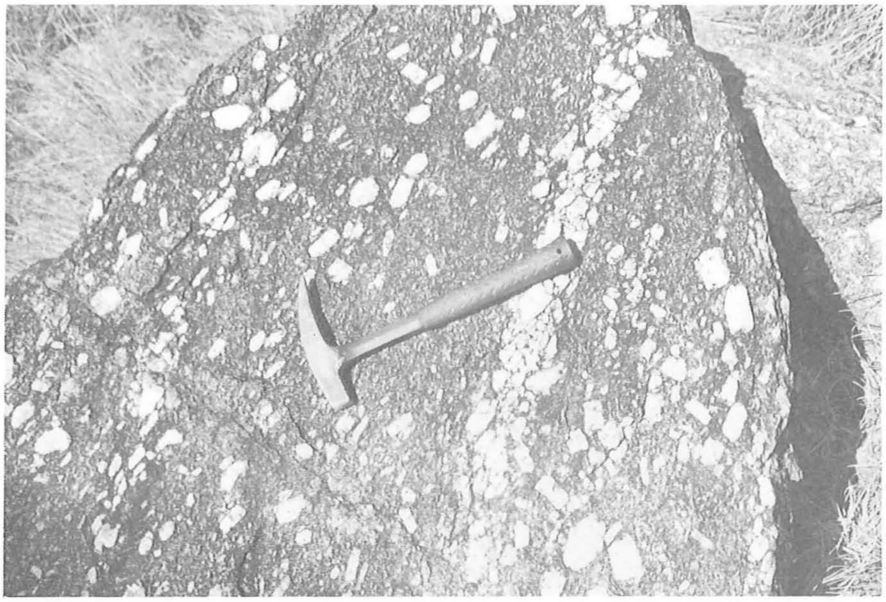


Fig. 15: Granitic gneiss with porphyroblasts of K-feldspar; Einasleigh Metamorphics in headwaters of Plum Tree Creek 7 km northwest of Fernhill outstation. M 1669 (J.H.C.B.).

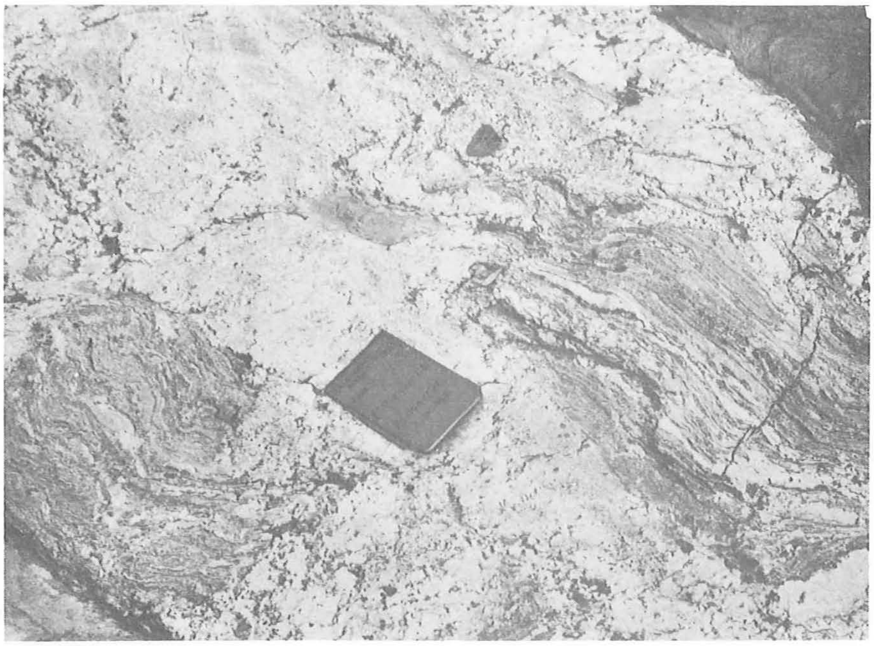


Fig. 16: 'Migmatite', banded gneiss with concordant and crosscutting pegmatoid veins; Einasleigh Metamorphics at the Stockman Creek crossing on the Einasleigh-Forsayth road. GA9517 (I.W.W.).

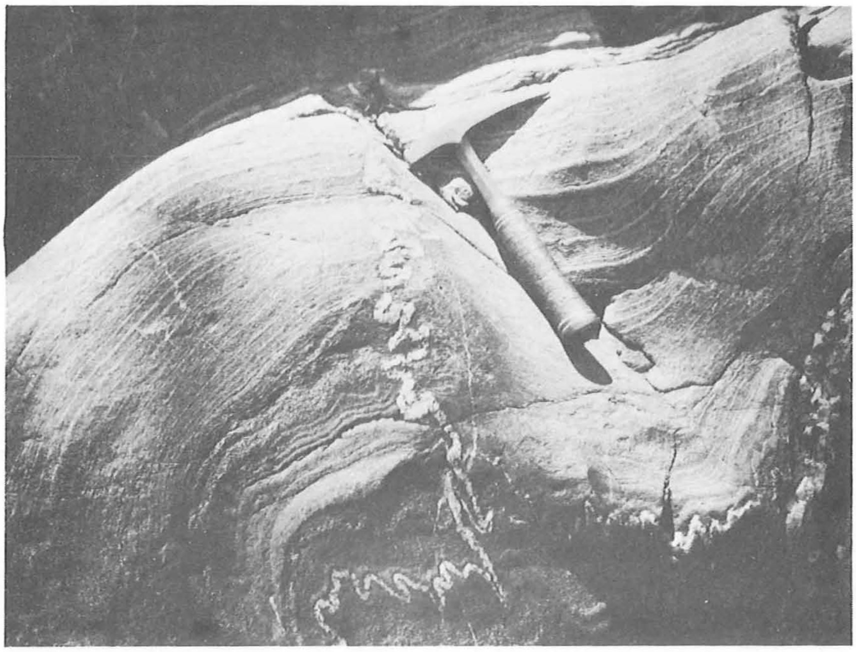


Fig. 17: Banded gneiss with crosscutting ptygmatic granitoid veins; Einasleigh Metamorphics at the Stockman Creek crossing on the Einasleigh-Forsayth road. GA9509 (I.W.W.).

both concordant and discordant to the foliation. Many consist almost entirely of quartz and feldspar, with sporadic patches of biotite, and locally some garnet. The veins and dykes are usually irregular in outline but have sharp boundaries; 'pinch and swell' structures and ptygmatic folds (Fig. 17) are common. Where present, the density of occurrence of veins and dykes ranges from only a few per ten metres to ten or more per one metre. Where pegmatoid bodies are abundant the term migmatite could be applied to the outcrop (Fig. 16).

The veins and dykes may have been intruded from elsewhere (arterites), or be a mobilized in situ component of the country rocks (venites). If the veins are venites they should have a mafic-rich rim or melanosome which represents surplus mafic material left after anatexis. In the Stockman Creek area, some small pegmatoid veins do appear to have a concentration of biotite around their edges and may be venites. However, most large veins and dykes have no melanosomes and are arterites, although they were probably originally mobilized by metamorphism from source material that probably lay at shallow depth beneath the present land surface. Kretz (1966) showed that in similar pegmatoid veins at Einasleigh a significant portion of the vein forming matter was locally derived. Several generations of veins occur,although all appear to be mineralogically similar. Small concordant pods of possible local origin may represent the earliest phase, formed during or after a first deformation. Another group of veins which cut across the foliation have been folded by subsequent deformations. This group may comprise one or more discrete generations or episodes of veins. In the Welfern area many of the concordant pegmatoid veins and pods have distinct biotite rims, and they are associated with migmatite bands in which gneiss has been separated into small quartzofeldspathic aggregates and intervening biotite-rich layers. These pegmatoids are probably locally derived. Some of the larger pegmatite and aplite dykes and veins which do not show mafic rims may have originated at depth and then intruded their present host rock. However, many probably came from biotite leucogranite and muscovite-bearing Digger Creek Granite magma rather than from melted country rocks. The pegmatites which contain muscovite rather than biotite are almost certainly related to the latter granite.

The veins range in grainsize from 1 mm to several centimetres and consist of plagioclase and subordinate quartz, microcline, biotite, and garnet. Plagioclase (An$_{30}$ in specimen GSQ 6950) occurs as large subequant grains slightly sericitized along cracks and cleavage planes. Grain boundaries are usually smooth; garnet, biotite, quartz, and zircon inclusions are common. Microcline forms smaller equant grains characterized by fine cross-hatch twinning and microperthite; they are often rimmed by myrmekite. Quartz is interstitial to the feldspars and occurs as mosaics of interlocking grains. Biotite commonly occurs as clusters of randomly oriented deep reddish-brown flakes; abundant idiomorphic zircon inclusions up to 0.6 mm in length are surrounded by very dark pleochroic haloes. The biotite flakes are rimmed by fine secondary muscovite, and are slightly altered to chlorite. Garnet is present as subhedral grains up to 5 mm in diameter; it is fractured and partly altered to chlorite. Deformation is suggested by fracturing of garnet, kinking of plagioclase twin lamellae, and slight bending of some biotite flakes; some quartz and feldspar grains show undulose extinction, and sporadic minor granulation occurs along some grain boundaries. However, the quartz is not excessively strained, possibly because of annealing of recrystallization after deformation.

The abundance of plagioclase with respect to K-feldspar in most pegmatoid veins supports the conclusion that the veins were derived from partial melting of gneiss rather than being differentiates of granite intrusions.

Metamorphism

The common occurrence of sillimanite and brownish-green hornblende indicates that the Einasleigh Metamorphics are in the middle or upper amphibolite facies. There is also evidence of granulite facies Einasleigh Metamorphics at Einasleigh, just to the east of the Forsayth 1:100 000 Sheet area (N. McNaughton, Qld Univ., pers. comm.). The occurrence of migmatites, is consistent with high-temperature upper amphibolite and granulite conditions. Mehnert (1968) noted that migmatite formed mainly in the high temperature of amphibolite facies conditions. The absence of primary muscovite and the presence of K-feldspar characterize most migmatite terrains. The gneiss and schist of the Stockman Creek area contain abundant muscovite and only minor K-feldspar, but muscovite occurs mostly as fine-grained aggregates of secondary origin, derived from sillimanite. Insufficient work has been done to establish definitely when this secondary muscovite formed, or when the rest of the retrogression occurred. Several alternative hypotheses are offered below.

Initially, perhaps during the deformation which produced the gneissic foliation, the temperature was greater than that within the stability field of muscovite, i.e. upper amphibolite facies conditions. Small quantities of in situ pegmatoid mobilizate may have formed at this stage. Subsequently, the temperature in the Stockman Creek area fell below the stability fields of K-feldspar and sillimanite, and the sillimanite retrogressed to muscovite. Most muscovite occurs in lenses or bands parallel or subparallel to, and deformed with, the foliation, suggesting that it was derived from original patches of fibrous sillimanite lying parallel to the foliation. Outside the Stockman Creek area temperatures remained high enough for continued generation of pegmatoid mobilizate, some of which was injected into adjacent slightly cooler rocks. Temperatures may have continued to decline gradually until greenschist facies conditions were reached, possibly after the last phase of deformation. Biotite and garnet retrogressed to chlorite, and plagioclase to epidote, particularly in the more calcium-rich rocks; in other rocks plagioclase became clouded.

If the amphibolite facies part of the Robertson River Metamorphics is younger than the Einasleigh Metamorphics, as least part of the retrogression in the latter may have been produced during the prograde metamorphism of the former. Although middle amphibolite conditions were reached in parts of the Robertson River area, only greenschist facies conditions may have affected the Einasleigh Metamorphics farther east.

White (1965) suggested that the retrogression was produced by the intrusion of granites of the Forsayth Batholith. Although metamorphic rocks in the Stockman Creek area are intruded by several small granitic bodies, the closest large granitic mass is 15 km away from the area. It is possible, however, that because of its volume the batholith supplied sufficient heat to convert the country rocks to greenschist facies metamorphics over a wide area. K-Ar dating by Richards et al. (1966) indicates that a Devonian thermal event affected much of the Georgetown Inlier. This event may also have been responsible for some of the retrogression. It is probably the same event as the Devonian metamorphism recorded in the Coen and Dargalong Metamorphics on Cape York Peninsula (Cooper et al., 1975). The Einasleigh Metamorphics in the Welfern area, although locally metasomatized, commonly show fewer signs of retrogression than those in the Stockman Creek area.

At present, no single consistent theory explains all of the features of the Einasleigh Metamorphics; a combination of parts of various theories may ultimately provide the solution. For example, it may be that muscovite was produced by waning temperatures of an early metamorphism, whereas some other features may be due to later metamorphism.

Relations to other units

The relations between the Einasleigh Metamorphics and other Precambrian metamorphic rocks in the Georgetown Inlier is a major unsolved problem. White (1965) hypothesized that the Einasleigh Metamorphics were part of an Archaean basement on which the supposedly younger Etheridge Formation and equivalent units were deposited. He speculated that the amphibolite facies part of the Robertson River Metamorphics may have been part of the basement 'thrust out of the core of the Georgetown Inlier over the Etheridge Geosyncline' (White, op. cit. p. 38). However, the Etheridge Formation and the Robertson River Metamorphics were deposited synchronously, and the Einasleigh Metamorphics may also have been deposited at the same time.

It is relevant here to briefly compare the rock types of the Einasleigh Metamorphics and amphibolite facies Robertson River Metamorphics. Basic amphibolite occurs in both units. The Robertson River Metamorphics consist mainly of schist, quartzite, and minor calc-silicate rocks; the schist and quartzite contain muscovite and generally only minor feldspar. The unit does not contain any rocks equivalent in composition to the plagioclase-rich biotite gneiss of the Einasleigh Metamorphics. This distinguishes the Einasleigh Metamorphics as a distinct mappable rock unit. The two units are mostly separated by the Newcastle Range Volcanics and Robin Hood Granodiorite. The only area in the Forsayth 1:100 000 Sheet area where the contact between them may be exposed is in the vicinity of Fraser's Well (GR 950015) in the southern part of the area (see map); exposures here are very poor, however. Schist and quartzite, which are similar to rocks in the Robertson River Metamorphics, except for being feldspathic, crop out at Fraser's Well. In Carpentaria Gully and its tributaries, 8 km to the east, banded biotite gneiss characteristic of the Einasleigh Metamorphics crops out. In between there are several outcrops of very weathered rocks which might have been either schist or gneiss originally; no objective boundary can be drawn here, and a gradation from one unit into the other is possible. The rocks at Fraser's Well have been assigned provisionally to the Einasleigh Metamorphics although they are lithologically more akin to the Robertson River Metamorphics.

There is no good reason to suppose that the Einasleigh Metamorphics are older than the Robertson River Metamorphics. The lithological differences could be the result of variations in the grade of metamorphism, style of deformation and, in particular, original lithofacies. The feldspar in the Einasleigh Metamorphics gneiss is mainly plagioclase; this may have originated either as detrital plagioclase or as a marly component in the original sediments. The calc-silicate rocks in the Einasleigh Metamorphics of the Welfern area may be correlated with the Bernecker Creek Formation, which occurs to the south in the Gilberton 1:100 000 Sheet area. This formation contains calc-silicate-bearing metasediments in the greenschist and amphibolite facies, and may be a shelf facies equivalent of the Robertson River Metamorphics (White, 1965). Detailed mapping by Llewellyn (1974) southeast of Percyvale homestead has not clarified the relation between the Bernecker Creek Formation and Einasleigh Metamorphics, nor have structural data so far clarified the relations between the Einasleigh Metamorphics and other metamorphic units. Both the Robertson River and Einasleigh Metamorphics have probably been deformed by at least four sets of folds, as discussed in detail below (pp.37-42).

The Einasleigh Metamorphics in the Forsayth Sheet area are in the upper amphibolite metamorphic facies: the Robertson River Metamorphics immediately west of the Newcastle Range are probably also in the upper amphibolite facies. These facts are consistent with the hypothesis that the Einasleigh Metamorphics are a higher-grade equivalent of the Robertson River Metamorphics. However, in the Stockman Creek area the Einasleigh Metamorphics have undergone a retrogression which appears to have had little effect on the Robertson River Metamorphics to the west. If the Robertson River Metamorphics were metamorphosed later than the Einasleigh Metamorphics, this metamorphism may have caused the retrogression of the latter. Alternatively the retrogression may be due to an even later thermal event which affected only the eastern part of the Forsayth Sheet area or, as suggested above (pp.14-15), the prograde and retrograde metamorphism may have occurred in the one event. Thus the effects of metamorphism provide no definite evidence on the relative original ages of the Einasleigh and Robertson River Metamorphics. Information from other sheet areas may eventually provide the answer. Mapping in the Georgetown 1:100 000 Sheet area in 1974 provided field evidence pointing to the two units being equivalent but did not unequivocally rule out an age difference.

In the Gilberton 1:100 000 Sheet area, near Gilberton homestead, the presence of a sharp 'metamorphic unconformity' has been inferred between highly deformed upper amphibolite facies rocks assigned to the Einasleigh Metamorphics and much less deformed lower greenschist facies siltstones, phyllitic shales and metabasalt, originally assigned to the Etheridge Formation (White, 1962c). Assuming these rocks are part of these two formations the presence of a 'metamorphic unconformity' would suggest that the Robertson River Metamorphics were deposited after the original metamorphism and deformation of the Einasleigh Metamorphics had taken place. However, as this 'unconformity' is in fact a fault it is possible that the rocks on either side are of similar age but have undergone different degrees of metamorphism and deformation and have been juxtaposed by major vertical or transcurrent movement, or both. It is also possible that the rocks mapped as Einasleigh Metamorphics belong to lithologically similar suites of two different ages. Deformation and metamorphism of the younger suite to middle or upper amphibolite grade may have produced rocks like those in the older suite which would probably be locally metamorphosed and redeformed with consequent destruction of their earlier structure. In this case the high grade rocks south of Gilberton homestead may be part of the older suite.

Preliminary Rb-Sr dating by Black (pers. comm., 1975) suggests a metamorphic 'age' of 1500 m.y. for the Robertson River Metamorphics, whereas the Einasleigh Metamorphics may have been metamorphosed at about 1700 m.y. (see below).

The following granitic rocks intrude the Einasleigh Metamorphics: the Robin Hood Granodiorite, the Oak River Granodiorite, and the Digger Creek Granite with its related aplites and pegmatites.

Age

White (1959, 1962 a-d, 1965) assigned a tentative Archaean age to the Einasleigh Metamorphics, presumably because they were more highly deformed and metamorphosed and therefore supposedly older than the other Precambrian units. However, there is no definite evidence to suggest that rocks as old as the Archaean occur in eastern Australia, and we prefer to assign a Proterozoic age to the rocks. No reliable isotopic dates have been obtained because of the effect of a Palaeozoic event, which caused extensive argon loss even in muscovite. K-Ar dating on a pegmatite in the Einasleigh Metamorphics gave 414 m.y. (biotite) and 432 m.y. (muscovite) (Richards et al., 1966); a preliminary Rb-Sr date on muscovite from the same sample indicated 1700 m.y. (Black, 1973).

In the Yambo Inlier, to the north of the Georgetown Inlier the Dargalong Metamorphics, which are similar to, and may be related to at least part of the Einasleigh Metamorphics are intruded by unmetamorphosed dolerite which has given a K-Ar age of 1884 + 40 m.y. Cooper et al., 1975), indicating that the metamorphics may be older than 1900 m.y.

Further samples of the Einasleigh Metamorphics were collected by Black in 1973 for Rb-Sr dating. Dating by the ^{40}Ar/^{39}Ar incremental heating method is planned by the GSQ in conjunction with the University of Queensland.

Origin

The Einasleigh Metamorphics appear to have been a sequence of feldspathic or marly sandstone, siltstone, and shale. Dolerite, and possibly andesite, sills and dykes intruded the sequence prior to metamorphism.

Robertson River Metamorphics

Introduction

The Robertson River Metamorphics were named by White (1959b) after the Robertson River. They crop out over an area of 600 sq km in the western part of the Forsayth 1:100 000 Sheet area, where they consist of mica schist quartzite, and subordinate graphitic schist and calc-silicate rocks. The mica schist, depending on the metamorphic grade, which ranges from upper greenschist to uppper amphibolite facies contains such minerals as staurolite, andalusite, garnet, and sillimanite. No type section was originally proposed, although the area traversed by the Robertson River between the Forsayth-Agate Creek road and Tin Hill, a prominent quartzite ridge at GR 730165 (Fig. 25) was designated the type area. The rocks exposed there are mostly in the lower amphibolite facies and consist of garnet-staurolite-mica schist, graphitic schist, pure and impure quartzite. The thickness of the unit cannot be determined because of the complex deformation.

The Robertson River Metamorphics occur in undulating to hilly country with local resistant ridges of quartzite up to 100 m high. Strike ridges are locally well developed, especially in the western part of the sheet area. Outcrop is generally from poor to fair although the metamorphics are well exposed in major streams such as the Robertson and Little Robertson Rivers. The area is covered by open ironbark woodland, which in places has a thick understorey of quinine bush.

Relations to other units

White (1965) suggested that the Robertson River Metamorphics as he defined them may have been equivalents of the Einasleigh Metamorphics thrust over lower-grade rocks he mapped as Etheridge Formation. Earlier (White, 1959b; White & Hughes, 1957) it was hypothesized that the Robertson River Metamorphics either overlie or are simply a highergrade equivalent of the Etheridge Formation.

Mapping by us and Fitzgerald (1974), suggests that the low-grade rocks along the western edge of the sheet area mapped by White as Etheridge Formation are the less intensely metamorphosed equivalents of the Robertson River Metamorphics, into which they grade. Fitzgerald (op. cit.) showed that both the high- and low-grade rocks have undergone the same series of folding events.

The rocks previously mapped as Etheridge Formation, mainly phyllites, are now mapped as part of the Robertson River Metamorphics (Ᵽmr$_p$). This is in accordance with the Australia Code of Stratigraphic Nomenclature (1964, Article 20) which states that 'where a formation can be traced through various zones of metamorphism it should be classed as a formation and should retain its name even though its metamorphic grade changes....' The problem of nomenclature of the metamorphic units will be reviewed when mapping of the adjacent areas is completed.

The boundary between the 'phyllite phase' (Ᵽmr$_p$) and 'schist phase' (Ᵽmr) of the Robertson River Metamorphics coincides approximately with the greenschist-amphibolite facies isograd, although phyllite containing amphibolite facies minerals such as staurolite is present locally.

The relation between the Robertson River Metamorphics and the Einasleigh Metamorphics has been discussed (pp.15-18).

The Forsayth Granite, Robin Hood Granodiorite, and Digger Creek Granite intrude the Robertson River Metamorphics. Pegmatite dykes and small bodies of muscovite granite pervasively intrude parts of the Robertson River Metamorphics; these minor intrusions are probably related to the Digger Creek Granite.

Lithology and petrography

(a) Phyllite (equivalent to Etheridge Formation of White, 1959b).

Greenschist facies. Quartz and sericite (average grainsize less than 0.2 mm) are the dominant constituents of the greenschist facies phyllite which represents metamorphosed siltstones and shales. The sericite flakes are generally parallel to the cleavage or schistosity although in some specimens flakes are parallel to the bedding. Chlorite (up to 5 percent) is present in most specimens both parallel to the foliation and crosscutting it. Slightly crosscutting flakes of chloritoid up to 1.5 mm across (Fig. 19) are locally common. The chloritoid is somewhat unusual in being colourless in thin section rather than having the characteristic green to blue pleochroism. Biotite occurs in many rocks but not in those containing chloritoid. Some phyllite also contains garnet porphyroblasts up to 1.5 mm across (Fig. 18).

Upper greenschist to lower amphibolite facies. Rocks in this facies, which are transitional between the Etheridge Formation and Robertson River Metamorphics of White (1959b) are well exposed in Dingo and Cave Creeks. Grey or greenish

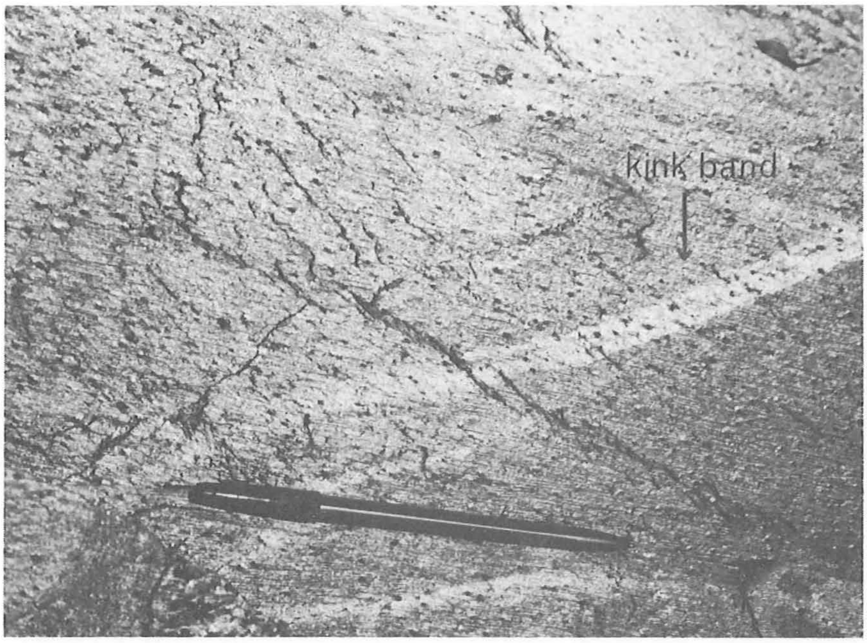


Fig. 18: Foliation plane (S_2) of phyllite showing fine lineation (due to intersection of S_1 and S_2), small garnet porphyroblasts and a crosscutting kink band; Robertson River Metamorphics (phyllite phase) in Cave Creek about 4.8 km south-southwest of where the Agate Creek road crosses the Robertson River. GA 9545 (I.W.W.).

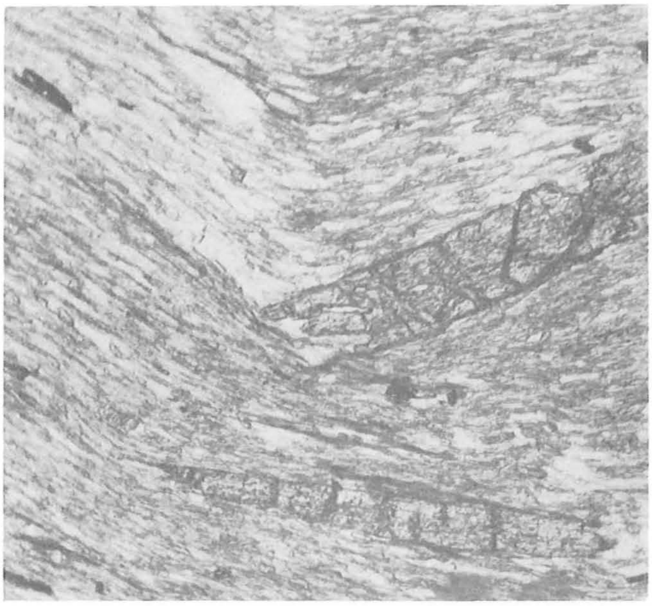


Fig. 19: Photomicrograph showing porphyroblastic flakes of chloritoid in phyllite; Robertson River Metamorphics (phyllite phase). GSQ Slide No. 6919. Magnification X 60 (plane polarized light). M1619/1 (I.W.W.).

grey phyllite, quartz-phyllite, and fine sericite-quartz schist are the predominant rocks. They have a well developed cleavage or schistosity and are commonly finely crenulate. Quartz, and sericite or muscovite, are the main constituents. Biotite, locally altered to chlorite is present as flakes generally cutting across foliation, defining a weak lineation on foliation surfaces. Garnet occurs as equant, pale pink, xenoblastic to subidioblastic grains up to 2 mm across with poikiloblastic cores; some grains have inclusion-free post-tectonic rims. Biotite sheaths the garnet grains, and the foliation wraps around them. Helicitic quartz inclusions indicate that many garnet grains have been rotated. Subidioblastic staurolite prisms up to 1 cm long with well-developed sieve texture are common; The staurolite prisms lie within the foliation, but are not aligned, and commonly show evidence of having been rotated. Very small specks of graphite are common; iron oxides and tourmaline are the main accessory minerals.

Staurolite is a definite indicator of amphibolite grade metamorphism. However, it will form in only a relatively narrow range of composition, so its absence in metapelites cannot necessarily be taken as an indication of greenschist grade metamorphism. For this reason the boundary between the greenschist and amphibolite facies rocks is difficult to place precisely.

(b) Schist

Lower amphibolite facies. Fine- to medium-grained biotite-muscovite-quartz schist is the most common lithology within rocks of this facies. The schist is greyish yellow to grey when fresh, and has a well developed schistosity which is commonly crenulate (Figs 20 & 21). Some bands locally parallel to the schistocity and consisting of different proportions of quartz, muscovite, and biotite, probably represent transposed bedding. Muscovite generally predominates over biotite; both occur as flakes up to 1.5 mm long parallel to the schistosity. Randomly crosscutting flakes of muscovite and biotite are present locally; where both are crossuctting, the muscovite usually cuts the second-generation biotite flakes. Clusters of randomly orientated chlorite flakes (up to 2 mm long), are common locally and may indicate retrogression occurring in the waning stages of metamorphism. Also present are small garnet porphyroblasts which locally distort the foliation, and minute tourmaline grains. Andalusite is almost invariably pseudomorphed by fine-grained sericite which has locally recrystallized to aggregates of large muscovite flakes. The sericite pseudomorphs are up to 6 cm long and have prismatic forms and roughly square cross-sections.

Staurolite-bearing schist is interbedded with white quartzite along the Robertson River between Middle Yard and Quartz Blow Creek. This schist has a fine-grained, yellowish-grey matrix of quartz and muscovite containing porphyroblasts of brown staurolite up to 5 mm long, biotite up to 7 mm long, and garnet up to 3 mm across. The biotite flakes are elongate and lie in the plane of foliation with their long axes defining a weak lineation. The cleavage planes of the flakes are inclined at up to 90° to the foliation. The staurolite porphyroblasts are pale yellow to golden yellow in thin section and have a well-developed sieve texture; typical interpenetrating twins occur sporadically; helicitic inclusions indicate that the porphyroblasts were rotated during growth. Similarly, the garnets show evidence of rotation, commonly by between 45° and 90°, but also by as much as 120° locally. The foliation is wrapped around the garnet and staurolite, both of which commonly have idioblastic post-tectonic rims. Some garnet crystals which are partly enclosed within syntectonic staurolite have post-tectonic rims, suggesting that they continued growing within their host.

Staurolite-bearing schist also crops out along the Agate Creek road between the Robertson River and Cave Creek and the soil beside this road contains small staurolite crystals for several hundred metres south of the river. In thin section the staurolite and garnet of these rocks have similar habits to those described above, but the cleavage planes of the biotite flakes are parallel to the foliation and there is no lineation. Most staurolite is pseudomorphed by sericite-chlorite aggregates, suggesting that it has been retrogressively metamorphosed. Pseudomorphs after cruciform twins occur sporadically. In one rock, partly sericitized andalusite rims the partly altered staurolite.

Kyanite has been found only in a fine-grained slightly graphitic schist at GR 661257. Muscovite-biotite aggregates pseudomorphing cruciform twins of staurolite occur with the kyanite. Staurolite forms cores in some of the kyanite, suggesting that the latter may have replaced the former. Andalusite also occurs in the same rock, suggesting that the pressure/temperature conditions under which the minerals formed were close to the univariant phase boundary between andalusite and kyanite.

Middle and upper amphibolite facies. Fine- to medium-grained biotite-muscovite-quartz schists similar to those in the lower amphibolite facies are also the most common rocks in the middle amphibolite facies. The difference between schists of the two facies is in the presence of up to 5 percent sillimanite in the middle amphibolite facies rocks.

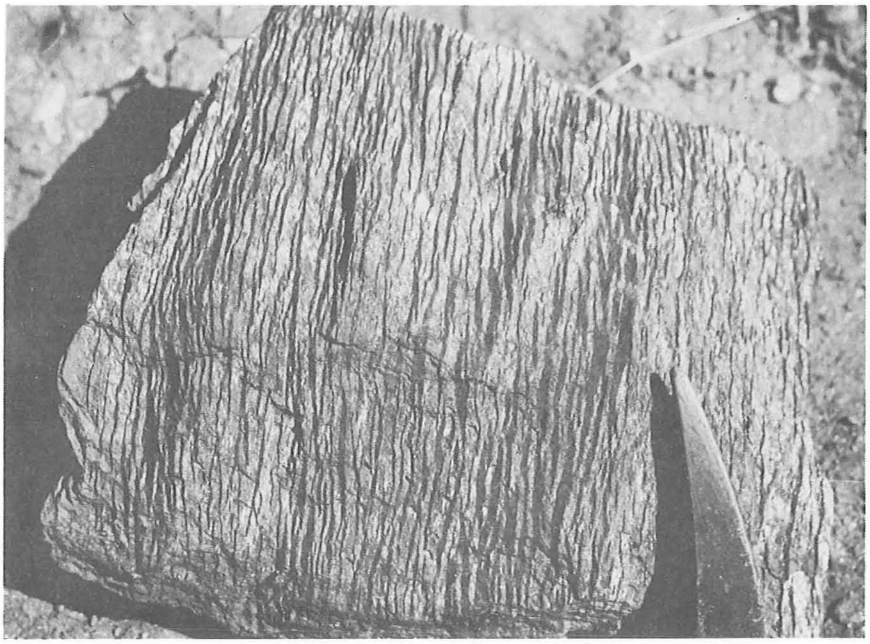


Fig. 20: Typical crenulate mica schist; Robertson River Metamorphics (schist phase). GA9496 (I.W.W.).

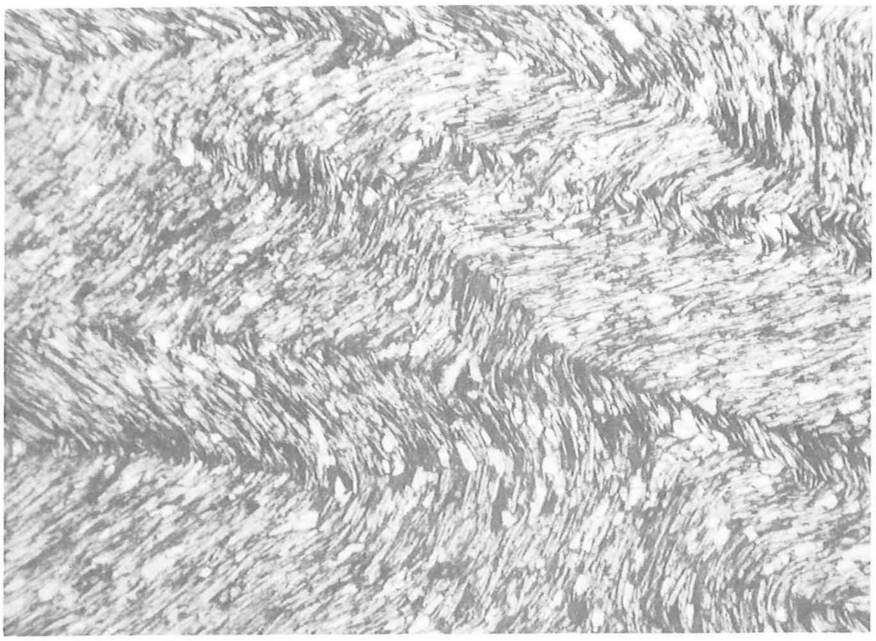


Fig. 21: Photomicrograph of crenulate quartz-mica schist; Robertson River Metamorphics (schist phase). GSQ Slide No. 6887. Magnification X 25 (plane polarized light). M1619/25 (I.W.W.).

Fig. 22: Photomicrograph of portion of quartz-sillimanite aggregate showing bundles of fibres of 'fibrolite' (grey); Robertson River Metamorphics (schist phase). GSQ Slide No. 6881. Magnification X 60 (plane polarized light). M1619/29 (I.W.W.).

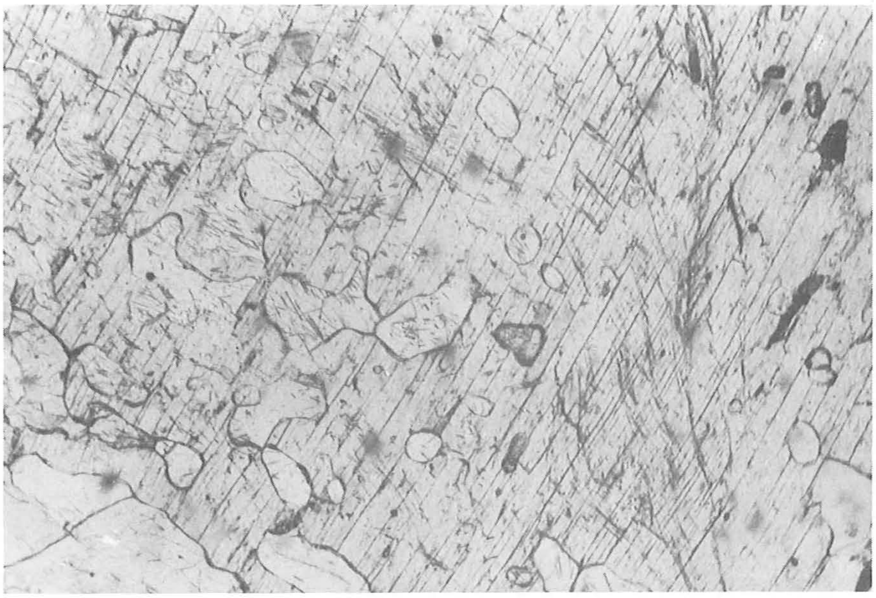


Fig. 23; Photomicrograph showing portion of a post-tectonic muscovite flake containing inclusions of quartz (pale) and needles of sillimanite; Robertson River Metamorphics (schist phase). Magnification x 60 (plane polarized light). M1619/30 (I.W.W.).

Sillimanite occurs as bundles of fibrolite, some of which are associated with biotite, on which they may have nucleated; fine needles of sillimanite also occur in quartz grains and muscovite flakes. Schists containing up to 30 percent of white ellipsoidal 'porphyroblasts', 1 to 3 cm long, crop out in Pinnacle Creek. The 'porphyroblasts' are aggregates of about 70 percent quartz and 30 percent fibrolite bundles (Fig. 22) aligned within the foliation and sheathed by muscovite flakes. The groundmass consists of quartz, muscovite, biotite, minor plagioclase, and commonly microcline, which occurs as irregular grains up to 3 mm across enclosing quartz grains. Both K-feldspar and plagioclase are more common in the eastern than in the western part of the outcrop area.

Schist containing large lenticular porphyrobalsts of muscovite is common to the north of the Robertson River and east from the Robin Hood-Forsayth road. Typical exposures occur at Stars Well (GR 728286). The porphyroblasts are subequant, about 1 cm wide, and commonly consist of several interlocking muscovite crystals. Although the lenses themselves are parallel to the foliation the cleavage planes of the muscovite randomly crosscut it. Smaller randomly orientated muscovite flakes cutting the muscovite and biotite which define the foliation are probably related to the large muscovite porphyroblasts. Sillimanite and quartz inclusions are common in the muscovite (Fig. 23). The random orientation of the large muscovite flakes indicates post-tectonic growth.

In some rocks none of the muscovite present is parallel to the foliation. This feature, together with the presence of sillimanite inclusions in the muscovite (Fig. 23) suggests that these rocks may have initially formed at a temperature above the stability field of muscovite, i.e., upper amphibolite facies; muscovite may then have grown post-tectonically at a lower temperature, replacing sillimanite.

(c) Graphitic schist

Graphite is present as minute specks in many of the lower amphibolite facies rocks in the vicinity of Dingo and Malcolm Creeks and southwest of Stars Well, and also in middle and upper amphibolite facies rocks further north, where the individual graphite particles are coarser but still rarely exceed 0.1 mm. In the more carbonaceous rocks which are common in the north of the sheet area near the edge of the Forsayth Granite, aggregates up to several millimetres across occur. The graphite content ranges from trace amounts to about 10 percent but is generally less than 5 percent. Quartz muscovite, sillimanite, and sometimes biotite are the other constituents of the graphitic schist. The muscovite commonly occurs as lenticular porphyroblasts similar to those described above. Most of the graphite particles are dispersed along quartz grain boundaries, but some form inclusions in muscovite. Roof pendants of hornfelsed graphitic schist are common in the granite near Forsayth. Lower amphibolite facies graphite-bearing schists are commonly finer-grained than adjacent non-carbonaceous schists.

(d) Quartzite

Impure quartzite bands ranging from a centimentre to several metres thick (Fig. 24) are interlayered with the schist. In places the quartzite is dominant and has been mapped out as a separate lithofacies (Ꝑmr$_1$).

The impure quartzite is grey, fine- to medium-grained with a sugary texture, and consists of quartz, subordinate muscovite and biotite, and in some cases minor feldspar. The quartz grains have a granoblastic texture and are subequant to elongate. Mica flakes lying along the quartz boundaries impart a weak foliation to the rock. With an increase in mica content the rocks grade into schist. In the higher-grade rocks, traces of sillimanite are present as interstitial fibrolite and as inclusions in quartz.

Quartzite containing calc-silicates is interbedded with micaceous quartzite and schist and is particularly common along the Little Robertson River in the quartzite-rich member of the metamorphics (Ꝑmr$_1$). It is white, light grey, or slightly greenish, locally banded, and commonly contains greenish spots about 1 cm in diameter flattened parallel to the layering and foliation of the adjacent rocks.

The spots consist of tremolite, clinozoisite, biotite, chlorite, and garnet. In thin section the tremolite is slightly greenish; rare actinolitic hornblende occurs locally. Other minerals present include traces of muscovite and secondary calcite. The matrix of these spotted rocks consists of 50 to 70 percent quartz as subsequent to elongate grains with sutured boundaries, and up to 30 percent plagioclase, which is commonly sericitized; when fresh, the plagioclase is labradorite. Small irregular grains of clinozoisite and sphene are scattered through the matrix. The grainsize of the matrix is usually less than 0.3 mm.

The banded rocks consist of alternating epidote-rich and quartz-rich bands, the epidote content ranging from 20 percent to 100 percent. Tremolite is sometimes associated with the epidote. Sphene as idioblastic grains about 0.2 mm across is a common accessory.

Fig. 24: Interlayered quartzite and schist; Robertson River Metamorphics (schist phase) in Bull Creek near track to Middle Yard. GA9506 (I.W.W.).

The plagioclase composition and the presence of garnet in the spotted and banded quartzites indicate at least lower amphibolite grade metamorphism. Chlorite and clouding in the plagioclase are attributed to the greenschist conditions which retrogressed the andalusite and staurolite in some of the adjacent schist. The clinozoisite may also be due to retrogression. However, the possibility of its stability in the lower amphibolite facies in coexistence with labradorite will be discussed later (p. 34).

Rocks of a similar composition which were metamorphosed in the middle amphibolite facies consist of a fine-grained granuloblastic matrix of quartz and plagioclase with 10 percent of green poikiloblastic hornblende prisms up to 1 cm long; garnet is present as irregular poikiloblastic grains up to 1.5 mm, sphene is an accessory. These calc-silicate-bearing rocks probably had a marly composition originally.

Massive beds of white and dark grey, almost pure quartzite (Ƀmr$_2$) are confined mainly to the central part of the sheet area, about 12 km west-northwest of Robin Hood homestead, where they are interbedded with staurolitebearing schist; because of their resistance they form prominent ridges (Fig. 25). Discontinuous quartzite beds can be traced east to the Fish Hole track, about 9 km north of Robin Hood. Although the quartzite is commonly massive some beds are only a millimetre to several centimetres thick; it is isoclinally folded.

In thin section the white quartzite is fine- to medium-grained and contains more than 95 percent granoblastic elongate quartz grains. The grains are strained and have highly sutured boundaries. Some granulation of shearing occurs in the finer-grained bands, which also contain minor amounts of sericite. Greyish bands tend to be coarser-grained, consist almost entirely of quartz, and are not sheared. Brown tourmaline grains ranging from 0.1 to 0.3 mm are present in some bands.

The white quartzites may originally have been chert beds.

(e) Calc-silicate rocks

Several types of calc-silicate-bearing rocks, that were probably originally impure limestone, dolomite and marly siltstone are present locally.

Impure marble. Rocks of this type are rare in the Forsayth Sheet area. Several thin beds of marble crop out near the Forsayth-North Head road at GR 657356. The marble consists of bands of fine granuloblastic calcite alternating with bands containing up to 50 percent tremolite as small colourless prisms, 0.3 to 0.6 mm long. These beds can be traced west for almost 2 km. A marble bed 1 m thick is present in sericite schist at GR 683138, about 500 m northwest of Middle Yard.

Fine-grained calc-granofels. This rock type is associated with the marble near the Forsayth-North Head road. It is a fine-grained bluish-grey banded rock containing 5 to 10 percent interstitial quartz and plagioclase, about 55 percent tremolite in rosettes and as aggregates of decussate needles, and about 40 percent of xenoblastic diopside containing quartz and plagioclase inclusions. The actual proportions of minerals in different bands vary considerably, and some bands consist mainly of diopside and quartz. Bands range in thickness from 1 mm to several centimetres, and in grainsize from less than 0.2 mm to 0.6 mm.

Laminated calc-granofels (Ꝑmr$_3$). About 12 km west-southwest of Robin Hood homestead a large lenticular body of laminated calc-granofels or calc-silicate gneiss, 3 km long by 1 km wide, occurs in the core of a large open anitform (see map). The rocks are green to grey, and consist of thin alternating light and dark bands ranging in thickness from 1 to 10 mm. The bands are probably primary. Small concordant veinlets and pods of quartz and plagioclase containing traces of hornblende, tourmaline, and pyrite are present locally. The banded rocks consist mainly of fine- to medium-grained subequant quartz and plagioclase (andesine to labradorite). In addition, biotite occurs as greenish brown flakes subparallel or parallel to the banding. Muscovite flakes generally about 0.5 mm long are associated with the biotite in some thin sections cutting across the bands. Epidote forms colourless to pale yellow subidioblastic grains which are usually more abundant in the quartz-rich bands. Accessory minerals include sphene, tourmaline, opaques and hornblende. In one specimen some bands contain 10 to 20 percent scapolite; a meionite-rich composition (Me_{70-80}) is indicated by the relatively high birefringence.

Although epidote could indicate greenschist facies metamorphism, the composition of the coexisting plagioclase (labradorite) suggests an amphibolite grade. This is supported by the assemblages in adjacent rocks.

Metamorphism

The metamorphism of the Robertson River Metamorphics is discussed in a separate section together with that of the Cobbold Metadolerite (pp 31-36).

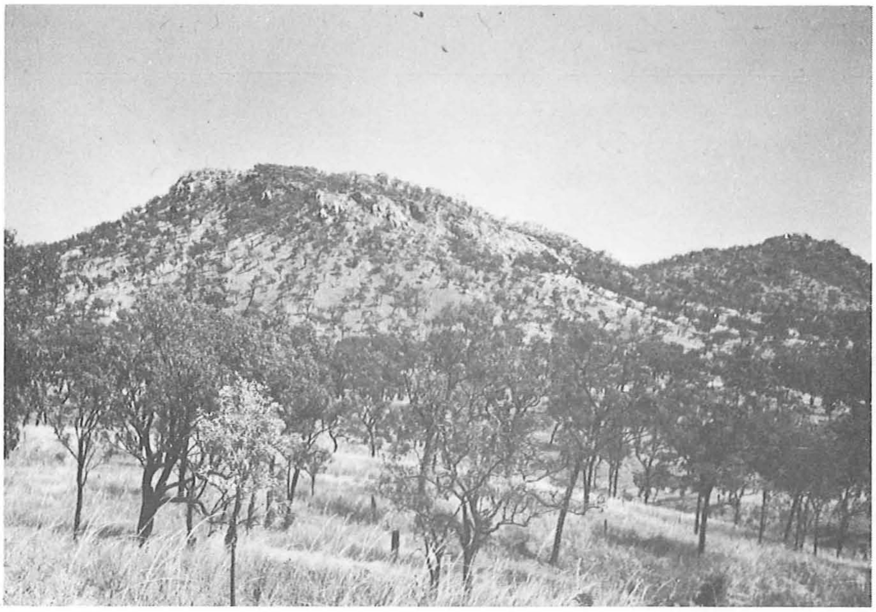


Fig. 25: Tin Hill, a ridge of white quartzite (Ɓmr$_2$); Robertson River Metamorphics, about 12 km west-northwest of Robin Hood homestead. GA9458 (I.W.W.).

Age

Black (pers. comm.) has dated samples of Robertson River Metamorphics from the Forsayth Sheet area by the Rb/Sr method. A sample of impure quartzite from Bull Creek at GR 715144 gave a total-rock Rb/Sr isochron indicating a metamorphic age of 1500 m.y.; muscovite from this sample gave a mineral age also of 1500 m.y. The dominant foliation at Bull Creek is S_2 and suggests that the second deformation and accompanying metamorphism occurred at 1500 m.y. Mica schist from Mailman's Track Creek at Stars Well (GR 729284) gave muscovite and biotite ages of 1436 and 1423 m.y. respectively. Most of the muscovite in the schist is post-S_2 which may account for the apparent age difference. Alternatively partial resetting during B^{S3}_{S2} or B^{S4}_{S2} folding may be responsible. Muscovite from the same sample was dated by $^{40}Ar/^{39}Ar$ total degassing technique by the University of Queensland for the GSQ. An age of 1451 m.y. was obtained (D.C. Green, pers. comm.). Argon dates are usually more susceptible to resetting than Rb/Sr dates; hence the close correspondence of ages by the two techniques suggests that resetting may have been minimal.

Origin

The Robertson River Metamorphics were originally a sequence of sandstone, siltstone, and shale with minor chert and marly or calcareous beds.

Cobbold Metadolerite

Introduction

White (1959b) gave the name 'Cobbold Dolerite' to a series of basic stocks, sills, and dykes intruding the Etheridge Formation. The name was later extended to include all the amphibolite and metadolerite in the Einasleigh and Robertson River Metamorphics (White, 1962a-d). Since the Etheridge Formation and Robertson River Metamorphics are equivalent, it is valid to equate the metadolerite and amphibolite in the Robertson River Metamorphics with the metadolerites intruding the Etheridge Formation. However, we prefer not to equate them at this stage with the amphibolites in the Einasleigh Metamorphics because the relation of these metamorphics to the other units is still uncertain.

We propose to modify the name 'Cobbold Dolerite' to 'Cobbold Metadolerite' because our studies on the Forsayth and Georgetown 1:100 000 Sheets in 1973 and 1974 and reconnaissance on the North Head 1:100 000 Sheet in 1972 indicate that the unit has been metamorphosed in most, if not all, of its outcrop area and no unaltered primary mineral assemblages have been found. The term 'dolerite' is therefore inappropriate; 'metadolerite' covers both massive metadolerites and foliated or lineated amphibolites.

Relations with other units

The Cobbold Metadolerite intrudes the Robertson River Metamorphics in the Forsayth 1:100 000 Sheet area. The metadolerite and amphibolite bodies were folded and metamorphosed with the metasediments. The Robin Hood Granodiorite and Digger Creek Granite intrude the Cobbold Metadolerite.

Field relations and lithology

The metadolerites and amphibolite crop out extensively in the Robertson River Metamorphics, mainly as concordant folded sills and as small irregular plugs or stocks. The bodies range in width from a metre or less to more than a kilometre but they are mainly 100 to 300 metres wide. The distribution of these rocks is not uniform and they are more abundant in certain belts; in some areas, such as those which are dominantly quartzite, amphibolite is rarely observed.

Where the adjacent metasediments have been isoclinally folded the basic rocks generally show a marked lineation and commonly a foliation due to the alignment of amphibole grains (Fig. 26). In some cases, however, particularly in the nontabular bodies, the central part of the intrusion may lack penetrative deformation structures and may even retain well preserved igneous textures, whereas the margins are strongly lineated. Blastophitic textures are the most common relict igneous feature recognizable in the field. The foliation, where developed, is parallel to that in the adjacent metasediments; it is therefore apparent that the basic bodies were emplaced before the deformation which produced the dominant schistosity. In places the lineation and foliation are folded.

In areas where deformation was less intense, e.g. to the north and west of Stars Well, the basic rocks are represented by metadolerite and metagabbro which are massive and almost completely lack any penetrative foliation of lineation.

It is possible that some of the concordant amphibolite bodies were extrusive like the pillow lavas recently discovered in the 'Etheridge Formation' near Gilberton homestead. However, no pillow structures, vesicles, or other

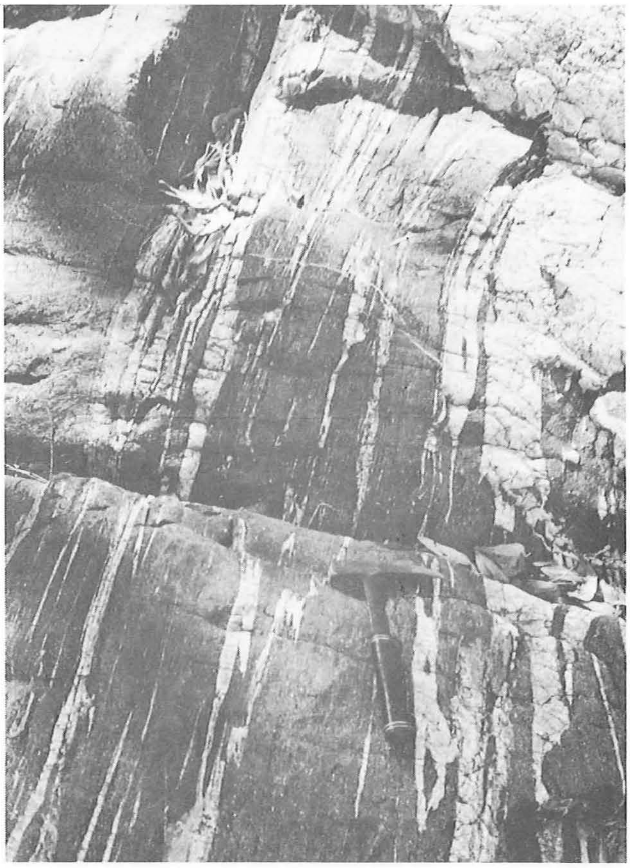


Fig. 26: Amphibolite possessing a well developed foliation parallel to the axial planes of almost isoclinally folded quartz veins; Cobbold Metadolerite in Little Robertson River about 7.5 km northwest of 'Old Robin Hood'. GA9528 (I.W.W.)

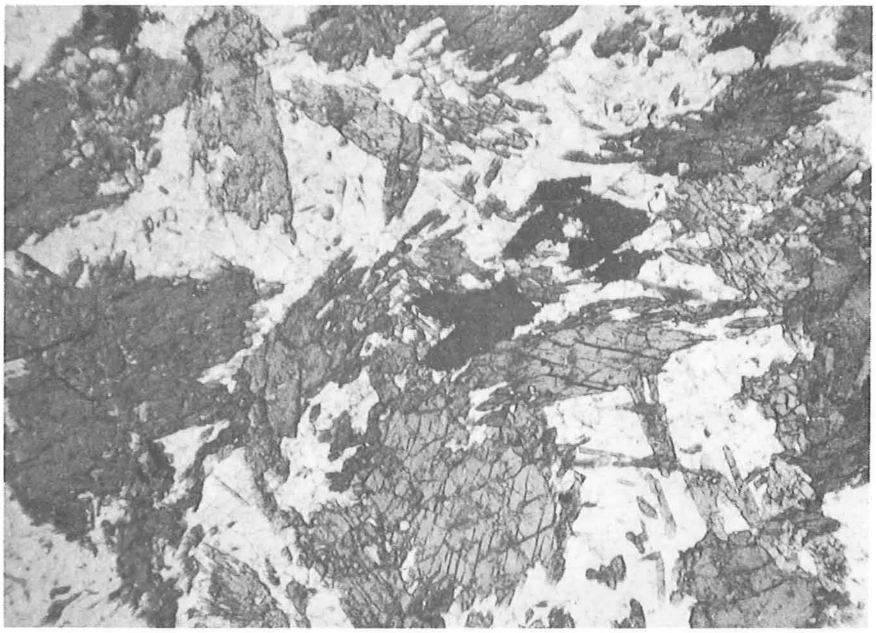


Fig. 27: Photomicrograph of massive metadolerite showing large ragged hornblende grains (grey) in a granular mosaic of plagioclase; the very dark grains are sphene; Cobbold Metadolerite. GSQ Slide No. 6851. Magnification X25 (plane polarized light). M1619/36 (I.W.W.).

volcanic features have been observed in the basic rocks of the Forsayth Sheet area and in spite of the fact that these could have been destroyed during the deformation, it is likely that most if not all of the amphibolite is intrusive. This conclusion is supported by the presence of blastophitic textures, and the grainsize.

Quartz lenses are commonly associated with amphibolite bodies. Most of these bodies probably formed during the main deformation and metamorphism; fracturing of the relatively brittle basic rocks under tension may have created openings that were then filled by silica 'sweated out' of the country rocks. Some may be related to the pegmatite dykes.

Petrography

(a) Metadolerite

The term 'metadolerite' is used for those basic rocks which in hand specimen still retain a massive igneous appearance and in some cases relict igneous textures. The mineral assemblages in these rocks, however, are the product of metamorphism; relict minerals rarely occur.

The metadolerites are fine- to medium-grained dark green to black rocks consisting dominantly of plagioclase and hornblende. Estimated modal compositions are given in Table 5. Plagioclase forms xenoblastic equant to subequant grains, generally less than 1 mm across; composition ranges from calcic andesine to labradorite. Quartz, when present, has similar habit to plagioclase; some is present as inclusions in the hornblende. Ragged subidioblastic prisms of green hornblende range in length from 0.1 to 3.0 mm (Fig. 27); clusters of grains up to 5 mm across and tabular blastophitic hornblende crystals of a similar size occur sporadically. The colour of the hornblende depends to some extent on the grade of metamorphism, the hornblende of lower amphibolite grade rocks being slightly bluish in the Z direction whereas in higher-grade rocks it usually has a brownish tint. However, since hornblende with a strong bluish tint has been observed in rocks of middle amphibolite grade, the colour is not considered a reliable indicator of grade.

Sphene is present as xenoblastic grains generally in aggregates up to 2 mm across and sometimes rimming magnetite. Apatite is a common accessory and traces of epidote, probably due to slight retrogression, occur. Cummingtonite is present in places as colourless strongly prismatic crystals, and intergrown with hornblende in sharply zoned grains.

Table 5: Visually estimated modal compositions of metadolerites and amphibolites of the Cobbold Metadolerite

MINERALOGY

	Q	Pl	Hbl	Cumm	Anth	Ga	Sp	Op	Cz/ep	Accessories
1	tr	50(An_{75})	45				5		5	
2	tr	45(An_{70})	45				1		tr	
3	-	30(An_{55})	65				5	tr	tr	ap
4	tr	50(An_{45})	50				tr			
5	tr	30(An_{65})	65				5	1		ap
6	-	20(An_{40})	75				5	tr	tr	
7	-	30(and)	25	25		10		5		
8	-	35(lab)	60				5			ap
9	-	40(An_{55})	60					1		
10	5	30(An_{60})	60				tr	5		ap
11	-	tr	75		10	10		1		chl (5%)
12	5	20(An_{55})	70				5			ap
13	5-10	10-15 (An_{35})	75	(actinolitic)				5		chl, ap
14	15	10-15 (An_{60})	70				2	1	tr	
15	15	5(An_{65})	70-75			5		5		chl
16	-	10(An_{65})	85	5				1		bi, ap
17	15	15(An_{50})	70					1	tr	
18	5-10	40(An_{55})	50					5		
19	-	40(An_{65})	60				tr	1		
20	-	40(An_{70})		40	20	tr		1		opx
21	5	20-25 (?)	70					5		zr, ap
22	10	10 (?)	80			tr				
23	-	20 (?)	80					tr	tr	chl
24	-	25 (?)	75				tr	tr		
25	5	30(An_{35})	60	5				5		ap
26	15	15(and/lab)	65					5		
27	-	40 (lab)	60					1		chl

Table 5 (continued)

Q	quartz	Ga	garnet
Pl	plagioclase (composition in brackets)	Sp	sphene
and	andesine	Op	opaques
lab	labradorite	Cz/ep	clinozoisite/epidote
Hbl	hornblende	ap	apatite
Cumm	cummingtonite	bi	biotite
Anth	anthophyllite	chl	chlorite
		opx	orthopyroxene

1. Hornblende-plagioclase amphibolite (6844/R5288*; F1/5654/6**). GR820496***
2. Metagabbro (6845/R5289; F1/5654/7). GR820496
3. Metadolerite (6846/R5290; F4/4864/5A). GR655359
4. Hornblende-plagioclase amphibolite (6847/R5291; F5/4810/4). GR7430334
5. Metadolerite (6848/R5292; F5/4810/8).
6. " (6849/R5293; F5/4812/11). GR698311
7. " (6850/R5294; F5/4814/2B).
8. " (6851/R5295; F5/4814/3).
9. Plagioclase-hornblende amphibolite (6852/R5296; F6/4768/5).
10. " " " (6853/R5297; F7/4754/4). GR801218
11. Garnet-anthophyllite-hornblende amphibolite (6855/R5299; F7/4756/16). GR722240.
12. Plagioclase-hornblende amphibolite (6856/R5300; F8/4510/2). GR799198.
13. Quartz-plagioclase-actinolite amphibolite (6857/R5301; F9/4562/6). GR655166.
14. Plagioclase-quartz-hornblende amphibolite (6858/R5302; F9/R4562/18). GR668137.
15. Garnet-plagioclase-quartz-hornblende amphibolite (6859/R5303; F9/4564/22B). GR715144.
16. Metadolerite (Clastophitic) (6860/R5304; F9/4566/3). GR723156.
17. Quartz-plagioclase-hornblende amphibolite (6861/R5303; F9/4566/4). GR723158.
18. " " " " (6862/R5306; F9/4568/1). GR814174.
19. Metagabbro (6863/R5307; F10/4608/2A). GR719118.
20. Metagabbro (6864/R5308; F10/4608/2C). GR719118.
21. Plagioclase-hornblende amphibolite (6856/R5309; F10/4610/13). GR665114.
22. Garnet-quartz-plagioclase-hornblende amphibolite (6866/R5310; F11/4618/3). GR656076.
23. Plagioclase-hornblende amphibolite (6867/R5311; F11/4620/12A).
24. " " " (6868/R5312; F11/4622/8). GR783079.
25. Metadolerite (6869/R5313; F12/4664/12). GR675030.
26. " (6870/R5314; F12/4664/13A). GR678036.
27. Plagioclase-hornblende amphibolite (6871/R5315; F12/4664/16B). GR681050.

* GSQ slide and rock number
** Field number (photo run/photo number/observation point)
*** Grid reference

An unusual mineral assemblage at GR669302, in part of a large irregular metadolerite body, consists of fine-grained hornblende and plagioclase, with randomly orientated prismatic idioblastic cummingtonite crystals up to 2 mm long, and idioblastic garnet porphyroblasts 2 mm across (Table 5, No. 7) The rock is greyish green and appears to be an inclusion within apparently normal metadolerite.

A small circular metagabbro body at GR719118 exhibits well preserved igneous textures, and in places contains primary orthopyroxene (Table 5, No. 20). Its margins consist of foliated amphibolite (Table 4, No. 19). The plagioclase in the metagabbro occurs as randomly orientated laths up to 3 mm long rather than as the small equant or subequant xenoblastic grains generally present in the metadolerites. Hornblende grains, in clusters up to 7 mm across, may represent large subophitic clinopyroxene crystals which broke down to fine-grained uralite and were then recrystallized as hornblende. In the orthopyroxene-bearing rock, anthophyllite rims and replaces orthopyroxene and is itself rimmed and intergrown with pale green cummingtonite. The orthopyroxene is ferro-hypersthene (indicated by a 2V of about -60°) and occurs as pleochroic, colourless to pink grains. There are traces of garnet and patches of medium- to coarse-grained plagioclase crystals with relict cumulate texture.

(b) Amphibolite

The amphibolites are basic rocks with a metamorphic fabric, generally a lineation; mineralogically they are identical to the metadolerite.

In the amphibolites, subidioblastic prisms of hornblende are up to 2 mm long, and range in colour from bluish green to slightly brownish green. They are generally strongly nematoblastic. Some rocks contain larger hornblende prisms lying parallel to the foliation but cutting across the lineation; these were probably produced by post-tectonic mimetic growth. Interstitial plagioclase ranges in composition from calcic andesine to bytownite. Most of the amphibolites contain only a little quartz but some contain up to 15 percent. Sphene, magnetite, and traces of apatite are commonly present, and small porphyroblasts of garnet up to 5 mm across are present locally.

At GR722240, within a body consisting mostly of amphibolite, a rock consisting largely of weakly nematoblastic hornblende (Table 5, No. 11) also contains poikiloblastic porphyroblasts of garnet, about 5 mm across, and prismatic and randomly orientated crystals of anthophyllite up to 4 mm in length. The anthophyllite is light brownish grey and slightly altered to chlorite. Only traces of plagioclase occur. The mineral assemblage suggests that the rock was originally ultramafic.

An amphibolite at GR681050 (Table 5, No. 27) contains large blastophitic hornblende crystals 1.5 cm across in a nematoblastic groundmass of hornblende and plagioclase. The hornblende in the groundmass forms needles up to 3 mm in length. The fabric of the groundmass appears to be folded around the larger crystals, which are probably pseudomorphing ophitic clinopyroxene.

Age

The Cobbold Metadolerite has been metamorphosed with the Robertson River Metamorphics. This event has been dated by Dr L.P. Black at about 1500 m.y. so providing a minimum age for both the Cobbold Metadolerite and the Robertson River Metamorphics. The Cobbold Metadolerite may be equivalent to unmetamorphosed, folded dolerite which intrudes the Dargalong Metamorphics in the Yambo Inlier to the north and which has been dated at 1884 ± 40 m.y. (Cooper, et al., 1975).

Metamorphism of the Robertson River Metamorphics and Cobbold Metadolerite

The Robertson River Metamorphics and the Cobbold Metadolerite which intrudes them (Fig. 28) show a gradual eastward increase in metamorphic grade from the greenschist to the upper amphibolite facies.

The significant minerals indicating the metamorphic conditions are discussed below.

Andalusite/Kyanite. Andalusite is rarely preserved in the Robertson River Metamorphics in the Forsayth Sheet area; generally it has retrogressed and been pseudomorphed by sericite. However, its former presence indicates that the pressure during the regional metamorphism was relatively low. Kyanite was observed in only one sample associated with staurolite and andalusite, where it may indicate a lowering of temperature while the pressure remained static, kyanite having replaced both the andalusite and staurolite.

Sillimanite. The appearance of sillimanite is used in this area to mark the isograd separating the lower and middle amphibolite facies. In the middle amphibolite facies it coexists with quartz and muscovite. Sampling was mostly too sparse to allow detailed plotting of this isograd, but along Bull Creek, between the Middle Yard track and the Robertson River, its position is known to within a hundred metres. Staurolite-bearing schists (lower amphibolite facies) crop out in the creek just south of the river whereas sillimanite is present in the schists at the track.

Staurolite. Staurolite is a critical mineral for identifying the amphibolite facies, although its formation is restricted by the bulk chemical composition of the rock. Fortunately rocks of the correct composition appear to be abundant in the Robertson River Metamorphics since staurolite is relatively common, especially in the southwest. However, its absence in the lower-grade rocks does not necessarily indicate greenschist facies conditions.

Staurolite is unstable in middle amphibolite facies conditions (Winkler, 1967), but the equilibrium curves in Figure 29 show that sillimanite and staurolite could coexist at moderately high pressures (3 to 6 kb) between 500°C and 650°C. The absence of coexisting staurolite and sillimanite in the Robertson River Metamorphics suggests that the rocks were metamorphosed at lower pressures.

The following reaction for the breakdown of staurolite may apply:

$$\text{Staurolite} + \text{Muscovite} + \text{biotite} + \text{quartz} \rightarrow Al_2\ SiO_5 + \text{biotite (richer in } Fe^{2+}) + H_2O$$

Staurolite is also replaced by coarse muscovite-biotite aggregates.

Chloritoid. Chloritoid can form only in rocks containing a high Fe/Mg ratio, a relatively high Al-content and low K, Na and Ca; as a result biotite and chloritoid cannot coexist. These conditions appear to be fulfilled in some of the lower-grade metapelites previously mapped as Etheridge Formation. Chloritoid forms mainly in the greenschist facies of both high- and low-pressure facies series. Winkler (1967, p. 179) notes that as a rule its disappearance takes place simultaneously with the appearance of staurolite. However, the experimental curve for the breakdown of chloritoid to staurolite is almost independent of pressure (Hoschek, 1967a), whereas the curve for the formation of staurolite by other reactions has a positive slope (Hoschek, 1967b). Hence at lower pressure the curves intersect, and chloritoid and staurolite can coexist in the lowermost part of the amphibolite facies. Therefore the presence of chloritoid is not a completely reialble indicator of the greenschist facies.

Muscovite. Muscovite is present in all the schists ranging in grade from greenschist facies (where it occurs as sericite) to the middle amphibolite facies. In the middle amphibolite facies muscovite coexists with sillimanite and quartz, but in the upper amphibolite facies it breaks down according to the following reaction:

$$\text{muscovite} + \text{quartz} \rightleftharpoons \text{K-feldspar} + \text{sillimanite} + H_2O$$

In the higher-grade parts of the Robertson River Metamorphics, peak conditions may have been in the upper amphibolite facies, i.e. above the stability field of muscovite. In the rocks examined from these areas muscovite occurs as large crosscutting post-tectonic porphyroblasts with some inclusions of sillimanite, but not as flakes parallel to the main tectonic foliation. After initial syntectonic metamorphism in the upper amphibolite facies the temperature may have decreased back into the stability field of muscovite, which then replaced sillimanite.

Biotite. Biotite was stable throughout the whole range of metamorphic conditions affecting this area and hence is of no value in determining metamorphic grade.

Chlorite. In the lower-grade rocks chlorite is parallel to the foliation and is probably prograde, indicating greenschist facies metamorphism. Where it occurs in the higher-grade rocks of the Robertson River Metamorphics it is retrograde, replacing biotite, garnet, and staurolite or else forming crosscutting post-tectonic flakes.

Hornblende. Hornblende is an important constituent of the amphibolite and metadolerite of the Cobbold Metadolerite. In both high- and low-pressure facies series, hornblende first appears in the upper greenschist facies and therefore, by itself, does not necessarily indicate amphibolite facies.

The colour of hornblende has been used by Miyashiro (1968) and Binns (1964) to define zones of different metamorphic grade: with an increase in grade from lower amphibolite to granulite facies, the colour of the hornblende changes from blue-green through brownish green to brown, due to increased Ti content. However, although higher-grade rocks in the Cobbold Metadolerite, do tend to have brownish green hornblende, there are some exceptions. Hence factors other than temperature probably affect the colour and Ti-content of the hornblende - for example the overall Ti-content of the rock and partitioning of the Ti between sphene, when present, and hornblende.

Diopside. Diopside first appears in the lowest grades of the amphibolite facies and hence is an important index mineral, although it is present only in some of the calc-silicate rocks.

Cummingtonite/Anthophyllite. Both these amphiboles, sporadically present in the Cobbold Metadolerite, first form in the lower amphibolite facies and are useful in identifying grade. They are stable throughout the amphibolite facies.

Garnet. The formation of garnet is controlled by temperature, pressure and also the chemistry of the rock. In the high-pressure (Barrovian) facies series, almandine first appears in the middle of the greenschist facies whereas in the low-pressure (Abukuma) facies series, almandine does not appear until the middle amphibolite facies. However, spessartine-rich garnet (almandine with MnO $>$ 10%) can occur even in lower greenschist rocks. As the garnet in the metasediments is likely to be Mn-rich, the presence of garnet in the metapelites is of little use in indicating either temperature or pressure conditions until some data are obtained on its Mn-content.

In the metadolerites, however, the garnet is less likely to be spessartine-rich, and its appearance should be a better indicator of grade. It has been observed in the Cobbold Metadolerite adjacent to rocks containing staurolite (i.e. lower amphibolite facies) which suggests that the pressure was intermediate between that in the classic Barrovian and Abukuma facies series.

The garnet in the calc-silicate-bearing rocks is probably grossularite/andradite which, according to Winkler (1967), marks the beginning of the amphibolite facies in both high- and low-pressure facies series.

Epidote. In the Abukuma facies series epidote becomes unstable before the beginning of the amphibolite facies, whereas in the Barrovian series it coexists with andesine in the lower amphibolite facies. The presence of epidote with andesine and labradorite in calc-silicate-bearing rocks may reflect lower amphibolite facies conditions at moderate pressure, although some may be due to retrogression to greenschist facies.

Conclusions

The greenschist-amphibolite facies boundary is defined by the appearance of staurolite, cordierite, diopside, anthophyllite, cummingtonite and, in metadolerite and calc-silicate rocks, garnet. The beginning of the middle amphibol-

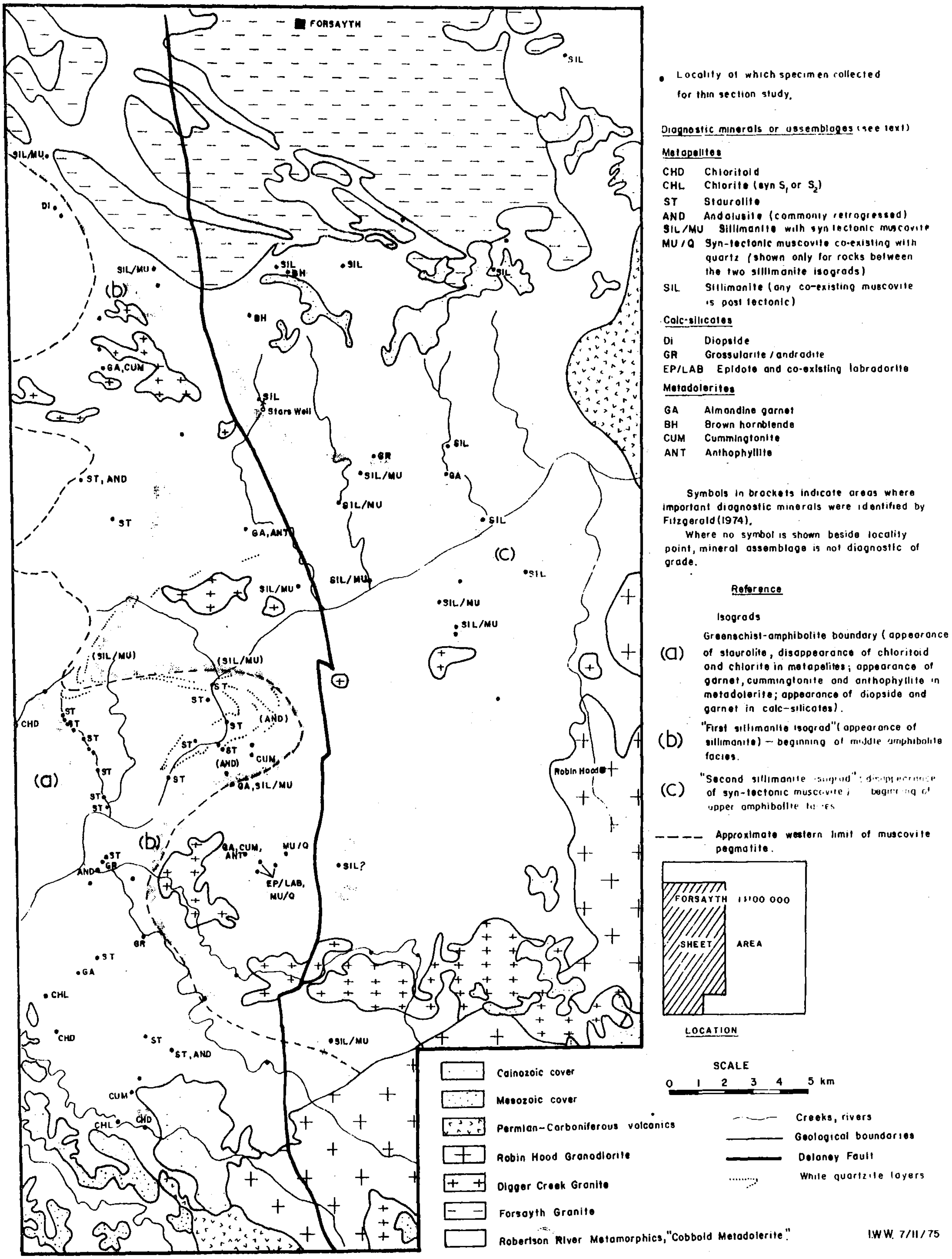


FIG 28: Simplified geological map of the Robertson River area showing distribution of metamorphic minerals diagnostic of grade, and tentative isograds.

ite facies is defined by the appearance of sillimanite (the first sillimanite isograd). The 'second sillimanite isograd', where quartz and muscovite react to give sillimanite and K-feldspar, marks the beginning of the upper amphibolite facies. The pressure appears to have been intermediate between those of the classic Abukuma and Barrovian facies series. A discussion of pressure-temperature conditions based on experimental data is given in the next section.

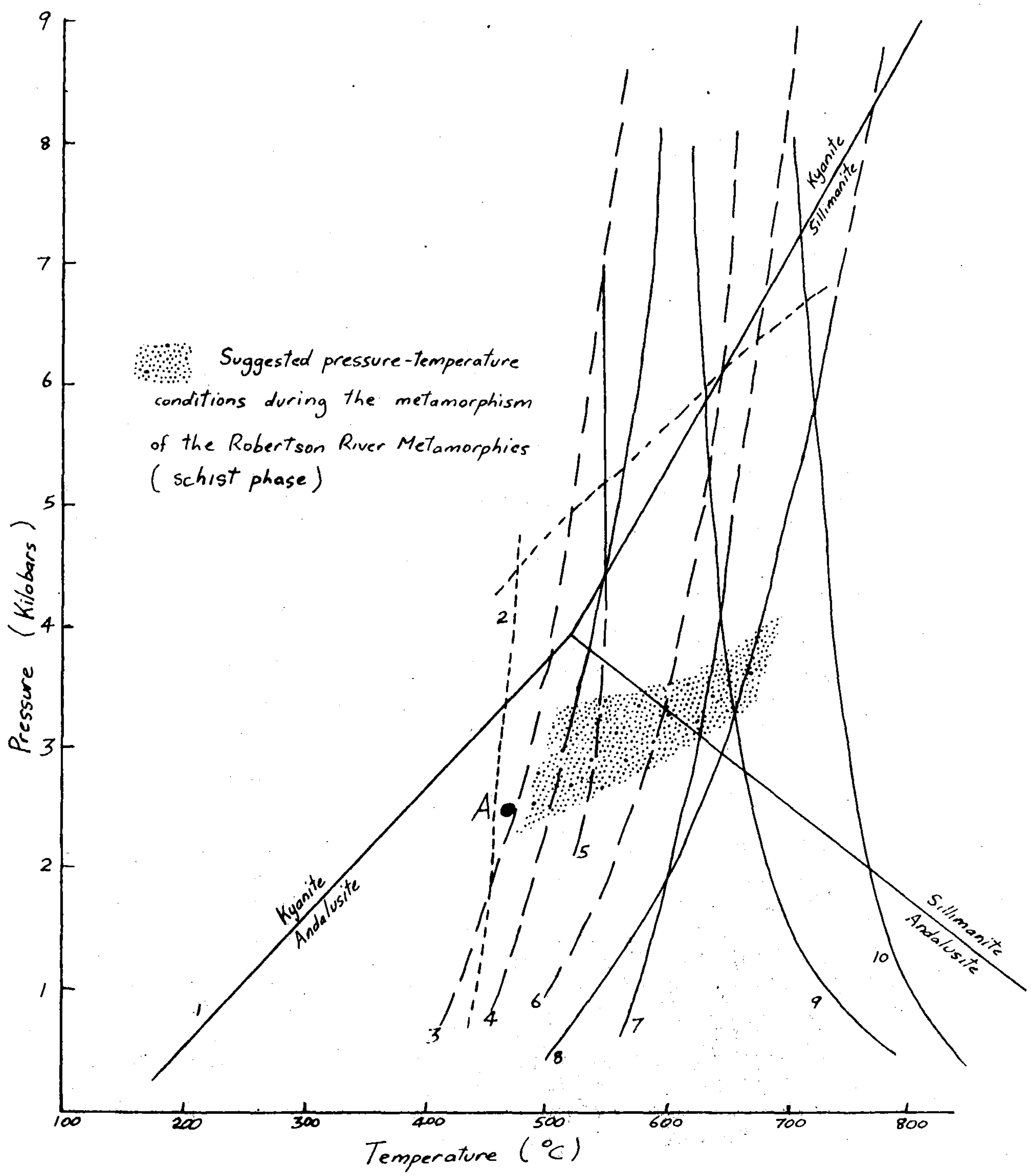
Metamorphic grades determined from our thin section studies and field observations are plotted in Figure 28 together with some data from Fitzgerald (1974). It can be seen that the isograds appear to be folded by the major east-west folds (B^{S3}_{S2}) suggesting the main metamorphism preceded this event. Although such a pattern could have been produced by an irregular metamorphic front, additional supportive evidence for our conclusions on the timing of the metamorphsim is provided by the textures in the metamorphic rocks (see pp.35-36).

Conditions of metamorphism

Equilibrium curves and stability fields for various minerals are plotted in Figure 29. Most of these are based on experimental work. The value taken for the Al_2 SiO_5 triple-point is that determined by Newton (1966) rather than that of Fyfe & Turner (1966). The reason for this choice is that, if the staurolite breakdown curve of Hoschek (1968) is valid, the chosen triple point is more compatible with the observations that andalusite rather than kyanite is the main polymorph, and that the breakdown of staurolite is accompanied by the appearance of sillimanite, at temperatures well below that at which muscovite breaks down.

These curves enable tentative limits to be set for the pressure/temperature conditions of the metamorphic facies in the Robertson River Metamorphics. The stipled area shows the probable pressure/temperature gradient deduced from the various stability fields and known mineral assemblages.

The transition from greenschist to amphibolite facies grade, as indicated by the appearance of staurolite, occurs at 450^{o} to 500^{o}C at 2.5 to 3.0 kb according to Guidotti (1974). On the basis of Hoschek's (1967b) curve for the formation of staurolite from chlorite and muscovite, a temperature of 500^{o}C at about 3 kb is indicated. Turner (1968, p. 366) tentatively places the greenschist/amphibolite transition at this pressure at between 400 and 450^{o} whereas Winkler (1967) places it at about 550^{o}C.



Record 1976/4

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(1) Al_2SiO_5 polymorphs (Newton, 1966)
(2) Deduced stability field of cordierite (Turner, 1968)
(3) Garnet + chlorite -- staurolite + biotite (Guidotti, 1974)
(4) Chlorite + muscovite -- staurolite + biotite + quartz + H_2O (Hoschek, 1967b)
(5) Chloritoid + Al_2SiO_5 — staurolite + quartz + H_2O (Hoschek,1967a)
(6) Breakdown of staurolite: staurolite + chlorite -- sillimanite + biotite (Guidotti, 1974)
(7) Breakdown of staurolite: (Hoschek, 1968)
(8) Breakdown of muscovite: muscovite + quartz sillimanite + K feldspar + H_2O (Evans, 1965)
(9) Minimum melting curve of granite (Bowen & Tuttle, 1958)
(10) Melting curve of sanidine + quartz + H_2O (Shaw, 1963)
. A Triple point for Al_2SiO_5 polymorphs determined by Fyfe & Turner (1966)
B Triple point for Al_2SiO_5 polymorphs determined by Newton (1966)

Fig. 29: Equilibrium curves and stability fields for critical metamorphic minerals minerals

Using the andalusite/sillimanite phase boundary of Newton (1966) and the curves of Guidotti (1974) and Hoschek (1968) for the breakdown of staurolite, a temperature of about 600°C at a pressure between 3 and 3.5 kb is indicated for the transition from lower to middle amphibolite facies grade. The transition to upper amphibolite facies as marked by the breakdown of muscovite occurs at 650°C at 3.5 kb. This is on the minimum melting curve of granite but still well below the melting curve of sanidine + quartz + H_2O, which would probably be more applicable to the pelitic sillimanite-(muscovite)-biotite quartz assemblages of the Robertson River Metamorphics.

Relation between metamorphism and deformation

Most of the metamorphic minerals crystallized during the folding episode which produced the main foliation of the rocks. This foliation, S_2, is defined mainly by the alignment of mica flakes in the metapelites and by hornblende in the amphibolites. Muscovite, biotite, and hornblende also define S_1 in rocks in which it has not been completely over-printed by S_2.

The other minerals which grew syntectonically include garnet and staurolite, which form porphyroblasts containing trails of quartz inclusions indicating rotation by up to 120° (Fig. 30); the foliation tends to be wrapped around such porphyroblasts. Some staurolite porphyroblasts also contain crenulate trails of quartz inclusions to which S_2 is axial planar; these represent an early stage in the transposition of the earlier foliation, S_1, into S_2. Inclusion-free rims around garnet and staurolite indicate that these minerals continued to grow post-tectonically (Fig. 31). Sillimanite was probably syntectonic, and was partly replaced by muscovite under static, post-tectonic conditions.

Some of the muscovite and biotite also grew post-tectonically, randomly cutting across the foliation (Fig. 32). Occasionally the crosscutting muscovite flakes are parallel, suggesting that a minor amount of mineral growth was synchronous with the east-west folding, B^{S3}_{S2}.

In summary it appears that the peak of metamorphism occurred during, or just after, the folding which formed the foliation, S_2, and that it was probably waning during the east-west folding. This is supported by the fact that the isograds appear to be folded by the east-west folds.

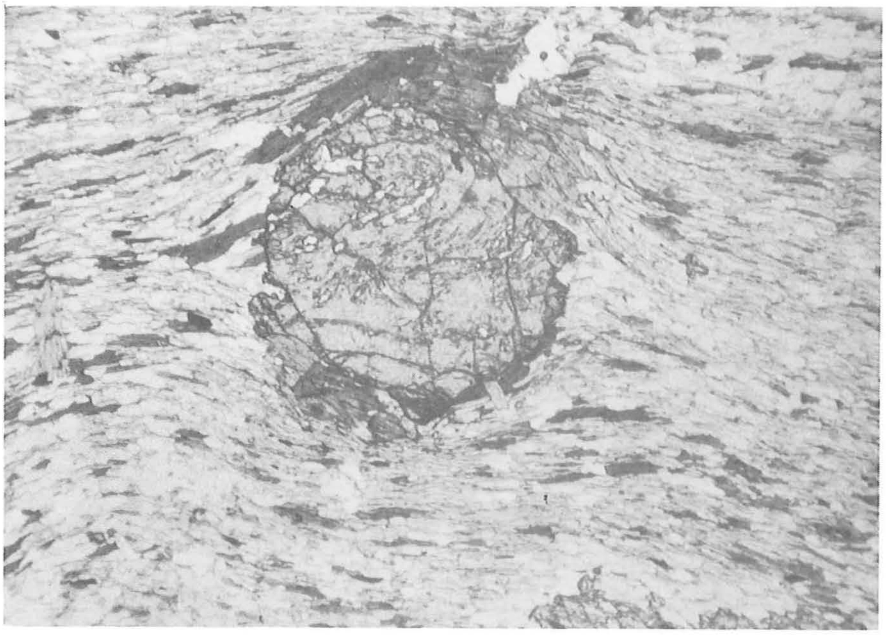


Fig. 30: Photomicrograph showing a rolled, syntectonic garnet; note foliation wrapped around the garnet and trails of quartz inclusions. Robertson River Metamorphics (schist phase). GSQ Slide No. 6894. Magnification X25 (plane polarized light). M1619/20 (I.W.W.).

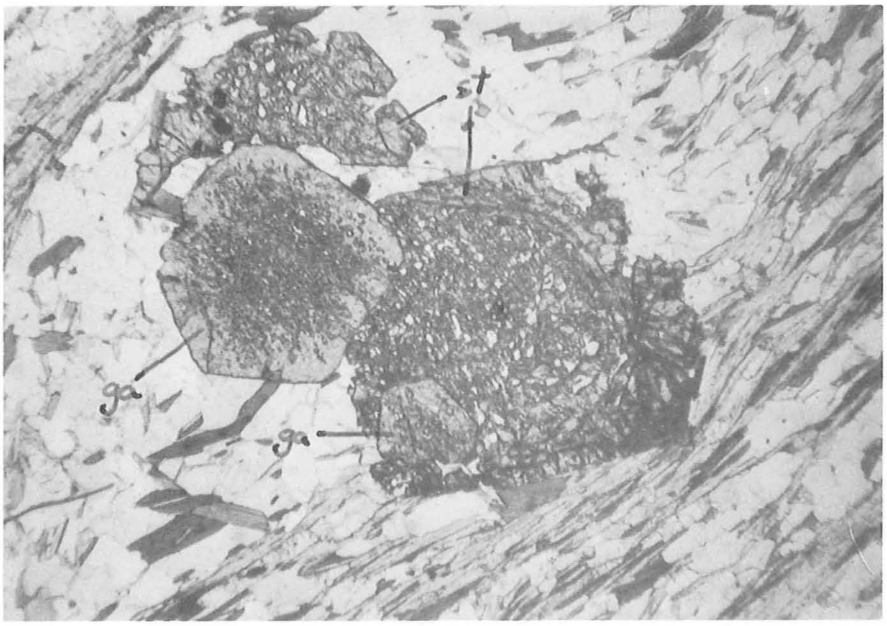


Fig. 31: Photomicrograph showing garnet (ga) and staurolite (st), both of which have syntectonic cores containing abundant quartz inclusions, and relatively inclusion-free post-tectonic rims. Robertson River Metamorphics (schist phase). GSQ Slide No. 6911. Magnification X25 (plane polarized light). M1619/9 (I.W.W.)

Fig. 32: Mica schist containing randomly orientated, post-tectonic muscovite and biotite flakes cutting across the main foliation; Robertson River Metamorphics (schist phase). GSQ Slide No. 6907. Magnification X25 (plane polarized light). M1619/12 (I.W.W.).

Folding of the metamorphic rocks

Einasleigh Metamorphics

No well defined marker horizons have been found in the Einasleigh Metamorphics, and no large-scale folds have been mapped. As a result the overall structure is interpreted from small-scale (mesoscopic) features.

The most obvious fabric in the Einasleigh Metamorphics is the compositional banding of the gneiss. Although this may partly reflect an original layering, any such layering has been extensively modified by transposition and metamorphic differentiation. The main evidence for the banding being largely tectonic in origin, and not a primary feature, is the existence of small tightly appressed (a fold whose limbs are almost closed together) isoclinal folds within the gneiss bands (Figs 33, 34). These intrafolial folds are commonly defined by thin quartzite or amphibolite bands. The orientation of the biotite flakes is axial planar to the intrafolial folds and parallel to the banding except in rare cases where a later mineral foliation has developed.

The banding in the calc-granofels may represent primary bedding. At GR 069019 structures bearing a strong resemblance to small-scale syndepositional faults occur (Fig. 35). However, this is the only locality where any possible primary sedimentary structures were observed.

In the Forsayth Sheet area the compositional banding and the associated foliation are the earliest fabrics recognized in the Einasleigh Metamorphics. Although there is some evidence of an earlier deformation in outcrops at Einasleigh to the east (T. Bell, pers. comm.), the banding and foliation in the Einasleigh Metamorphics have been designated as S_1 rather than S_2 in this report, the corresponding deformation being F_1. At least two later sets of folds have deformed S_1. Tight, almost isoclinal folds, designated as B_{S1}^{S2}, have been refolded by more open B_{S1}^{S3} (or B_{S2}^{S3}) folds (Fig. 36). An axial plane foliation is locally developed within the hinges of the B_{S1}^{S2} folds (Fig. 37). In some cases this appears to be a mineral foliation, defined by biotite in biotite gneiss and hornblende in the calc-granofels. Elsewhere the foliation is a crenulation cleavage. In the schists the main foliation may be S_1, but in places S_1 appears to be transposed parallel to S_2. There is no axial plane foliation associated with the B_{S1}^{S3} folds. Both the B_{S1}^{S2} and B_{S1}^{S3} sets of folds are associated with crenulations, particularly in the more micaceous bands.

Structural analysis

Data collected during mapping in the Stockman Creek and Welfern areas has been plotted on the lower hemisphere of the Schmidt equal-area net; the plots are shown in Figures 38 and 39. There are insufficient data to draw definite conclusions since observed variations may not be statistically significant and the areas taken may not represent homogeneous domains. However some tentative conclusions can be made.

Stockman Creek area. Because the B^{S2}_{S1} folds are relatively tight, having almost parallel limbs, the orientation of the banding and foliation over many domains is probably controlled by the later more open folds B^{S3}_{S1}. In Figure 38 it can be seen that 34 foliation readings taken in the northern part of the Stockman Creek area have a southerly dip. Vergences of mesoscopic folds (mainly B^{S3}_{S1}) in this area consistently indicate that the rocks are situated on the northern limb of a major synclinorium whose axis lies to the south. The foliation readings taken in subarea B show greater variation and suggest that the axis of the synclinorium may be in this area. This is supported by the prevalence of M-vergences such as those in Figure 40.

In subarea A in the Stockman Creek area the fold axes are crenulations show a maximum plunging about 45^{o} slightly south of east. The contours in Figure 38d show elongations along north-south and roughly east-west girdles, suggesting that two sets of folds are present. This is confirmed by interference patterns in the crenulations exposed in outcrops at the Stockman Creek road crossing. The east-west girdle is the more pronounced. In subarea B, most fold axes plot on a girdle striking approximately southeast (Fig. 38g). These folds were all identified in the field, prior to plotting, as belonging to the B^{S3}_{S1} set. The other axes and crenulations plotting well away from this girdle may be related to B^{S2}_{S1} folds The dispersion of the B^{S3}_{S1} axes along the girdles may be due partly to the folds being superimposed on an already folded surface, and partly to reorientation by a later set of folds which are not identifiable at the meoscopic level; Such folds may be broad open warps with axial planes trending north to northeast, similar to one of the latest phases recognized in the Robertson River Metamorphics, but more data would be needed to prove definitely whether or not these folds exist.

Summarizing the conclusions in the Stockman Creek area, there were definitely at least three phases of folding. As noted above, however, an earlier phase may be represented at Einasleigh and there is a suggestion of a later phase as well. Thus the Einasleigh Metamorphics in the Stockman Creek area may be deformed by as many as five phases of folding.

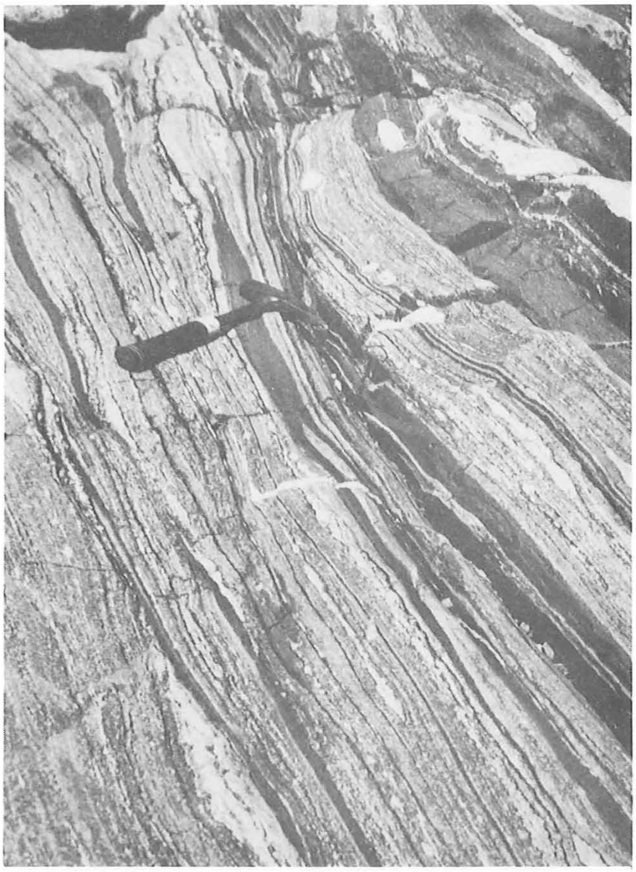


Fig. 33: Banded gneiss containing a thin, appressed, isoclinally folded amphibolite band (dark). Einasleigh Metamorphics in Louis Creek at GR127018. GB154 (I.W.W.).

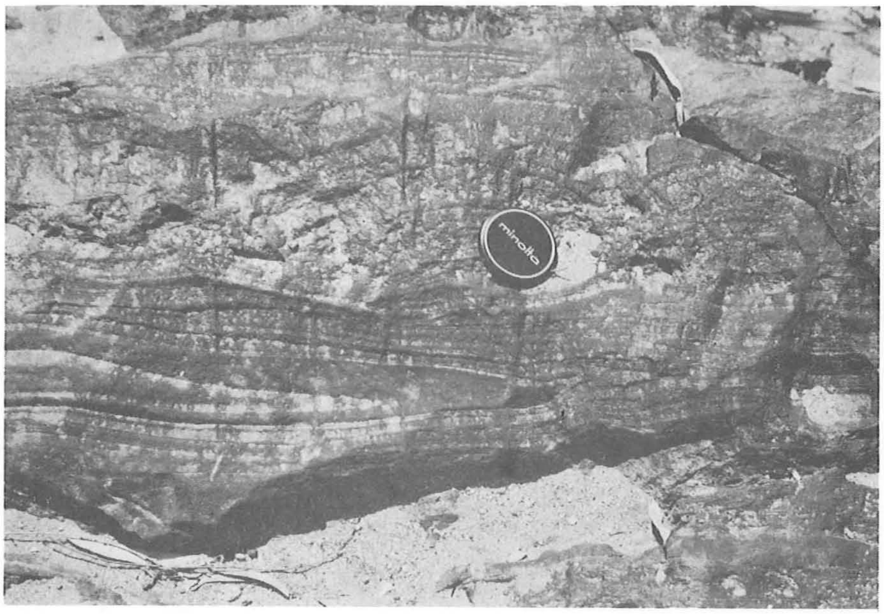


Fig. 34: Banded gneiss showing intrafolial folds defined by thin quartzite layers; Einasleigh Metamorphics about 4.2 km south of Stockman Creek crossing. GA 9457 (I.W.W.).

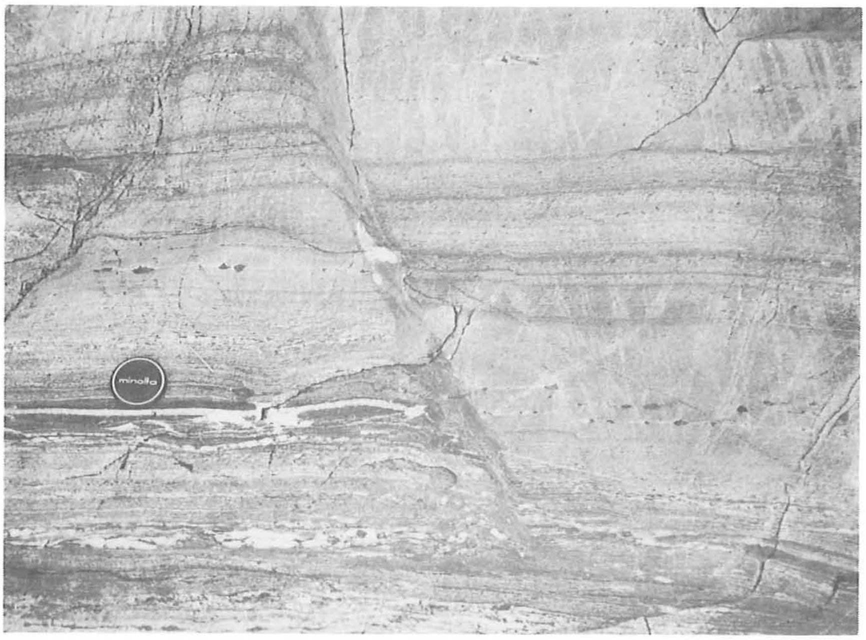


Fig. 35: A small possibly syndepositional fault in calc-granofels; Einasleigh Metamorphics about 2.2 km northwest of Fernhill outstation at GR068018 GB 140 (I.W.W.).

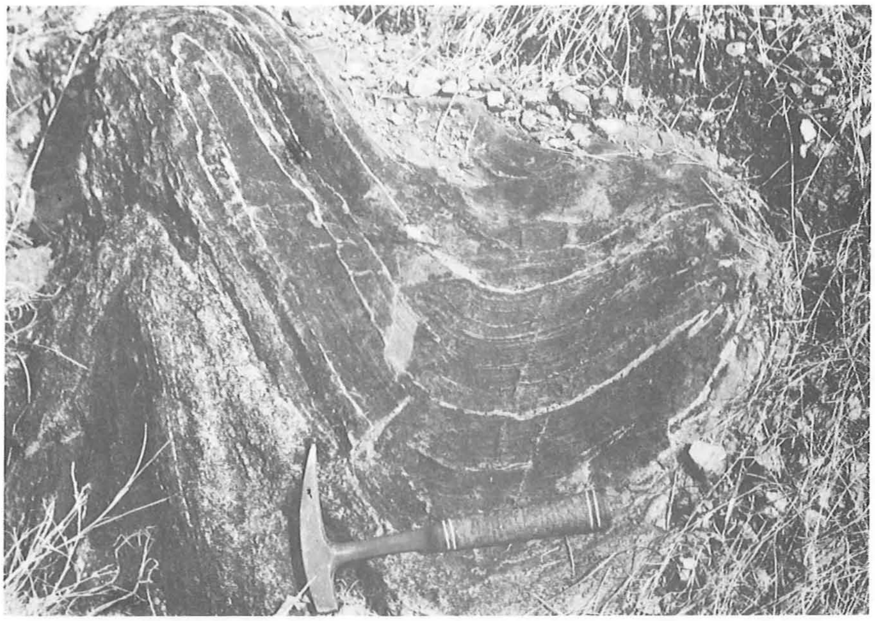


Fig. 36: Refolded folds in gneiss; banding and foliation (S_1) is folded about tight B_{S1}^{S2} folds and refolded about more open B_{S2}^{S3} (or B_{S1}^{S3}) folds. Einasleigh Metamorphics about 5.5 km south of Stockman Creek crossing on the Einasleigh-Forsayth road. GA9564 (I.W.W.).

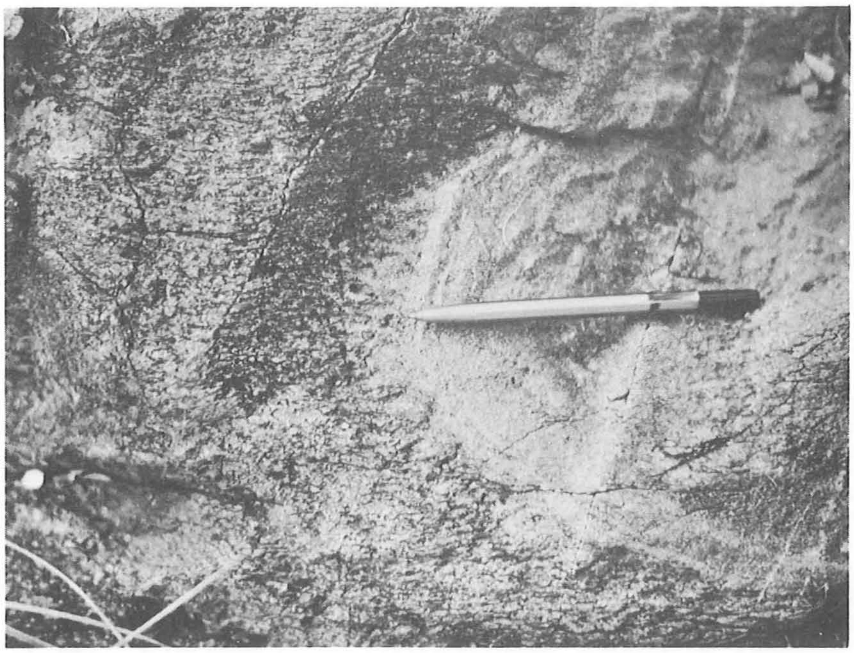


Fig. 37: Nose of B_{S1}^{S2} fold in gneiss showing an axial planar foliation, S_2; Einasleigh Metamorphics about 5.5 km south of Stockman Creek crossing on the Einasleigh-Forsayth road. GA9541 (I.W.W.).

Welfern area. Data from the Welfern area are plotted in Figure 39. The plots of poles to S_1 in Figures 39a and b show two maxima, suggesting folding about an axis plunging to the southeast. The dispersion of the points may be due to the fact that at least two later phases of folding deformed the foliation.

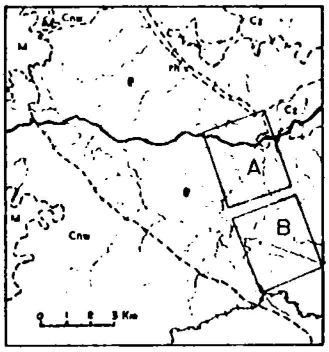
Fold axes and corresponding axial planes are plotted in Figures 39c and d. In the field, individual folds were assigned as far as possible to one of two phases on the of style. These two sets of folds are plotted separately; those which could not be assigned reliably to a set are also shown on each diagram. The B^{S2}_{S1} fold axes are concentrated mainly in the southeast quadrant, which is where the fold axis about which S_1 is folded (Fig. 39b) would plot. This indicates that the orientation of S_1 is largely controlled by B^{S2}_{S1} folds, perhaps because only one limb of a major B^{S3}_{S1} fold is present here, the other lying to the south in the Gilberton Sheet area. The dispersion of B^{S3}_{S1} folds along an east-west girdle (Fig. 39d) is probably due to their being superimposed on a folded surface. Not too much significance should be placed on the scattering of the poles to axial planes of the B^{S3}_{S1} folds, since only seven readings are plotted, but this could reflect a broad warping similar to that postulated for the Stockman Creek area.

Robertson River Metamorphics and Cobbold Metadolerite

The main fabric of the Robertson River Metamorphics in the Forsayth Sheet area is a foliation, mostly a schistosity, which is generally parallel to 'bedding' (S_o) defined by quartzite bands. Only in the western part of the area does the foliation consistently cut across the 'bedding', especially in the 'phyllite-phase' (Ᵽmr_p), as in Cave Creek, but also apparent in the 'schist-phase' in the northwest. This shows that the eastward increase in metamorphic grade was accompanied by a general increase in intensity of deformation, although local reversals of this trend are apparent.

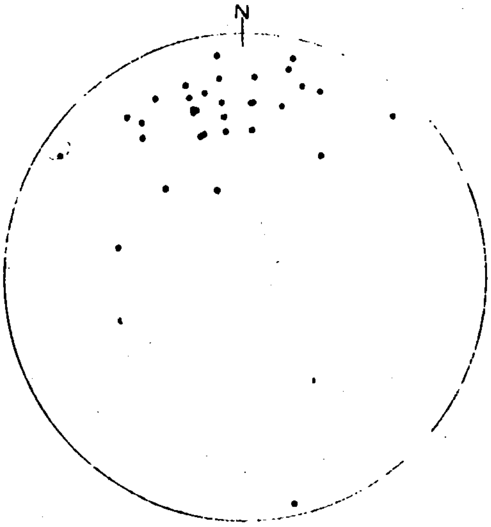
Generally the metamorphics have been isoclinally folded and transposed, as indicated by the parallelism of the foliation and bedding, and the presence of small rootless isoclinal folds in the schist. The folds are generally outlined by thin quartzite bands. Boudinage and mullions are common, particularly in the quartzite-rich belt (Ᵽmr_1) (Figs. 41, 42). Where a fabric is present in the Cobbold Metadolerite it is generally a lineation of hornblende crystals, although a foliation is associated with the lineation in places.

Fig. 38 Structural data - Einasleigh Metamorphics in the Stockman Creek area.

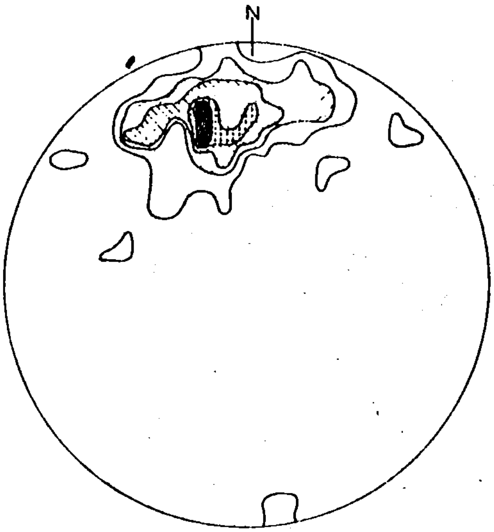


(a) Geological sketch map showing location of two sub-areas (A and B)

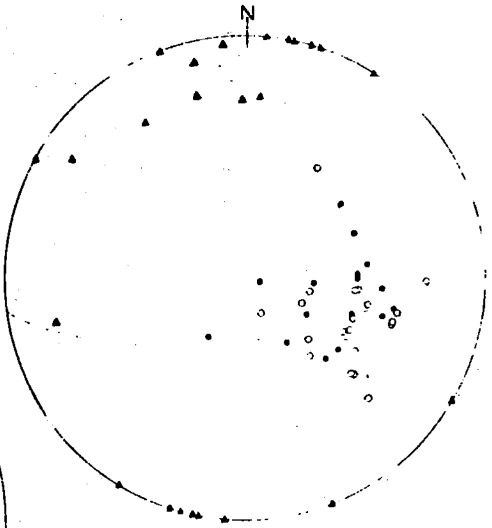
Cz	Cainozoic sediments
M	Mesozoic sediments
Cmw	Newcastle Range Volcanics
rh	rhyodocite dyke
Ꝑ	Einasleigh Metamorphics
------	geological boundary
━━━	road
+++++	railway



(b) Poles to 34 foliation planes (S_1) measured in sub-area A and north of road

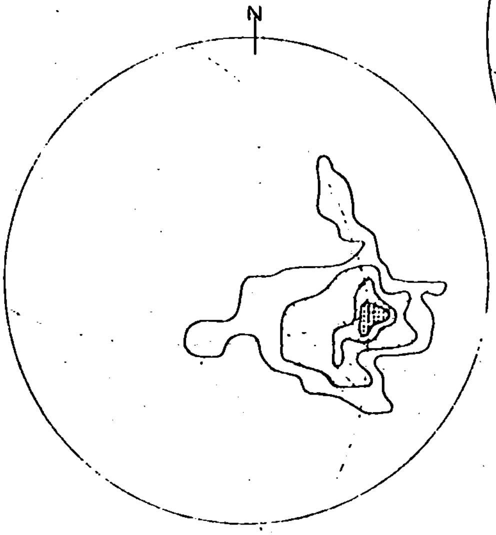


(c) Contoured plot of poles in (b). Contours at 3,6,9,12 a 15%.



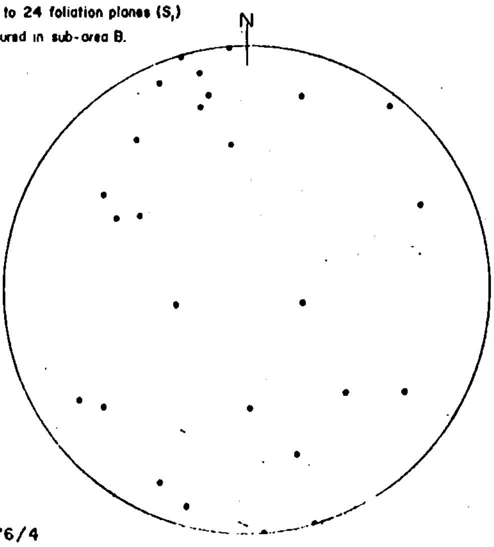
(d) Crenulations, fold axes and axial planes to folds in sub-area A

crenulation	○
axis to fold	●
axial plane to fold	▲

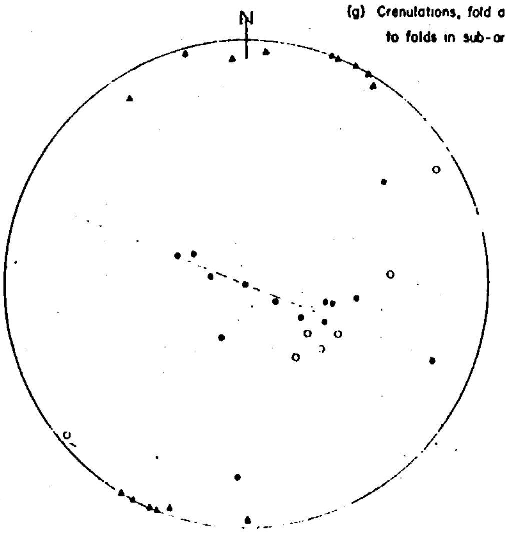


(e) Contoured plot of 37 crenulations and fold axes in (d). Contours at 3,9,17·5 a 20%

(f) Poles to 24 foliation planes (S_1) measured in sub-area B.



(g) Crenulations, fold axes and axial planes to folds in sub-area B (symbols as in (d



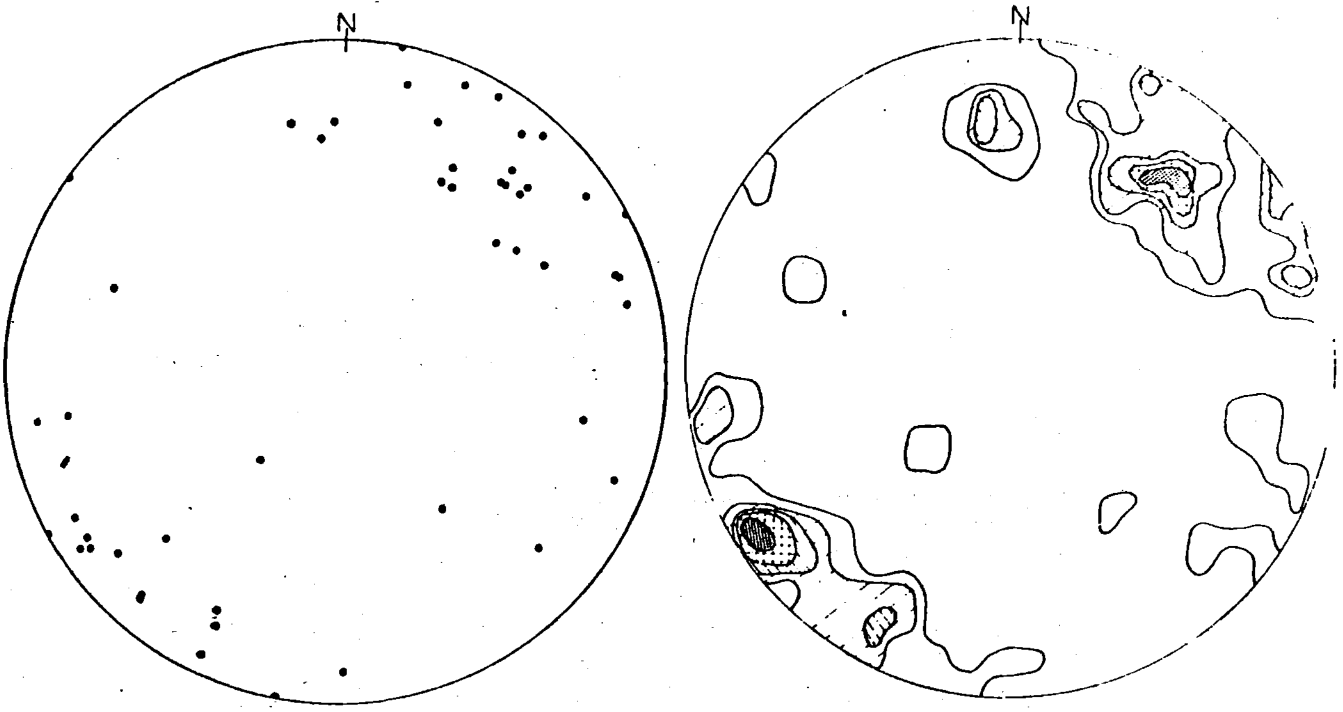
Isoclinal folds on a megascopic level may be present in the quartzite member (Pmr$_2$) as this is made up of several parallel quartzite bands which could be due to repetition by isoclinal folds. No definite closures have been recognized but this could be explained by poor exposure in critical areas, by facies changes, or by faulting. Parallel belts of metadolerite may also represent limbs of isoclinal folds.

The main foliation in the Robertson River Metamorphics has been designated S_2 rather than S_1 because, although in most places it is the only foliation present , there is strong evidence for an earlier one which has been largely overprinted and obliterated by the later isoclinal folding This earlier foliation (S_1) can be seen locally where S_2 is locally reduced in strength. According to Fitzgerald (1974) S_1 is almost always parallel to S_o. In the white quartzites it is defined by elongated quartz grains, and in the phyllite by small mica flakes parallel to S_o and at an angle to S_2. Some staurolite grains which are syn-S_2 contain inclusion trails which preserve crenulations of S_1; the schistosity of the host rock is the axial plane to such crenulations.

The isoclinally folded metamorphics were later tightly refolded into large recumbent folds with northerly dipping axial planes and wavelengths between 5 and 12 km. These folds B_{S2}^{S3} are delineated on the map by the outcrop pattern of the white quartzite member (Pmr$_2$), the quartzite-rich member (Pmr$_1$), and belts of Cobbold Metadolerite. Both S_2 and 'bedding' were folded by this deformation. Most of the crenulations, that are commonly developed on S_2 (Fig. 43); are probably parallel to the axes of the B_{S2}^{S3} folds, although some may be related to younger folds and some could be parts of conjugate sets of crenulations, produced during any of the later folding phases. An axial plane foliation, S_3, is developed where intense crenulation has produced a crenulation cleavage.

Later folding appears to have been a broad open style. These folds are outlined on aerial photographs by strike ridges and by small folds plunging approximately 30° to the north on the limbs of the recumbent folds in the white quartzite. Little evidence can be seen at the mesoscopic level for these later folds apart from the presence of more than one set of crenulations in some schist outcrops. However, geometric analysis of mesoscopic structures provides good evidence for the later folding, and indicates that there were two later episodes rather than one (see below).

Fig. 39 Structural data - Einasleigh Metamorphics in the Welfern area.

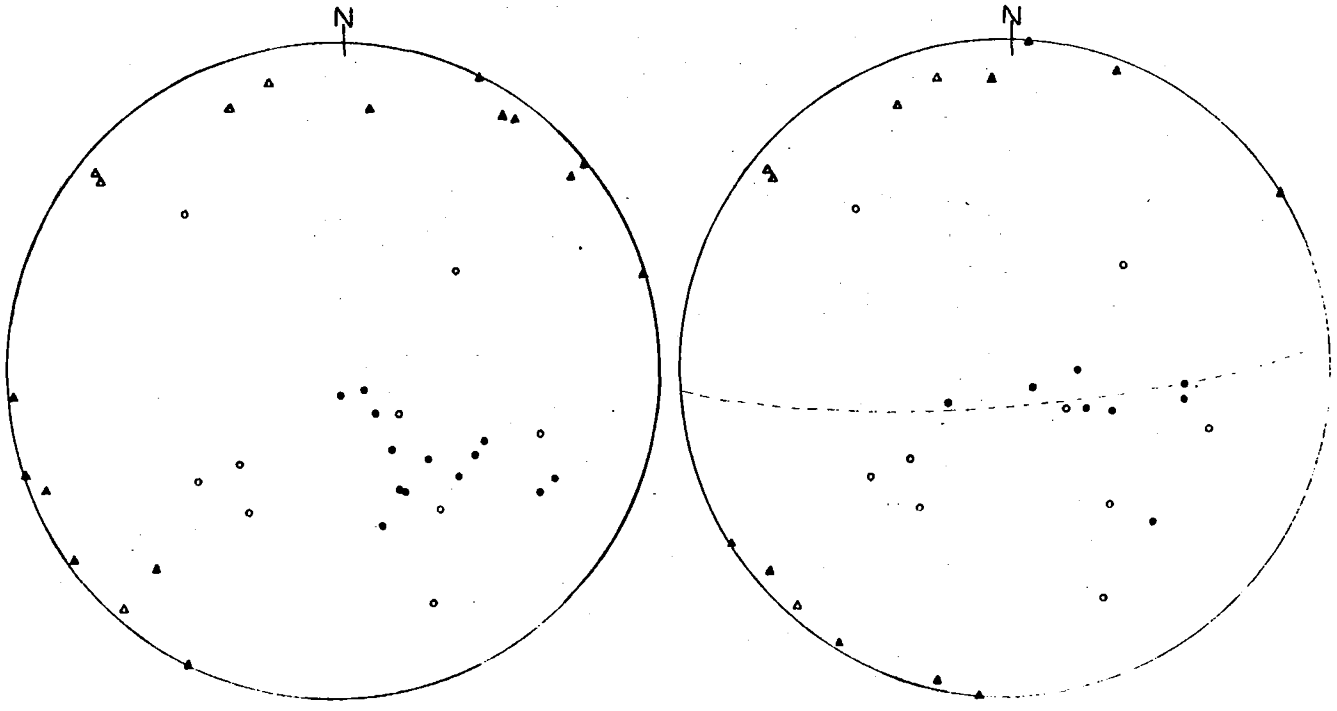


(a)

Poles to 47 foliation planes (S_1) measured in Louis and W-tree Creeks.

(b)

Contoured plot of poles in (a). Contours at 2,4,6,8 & 10%



(c)

Fold axes and axial planes to folds measured in Louis and W-tree Creeks.

axis to fold identified in field as $B^{S_1}_{S_2}$ ●

axial plane to fold identified in field as $B^{S_1}_{S_2}$ ▲

axis to fold, generation unknown ○

axial plane to fold, generation unknown △

(d)

Fold axes and axial planes to folds measured in Louis and W-tree Creeks

axis to fold identified in field as $B^{S_1}_{S_3}$ ●

axial plane to fold identified in field as $B^{S_1}_{S_3}$ ▲

axis to fold, generation unknown ○

axial plane to fold, generation unknown △

Fig. 40: Folds having M-vergence in calc-granofels with crosscutting and folded aplitic veins; Einasleigh Metamorphics near track about 1 km east-southeast of Mount Misery prospect. GA9567. (I.W.W.).

Fig. 41: Boudinaged quartz vein in mica schist; Robertson River Metamorphics (schist phase) in Bull Creek near the track to Middle Yard. GA 9519 (I.W.W.)

Fig. 42: Quartz mullions; Robertson River Metamorphics (schist phase) in the Little Robertson River about 7 km northwest of Old Robin Hood. GA9490 (I.W.W.).

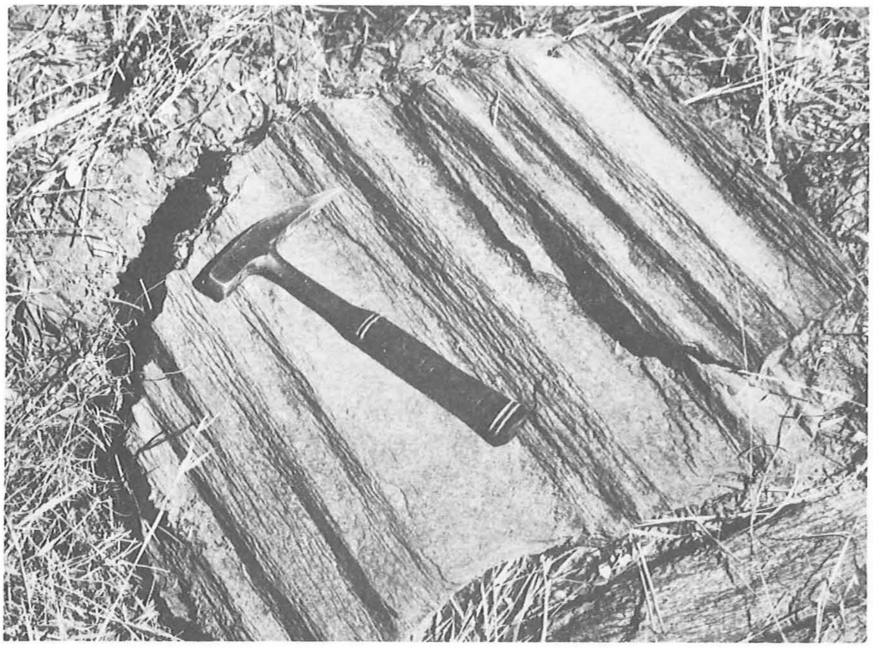


Fig. 43: Crenulate mica schist showing fine crenulations parallel to the axes of small folds; Robertson River Metamorphics Forsayth-Robin Hood road about 1 km northwest of Robertson River. GA 9516 (I.W.W.).

Structural analysis

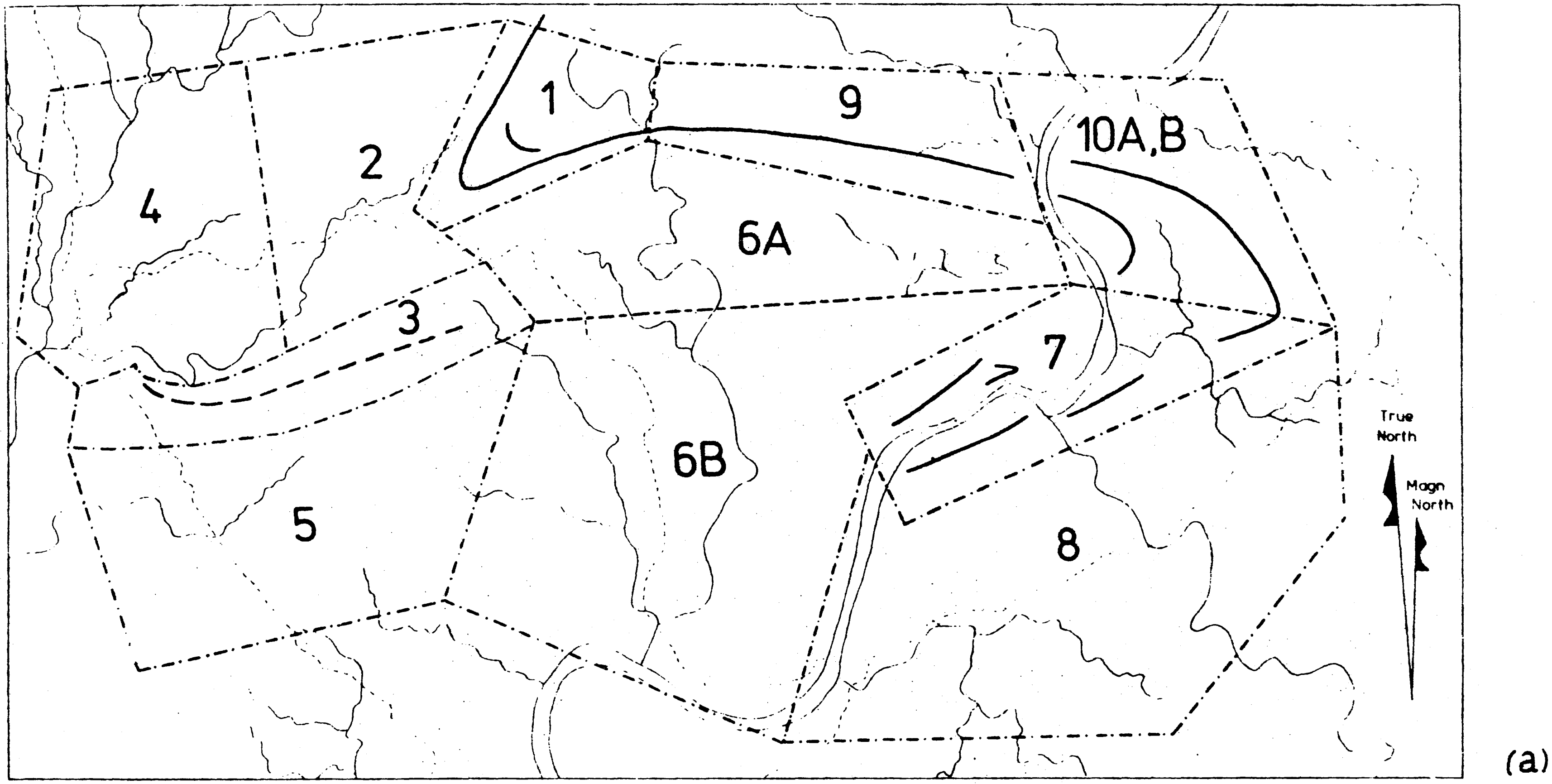
Figure 44 shows plots of structural data collected from the whole of the outcrop area of Robertson River Metamorphics.

The plot of poles to foliation S_2 (Fig. 44a) illustrates the tight recumbent nature of the B^{S3}_{S2} folds. All the maxima plot in the southern half of the diagram, showing that the limbs of the folds dip to the north. In Figure 44b the plot of crenulations shows three distinct maxima lying along a girdle. The largest maximum contains a large proportion of readings taken in the vicinity of the white quartzite ridges (Ꝑmr$_2$) and near the track between Middle Yard and the Agate Creek road; this suggests that the axes of the folds in this area plunge west-northwest to north-northwest at angles between 20° and 40°. Data from this area are replotted in Figure 45b. The major proportion of measurements contributing to the maximum in the northeast quadrant were taken north of the Robertson River and the white quartzite ridges. The readings from this region and to the southwest tend to be more widely dispersed, probably owing to refolding and/or the presence of more than one set of crenulations.

Fitzgerald (1974) undertook a detailed structural analysis of the Robertson River Metamorphics in the area around the white quartzite member (Ꝑmr$_2$), collecting data from 1300 locations in 10 subareas (Fig. 46). Evidence for two late phases of deformation was obtained from the analysis of S_3 geometrics. Contoured plots of S_3 measurements for indivicual subareas were found to form girdles on the stereo net, indicating localized folding; the poles to these girdles were different for each subarea and lie on a girdle of their own (Fig. 47a). This pattern can best be explained by there being two post-S_3 deformations. One was on a small scale, affecting significantly the orientation of S_3 at a subarea level, whereas the other was on a much larger scale, its effects being significant only over several subareas. Fitzgerald stressed that there were insufficient data to determine the sequence in which the two post-S_3 events operated. The small-scale deformation is possibly represented by the small open folds shown by the white quartzite ridges; in places these folds have steep north-south axial planes. The broad folding outlined by trend lines north of the Robertson River may represent the larger-scale reorientation phase, which here would also appear to have axial planes trending roughly north-south.

Comparison of the structure in the Robertson River Metamorphics and Einasleigh Metamorphics

Deformational events in the Einasleigh Metamorphics and Robertson River Metamorphics are summarized in Table 6. Not enough detailed work has been done to enable any definite



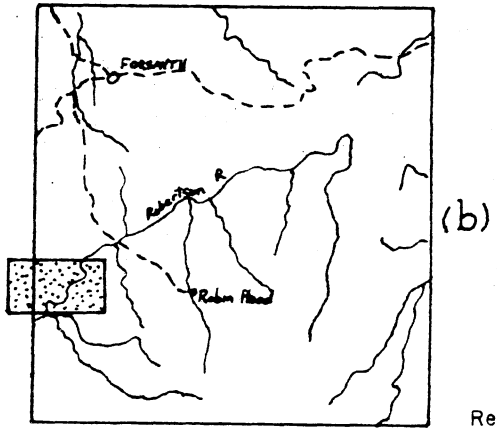
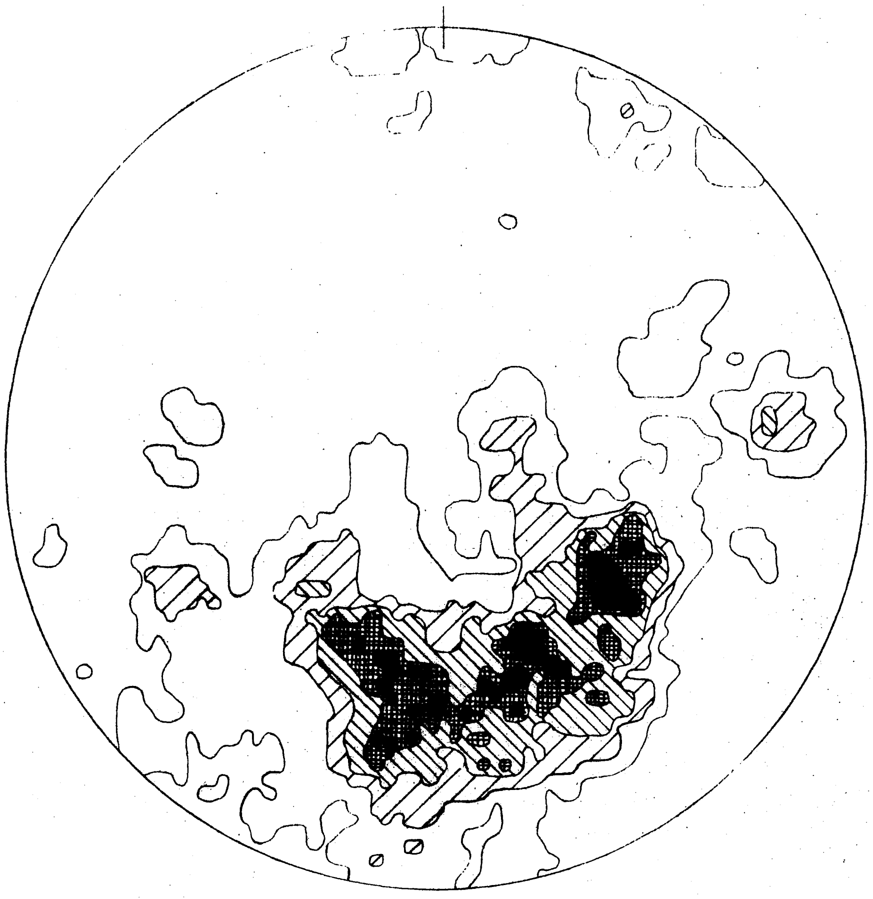
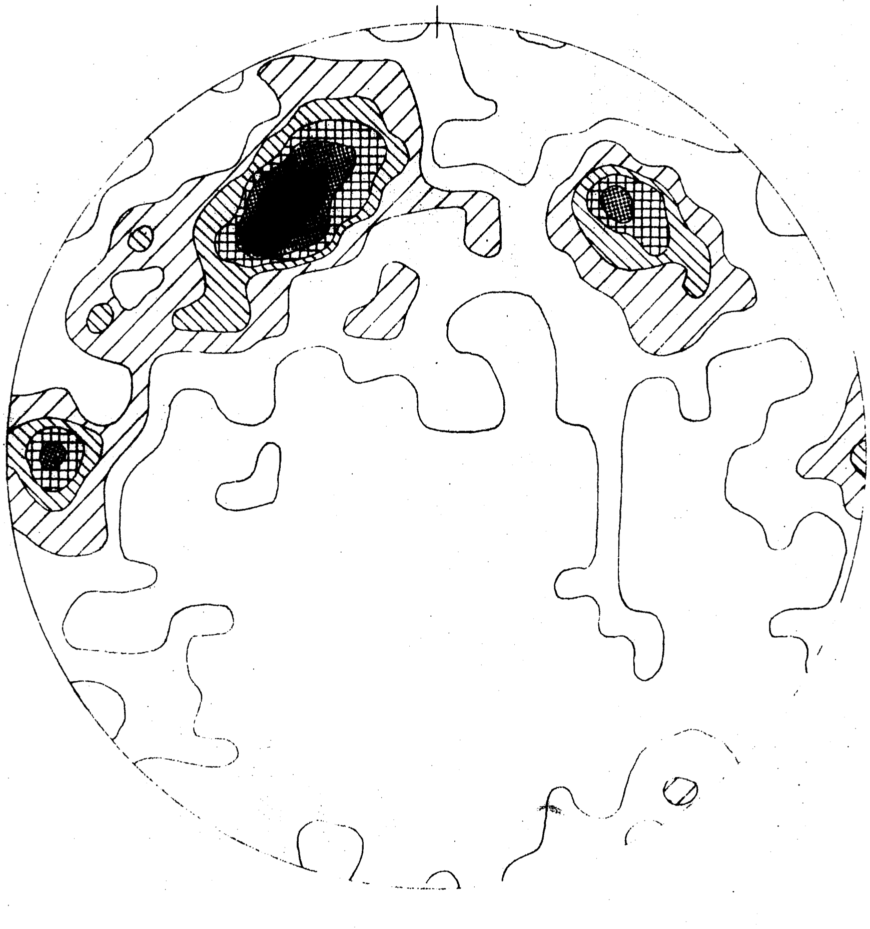


Fig. 44 Area mapped by Fitzgerald (1974)
(a) Distribution of subareas. Heavy solid lines represent ridge lines
(b) Location of area in relation to Forsayth 1:100 000 Sheet area

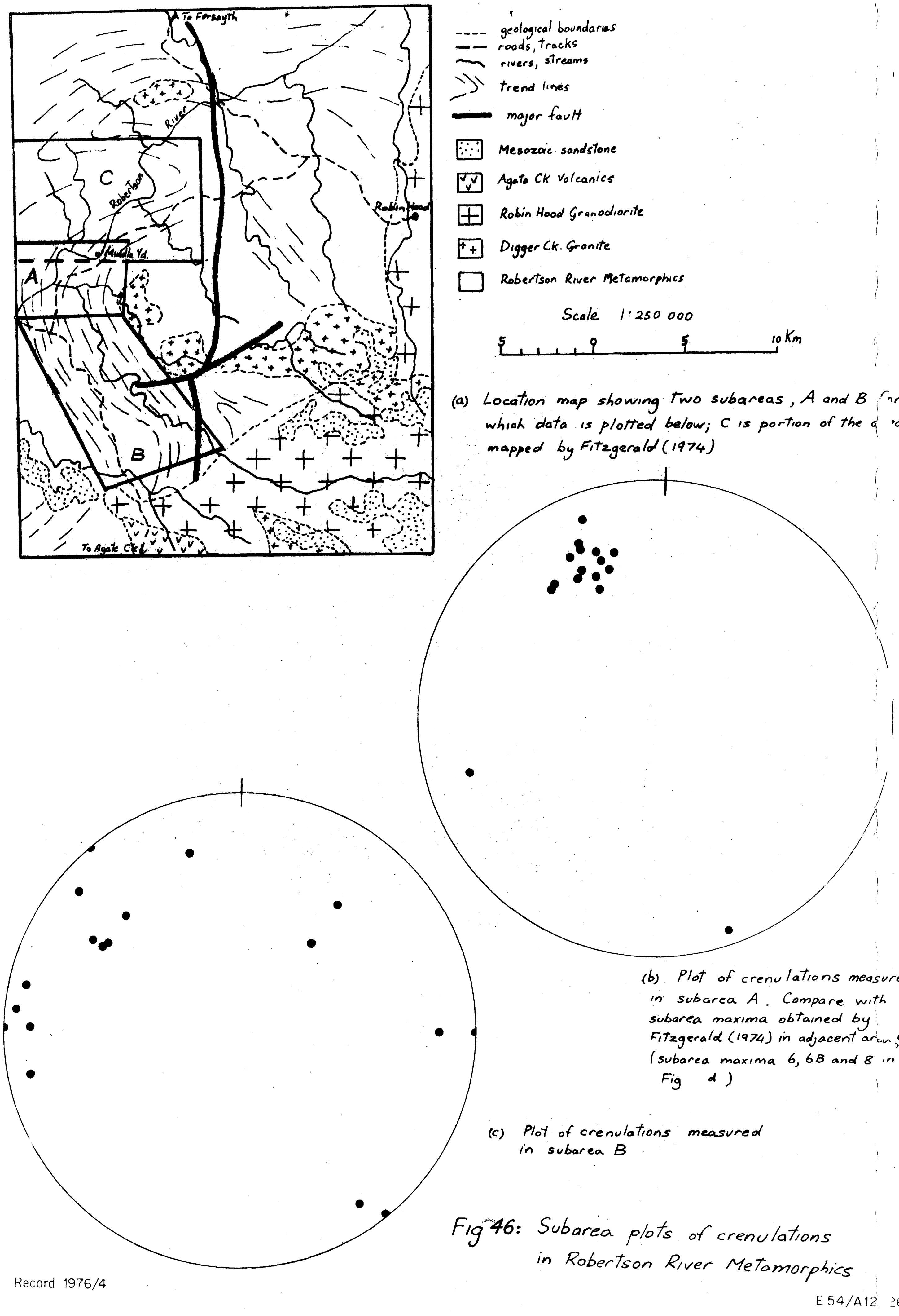
Fig. 45 Structural data — Robertson River Metamorphics.



(a) Contoured plot of poles to 282 foliation planes. Contours at 1,2,3,4 and 5%



(b) Contoured plot of 140 crenulations. Contours at 0·7,2,3·5,5,7 and 8·5%

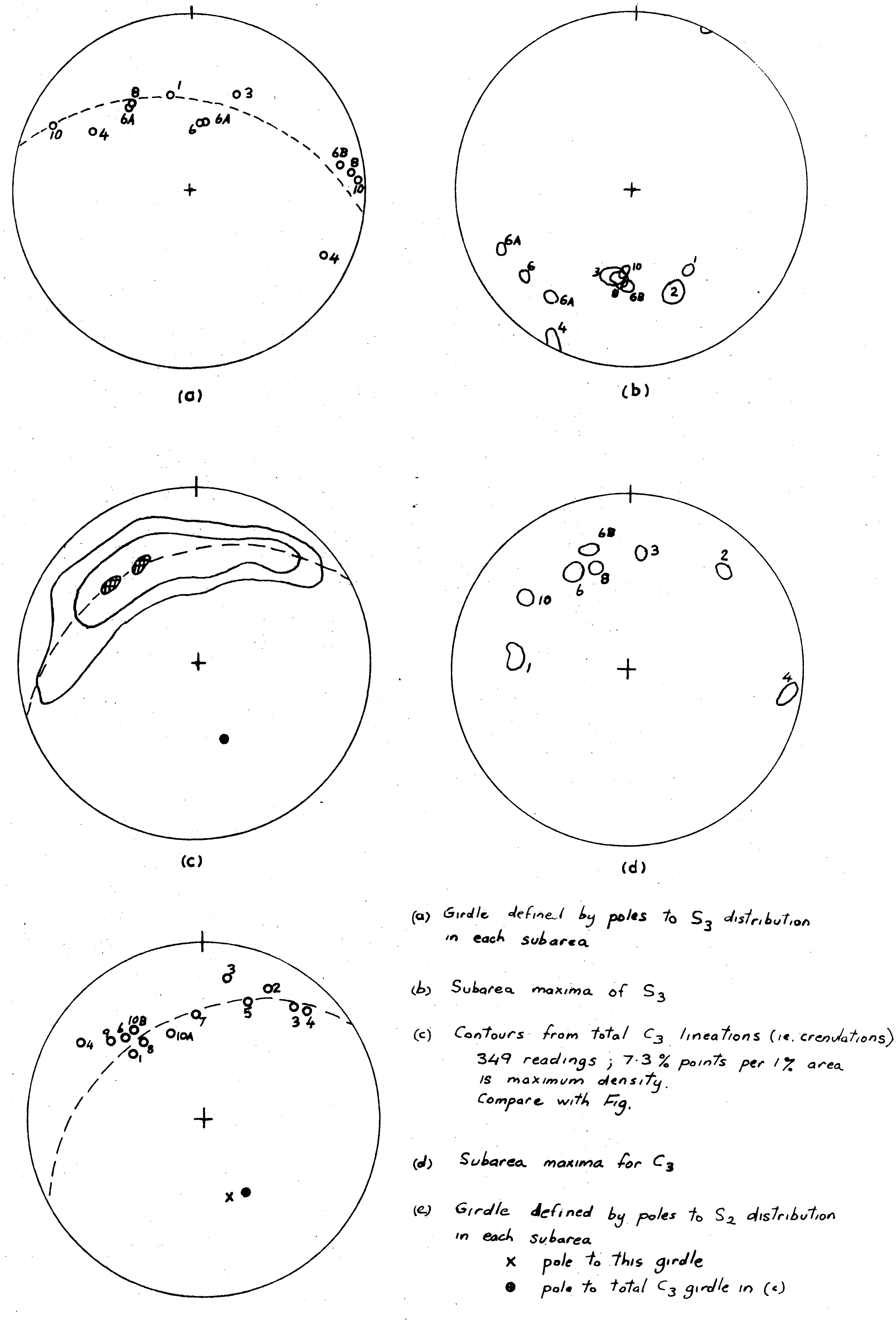


(a) Location map showing two subareas, A and B for which data is plotted below; C is portion of the a a mapped by Fitzgerald (1974)

(b) Plot of crenulations measured in subarea A. Compare with subarea maxima obtained by Fitzgerald (1974) in adjacent area, C (subarea maxima 6, 6B and 8 in Fig d)

(c) Plot of crenulations measured in subarea B

Fig 46: Subarea plots of crenulations in Robertson River Metamorphics



(a) Girdle defined by poles to S_3 distribution in each subarea

(b) Subarea maxima of S_3

(c) Contours from total C_3 lineations (ie. crenulations) 349 readings ; 7·3 % points per 1% area is maximum density. Compare with Fig.

(d) Subarea maxima for C_3

(e) Girdle defined by poles to S_2 distribution in each subarea

x pole to this girdle

● pole to total C_3 girdle in (c)

<u>Note</u> Numbers refer to subareas in Fig .

Fig. 47: Stereographic plots showing some results of a detailed subarea analysis of part of the Robertson River Metamorphics by Fitzgerald (1974). See Fig. for location

Einasleigh Metamorphics		Robertson River Metamorphics
1. Possible earlier event suggested at Einasleigh (T. Bell, pers. comm.)		
2. Isoclinal folding, transposition and metamorphic differentiation resulting in S_1 (gneissic foliation and banding).	——	1. Isoclinal folding producing S_1 (Fitzgerald, 1974)
3. Relatively tight folding about B^{S2}_{S1} axes. Minor development of axial plane foliation, S_2. Refolded by later folds.	——	2. Isoclinal folding and transposition producing main schistosity S_2
4. More open folding about B^{S3}_{S2} axes probably with east-west trending axial planes	——	3. Major tight recumbent folds, reorientated by later folding but with approximately east-west trending axial planes
5. Later event suggested by reorientation of axial planes to B^{S3}_{S1} folds.	——	4a Small scale folding producing reorientation of S_3 (Fitzgerald, 1974).
		4b Large scale broad folding, possibly with roughly N-S trend.
		(Not known whether 4a or 4b is the earlier)

Table 6 : Summary and possible correlation of deformational events in the Einasleigh Metamorphics and Robertson River Metamorphics.

correlations to be made between the events recognized in the respective units, although a possible correlation is presented in the table. Because of this uncertainty, the structure provides no conclusive evidence on the relation between the two metamorphic rock units. There is also the possibility that the units may have reacted in different ways to the same events. For instance Hyndman (1972, p. 297) notes that in metamorphic complexes which consist of a deep-seated gneiss and migmatite 'infrastructure' with an overlying lower-grade 'suprastructure', the most prominent structures of the deep-seated rocks can be at right angles to those in the overlying rocks, although such contrasting structures could have developed at about the same time. By analogy the Robertson River Metamorphics may represent the suprastructure and the Einasleigh Metamorphics the infrastructure.

PROTEROZOIC GRANITIC ROCKS

Forsayth Granite

General

As defined by White (1959b, 1962b & d) the Forsayth Granite formed the northern half of a large Precambrian batholith (Forsayth Batholith) with a surface area of more than 10 000 km^2 in the central part of the Georgetown Inlier. Withnall et al. (in press) have redefined the unit, restricting it to two large bodies (about 875 km^2 in surface area) and numerous small apophyses of grey porphyritic biotite granite in the Georgetown-Forsayth area.

The Forsayth Granite as now defined is confined to the northwest corner of the Forsayth 1:100 000 Sheet area. Forsayth Granite shown by White (1962d) in the southeast corner of the Sheet area is now mapped as Oak River Granodiorite and Digger Creek Granite. The Forsayth Granite intrudes middle Proterozoic Robertson River Metamorphics, and is probably also of middle Proterozoic age; it is intruded by Upper Palaeozoic rhyolitic dykes and is overlain by Mesozoic sedimentary rocks.

Most of the mineral deposits in the sheet area are in this unit or immediately adjacent metasedimentary rocks. The deposits are mostly gold-silver-quartz lodes of the fissure vein type.

A characteristic tor topography is developed on much of the granite (Fig. 49), especially north of Forsayth, but not near the granite margins south and west of Forsayth; consequently the granite boundaries are commonly difficult to locate precisely by airphoto interpretation.

Lithology, relationships, and distribution

The dominant lithology is fine-to coarse-grained biotite (2 to 25 percent) granite containing some secondary muscovite. Varieties comprise virtually every gradation from light to dark and from equigranular to porphyritic; most are foliated, some more strongly than others. They are divided into five types (A, B, C, D, & E, Fig. 59) on the basis of hand-specimen appearance.

Subordinate rock types (F, G & H, Fig. 62) include dark grey biotite microtonalite, buff aplite and pegmatite, and pink biotite granite. Some light grey to pink, medium equigranular muscovite-biotite granite between Tenavute and Mount Talbot homesteads and Spring Creek, probably belongs to another unit - Talbot Creek Granodiorite (Georgetown 1:100 000 Sheet area) - but it has not been distinguished separately on the Forsayth preliminary map.

Type A. The darker varieties of biotite granite are commonly medium- to coarse-grained and contain white euhedral alkali feldspar phenocrysts 2-7 cm long. The size, abundance, and orientation of phenocrysts vary considerably from outcrop to outcrop, and locally even within the one outcrop (Fig. 51). A foliation defined by the alignment of biotite crystals in the groundmass, and less commonly by the alignment of alkali feldspar phenocrysts, is probably due in part to a primary platy flow foliation, as suggested by White (1965); much of the foliation is a postmagmatic feature, however. In some places the feldspar phenocrysts cut across thin leucocratic veins and are probably porphyroblastic.

Type B. Strongly foliated, fine- to medium-grained equigranular biotite granite (Fig. 46) is the other main dark-coloured variety; it is particularly abundant in the southwest, where it forms a zone 1-6 km wide of elongate apophyses (see map). The foliation is steep (Fig. 53) and mostly trends east to east-southeast (Fig. 64); it is defined by the alignment of biotite, elongate metasedimentary xenoliths (Figs 54, 55), and mafic schlieren.

The lighter-coloured, leucocratic variaties of biotite granite are typically fine- to medium-grained, equigranular to slightly porphyritic, and commonly foliated.

Type C. The medium grey, slightly porphyritic varieties (Type C) of the light-coloured group constitute most of the Forsayth Granite outcrop southeast of Forsayth. The rock is commonly foliated, and as with the Type A granite the phenocrysts are of various sizes (up to 2 cm), abundances (mostly sparse), and orientations.

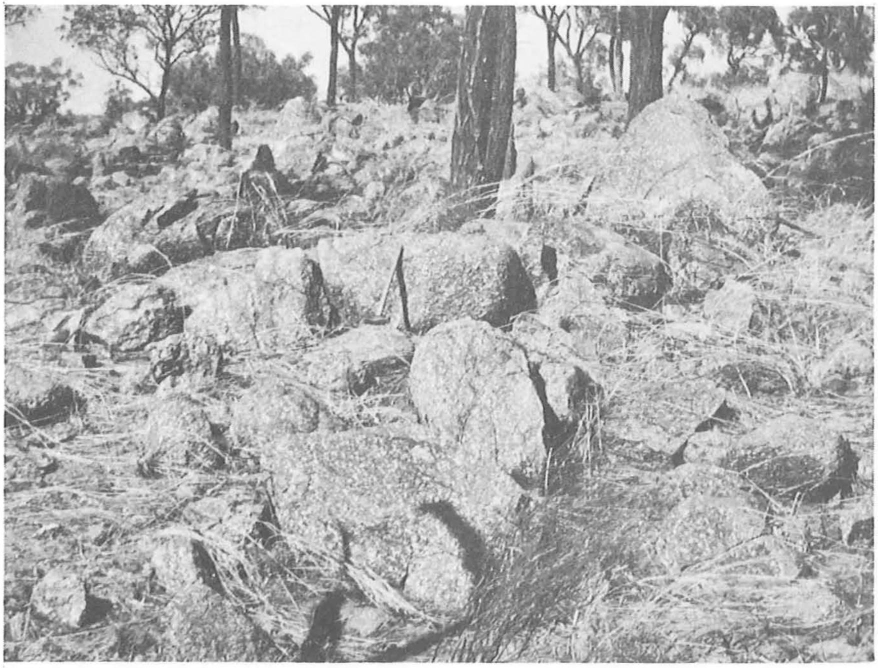


Fig. 48: Coarsely porphyritic dark grey biotite granite (Forsayth Granite, Type A), Jenkins Creek, 6 km north of Forsayth. (J.H.C.B.)

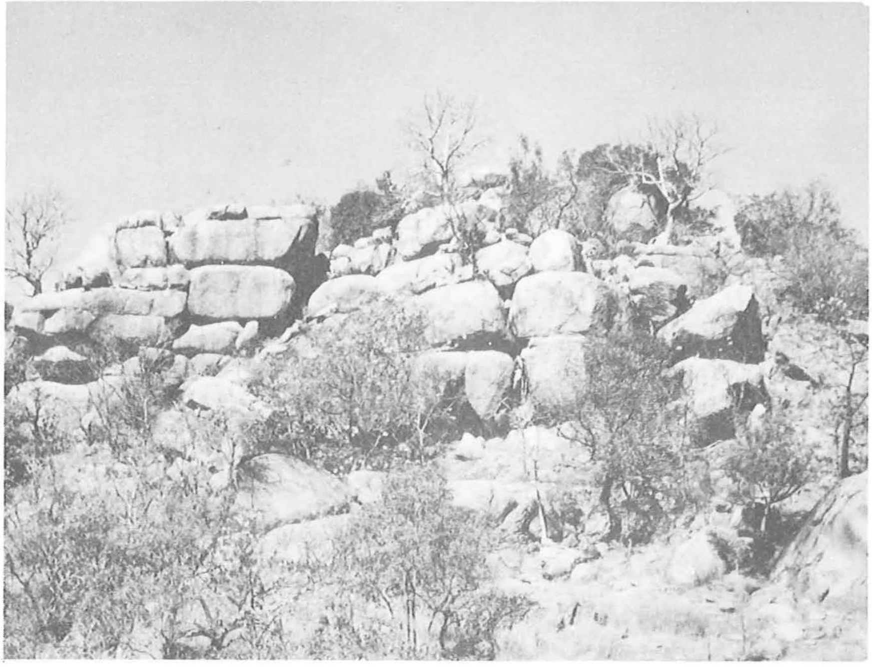


Fig. 49: Typical tor of Forsayth Granite, 6 km north-west of Forsayth. (J.H.C.B.)

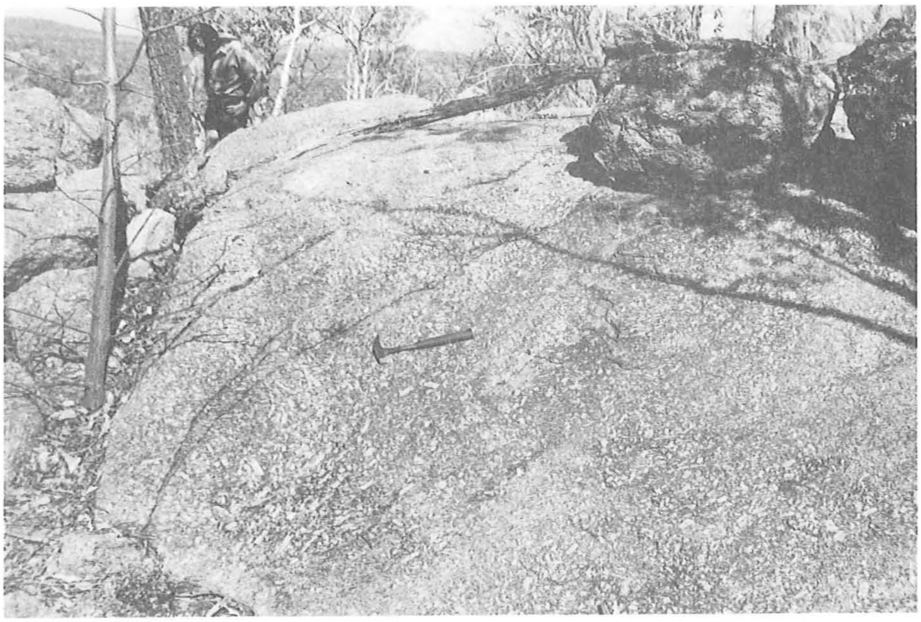


Fig. 50a: Dark grey biotite granite (Type A) containing alkali feldspar phenocrysts; Forsayth Granite 3 km north of Forsayth. M1410 (J.H.C.B.)

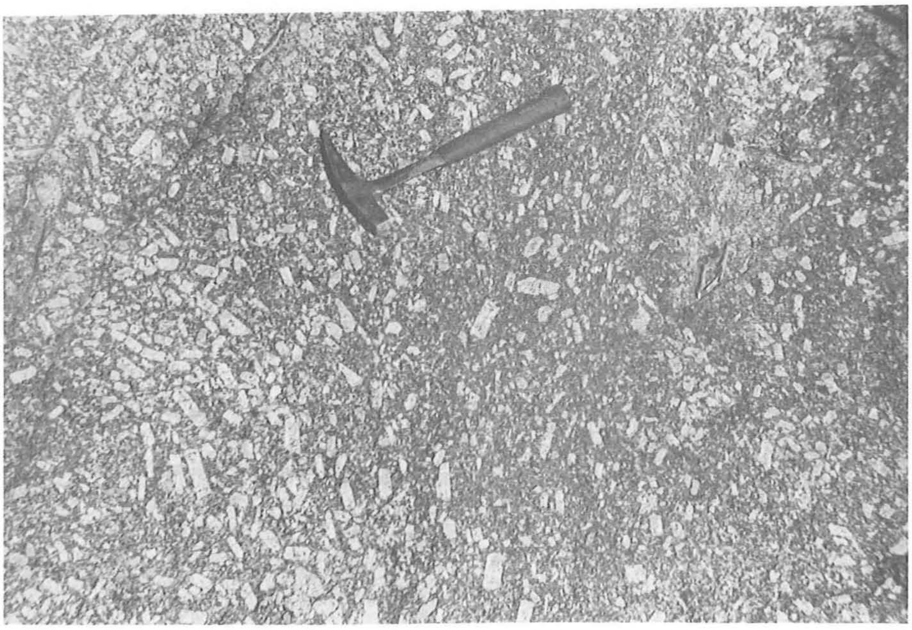


Fig. 50b: Closeup of the above outcrop. M1410 (J.H.C.B.)

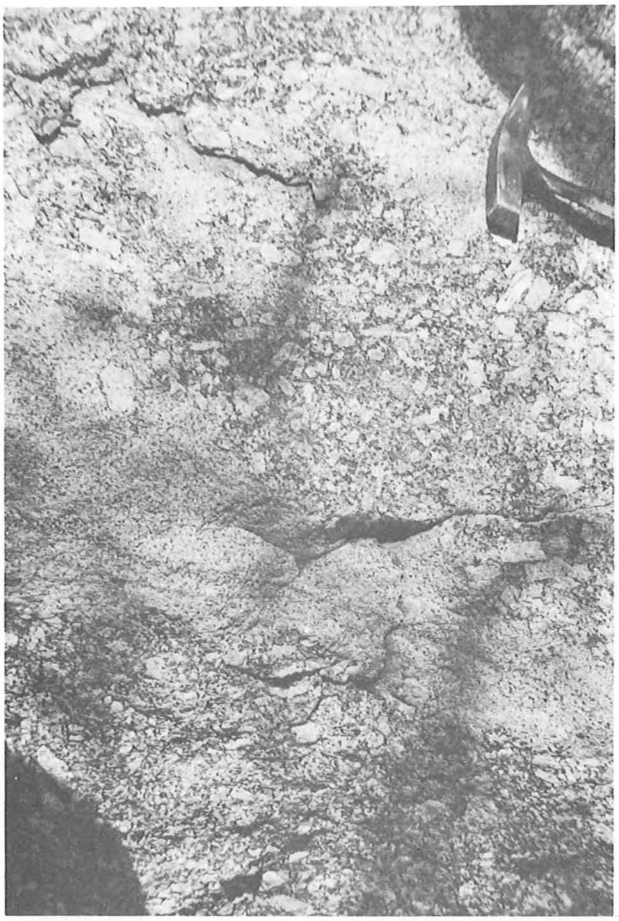


Fig. 51: Biotite granite (Type A) showing variable abundance, size, orientation, and distribution of alkali feldspar phenocrysts; Forsayth Granite north of Forsayth. M1410 (J.H.C.B.)

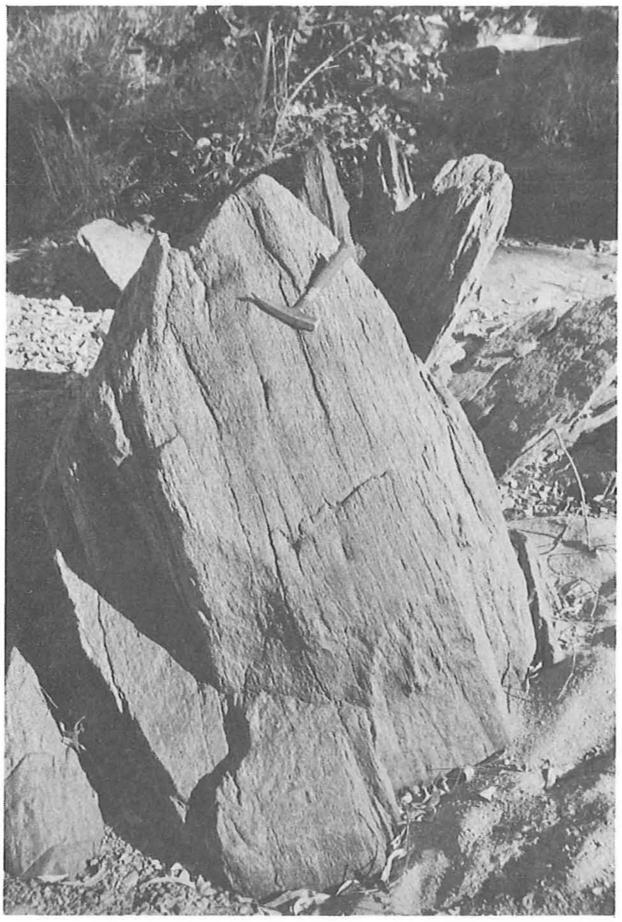


Fig. 52: Strongly foliated, equigranular, dark grey biotite granite (Forsayth Granite, Type B); Tweedside Creek 9 km southwest of Forsayth. M1410 (J.H.C.B.)

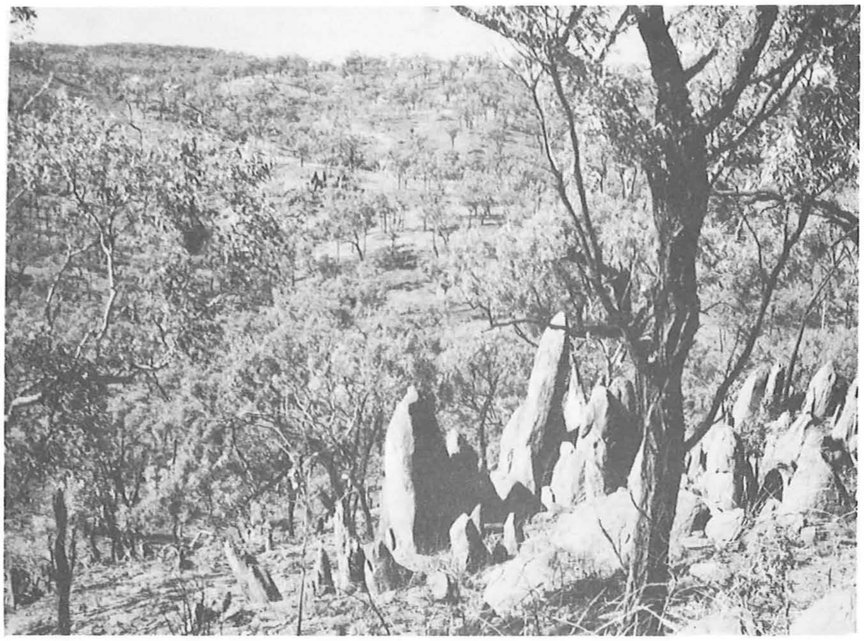


Fig. 53: 'Needles' of foliated dark grey equigranular biotite granite (Forsayth Granite, Type B); 2 km southwest of Big Reef mine. GA9507 (I.W.W.)

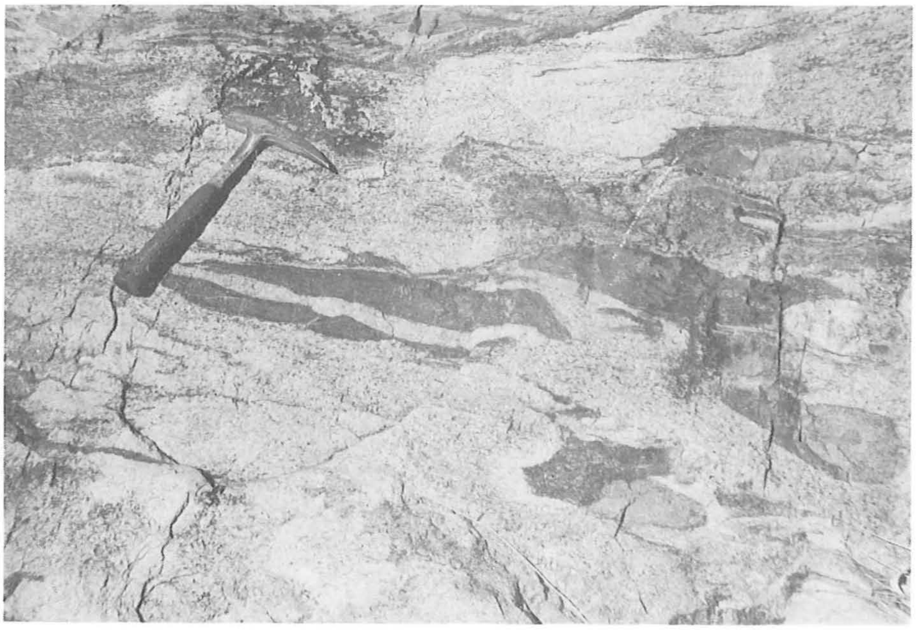


Fig. 54: Elongate metasedimentary xenoliths oriented parallel to the foliation in equigranular biotite granite (Forsayth Granite, Type B); about 10 km southeast of Forsayth. M1410 (J.H.C.B.)

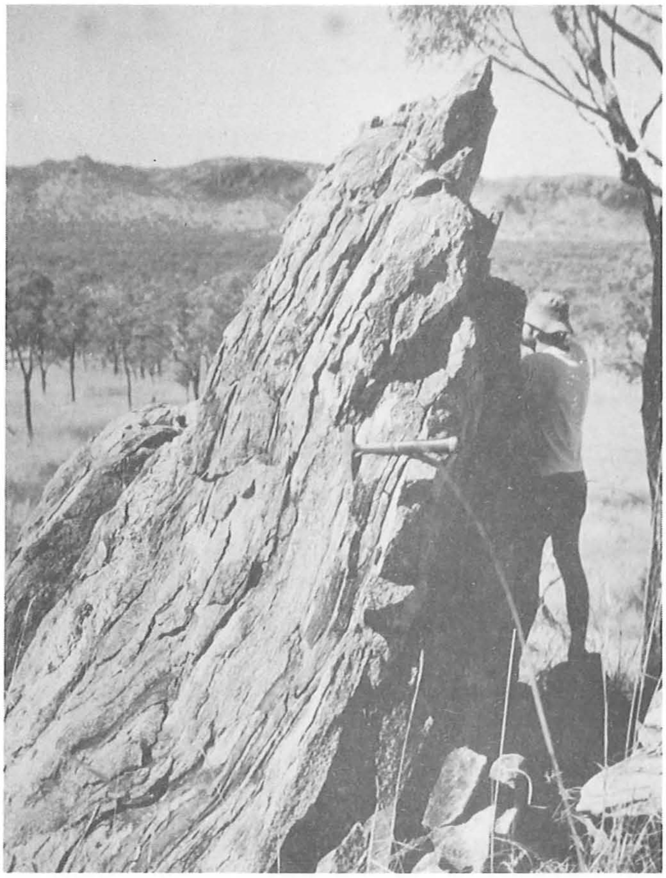


Fig. 55: Foliated even-grained biotite granite (Forsayth Granite, Type B) with numerous elongate metasedimentary xenoliths; 7.5 km east of Stars Well (I.W.W.)

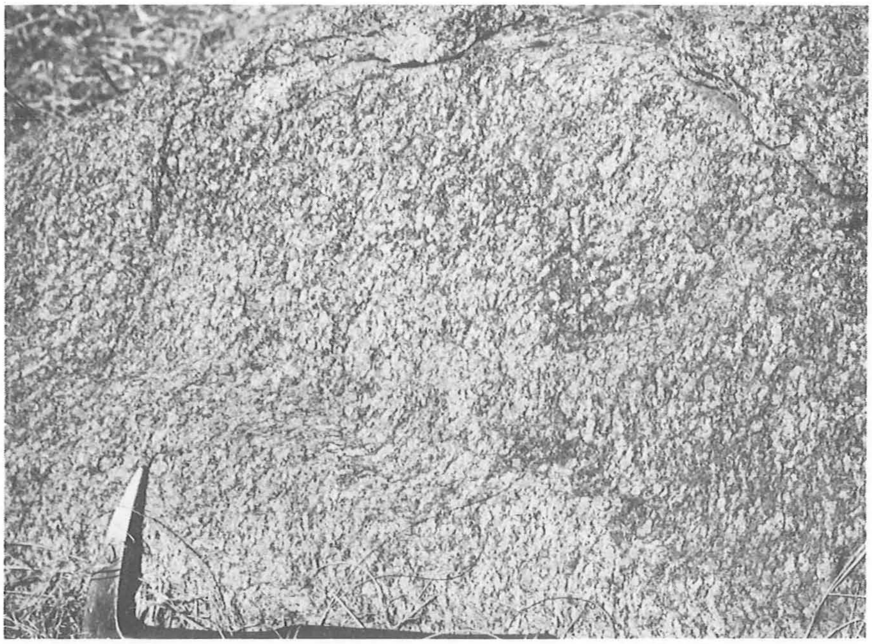


Fig. 56: Foliated, medium-grained porphyritic biotite leucogranite (Forsayth Granite, Type D); headwaters of McDermott Creek, 10 km northeast of Forsayth. GA9501 (J.H.C.B.)

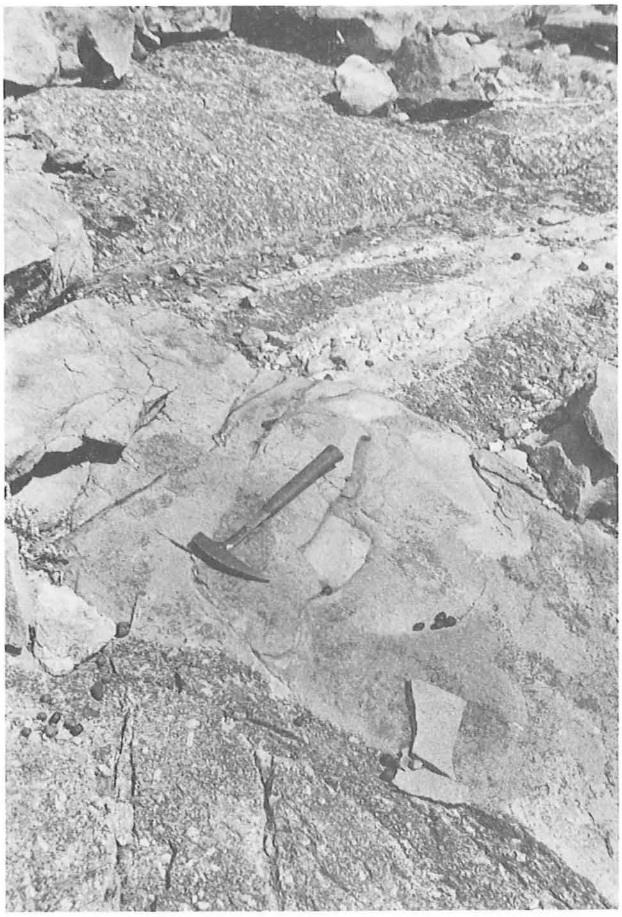


Fig. 57: Coarse-grained foliated, porphyritic dark grey biotite granite (Type A) and leucocratic pegmatite veins (Type H) cut by younger intrusion of medium non porphyritic biotite leucogranite dyke (Type E); Forsayth Granite at The Brothers, 12 km north of Forsayth. M1410 (J.H.C.B.)

Fig. 58: Light grey equigranular biotite granite (Forsayth Granite, Type E) with xenoliths of dark coarsely porphyritic biotite granite (Forsayth Granite, Type A); The Brothers, 12 km north of Forsayth. M1410 (J.H.C.B.)

Type D. In the headwaters of McDermott and Jenkins Creeks, northeast of Forsayth, the granite is medium-grained and light grey, and markedly porphyritic (Fig. 56). The phenocrysts in this granite, Type D, however, are considerably smaller than those in the dark Type A granite and are commonly much more abundant than in Type C. Muscovite is common in both Types C and D, but subordinate to biotite.

Xenoliths and enclaves of mafic and metasedimentary rocks are common and locally abundant in Types A to D. Patches of elongate metasedimentary xenoliths are most common in the dark fine-grained equigranular biotite granite of Type B (Figs. 54, 55).

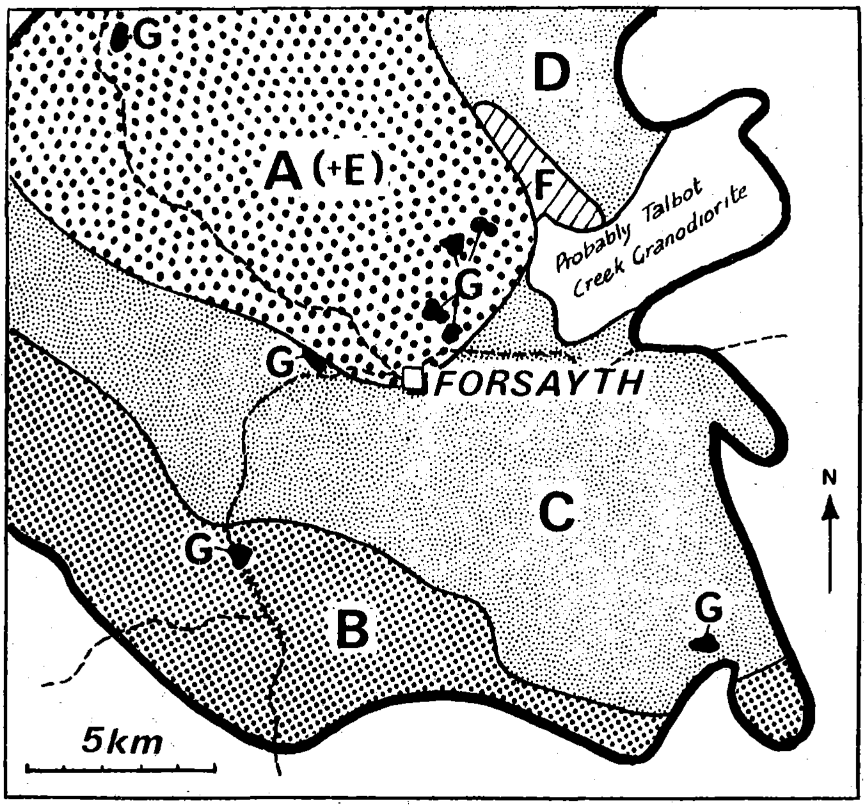
Type E. This type consists of the lightest coloured finest-grained varieties of biotite granite (Figs. 57, 58); these are more homogeneous than the coarser, darker, slightly porphyritic varieties (Type C), and are most common within the main body of Type A granite. There, contacts between the fine leucogranite (Type E) and dark porphyritic granite (Type A) are sharp but complexly interfingered. These relationships are clearly displayed in outcrops at Forsayth and at The Brothers, 12 km to the northwest (Figs. 57, 58).

Type F. A small area of pink leucocratic biotite granite, Type F, cropping out 1.5 km northeast of Jenkins Creek homestead, may be a separate intrusion but is more likely to be an altered portion of the adjacent biotite granite (Type D?), as the pink colour is due to iron-staining of the sericitized feldspars, especially as adjacent light and dark porphyritic biotite granites of Types A and D, cut by pink pegmatite veins, are also locally pink.

Type G. Small bodies of melanocratic, locally porphyritic, biotite microtonalite, Type G, are present within the Forsayth Granite at The Brothers, near the Forsayth airstrip, along the road from Forsayth to Jenkins Creek homestead, near Ropewalk homestead, and near the headwaters of Goldsmiths Creek. At each locality the microtonalite is clearly the oldest intrusive rock type.

Type H. Small dykes, veins, and irregular patches of buff to cream aplite and biotite-quartz-feldspar pegmatite Type H (Fig. 57), occur sparsely throughout the dark, coarse porphyritic biotite granite of Type A. They are cut by the fine-grained biotite leucogranite of Type E.

Small bodies of muscovite-bearing pegmatite and aplite present locally but not shown on the map are probably related to the younger Digger Creek Granite.



A — *Dark coarse porphyritic granite*

B — *Dark fine equigranular granite*

C — *Light slightly porphyritic granite*

D — *Light medium porphyritic granite*

E — *Fine equigranular leucogranite*

F — *Pink granite*

G — *Dark microtonalite*

H — *Pegmatite and aplite (occur throughout the area)*

--- *Road*

Fig. 59 Generalized distribution of main rock types, Forsayth Granite

Scintillometer (Austral SG1) readings on granite outcrops range from 70 to 180 counts/second and fall into two distinct groups, with peaks at 95-100 counts/sec and 150 counts/sec. Mostly the granites giving 150 counts/sec are melanocratic and porphyritic.

The various main rock types (Types A to E) appear to be distributed systematically (Fig. 59): Types A and E are confined to the northwest and surrounded by Types C and D which, in turn, are flanked on the south and southwest by Type B. The reason for this apparently concentric distribution is not known.

Petrography

According to Sheraton & Labonne (in press) the granites 'are generally medium- to coarse-grained; many are foliated and many porphyritic. The texture is normally allotriomorphic granular+, but grades into hypidiomorphic granular. Quartz forms aggregates of small grains and many of the grains show undulose extinction. Larger grains have serrated boundaries. Alkali feldspar is almost invariably microcline and is usually perthitic. It forms large, tabular, poikilitic phenocrysts as well as smaller anhedral grains. The plagioclase is subhedral and generally altered to sericite or saussurite. It ranges from oligoclase to sodic andesine and is usually zoned, except in the most acid rocks. The grains are corroded or form myrmekitic intergrowths close to microcline. Brown or reddish-brown biotite (up to 10%) is present in all samples and is often associated with muscovite, epidote, zircon and opaque minerals. Muscovite (up to 4%) occurs in most specimens, although only in trace amounts in some. Accessory minerals include epidote, zircon, apatite, allanite, sphene, opaque minerals and occasionally garnet and fluorite. The granites are relatively poor in accessories'.

Geochemistry and petrogenesis

Sheraton & Labonne (in press) have too few data from the Forsayth Granite to define chemical trends. This is mostly because they collected many of their 'Forsayth Granite' samples from outcrops now excluded from the unit. Even so, it is possible to draw some general conclusions from the data: element abundances are fairly typical of calcalkaline rocks; the main varieties of granite in the Forsayth area are corundum-normative and hence probably derived from sedimentary materials (Chappell & White, 1974), and their chemistry has been significantly modified by metamorphic processes such as alkali metasomatism; Cu is low and Th and possible U are high compared

+ = xenomorphic granular (A.G.I. Glossary of Geology, p, 18) with the average granites of Turekian & Wedepohl (1961) and Taylor (1968).

Age

The relations between the Forsayth Granite and the deformation and metamorphism of the Robertson River Metamorphics are discussed in pages 154-156. In brief, the Forsayth Granite appears to antedate the Digger Creek Granite and to have been emplaced before completion of the deformation and metamorphism of the Robertson River Metamorphics. The two most likely possibilities are that it was emplaced during the first, isoclinal, folding of the metamorphics or during the third, more open, folding event. In either case the Forsayth Granite would appear to be of middle Proterozoic (Carpentarian) age - the age indicated for the main metamorphism of the Robertson River Metamorphics by Rb/Sr isotopic data.

Preliminary Rb/Sr isotopic data from muscovite and biotite in the Forsayth Granite indicate a minimum age of 1500 m.y. (Black, pers. comm.) which is consistant with the above reasoning. A strong Siluro-Devonian thermal event 380-420 m.y. ago reset most K-Ar and Rb/Sr mineral ages, however (Black, 1973).

Mineralization

More than 7500 kg of gold and silver bullion and minor amounts of lead, zinc, and copper have been obtained from fissure-vein deposits in the Forsayth Sheet area, mostly from within the Forsayth Granite. Individual mineral deposits are described by Withnall (in press).

Oak River Granodiorite

General

The Oak River Granodiorite (new name by Withnall et al., in press) consists of locally foliated biotite granodiorite commonly containing alkali feldspar phenocrysts, and foliated porphyroblastic hornblende-biotite tonalite, and is probably of middle Proterozoic age. It covers more than 120 km^2 in the sheet area, southeast of the Newcastle Range, and extends eastwards into the Einasleigh 1:100 000 Sheet area. The name is derived from the Oak River, which is the main stream draining the outcrop area. The type area is along the track leading from the Einasleigh-Kidston road near Edmonds Creek (Grid Ref. 863035, Einasleigh Sheet area) to yards near Duck Hole Dam on the Oak River (Grid Ref. 113094), about 15 km southeast of Beverly Hills homestead.

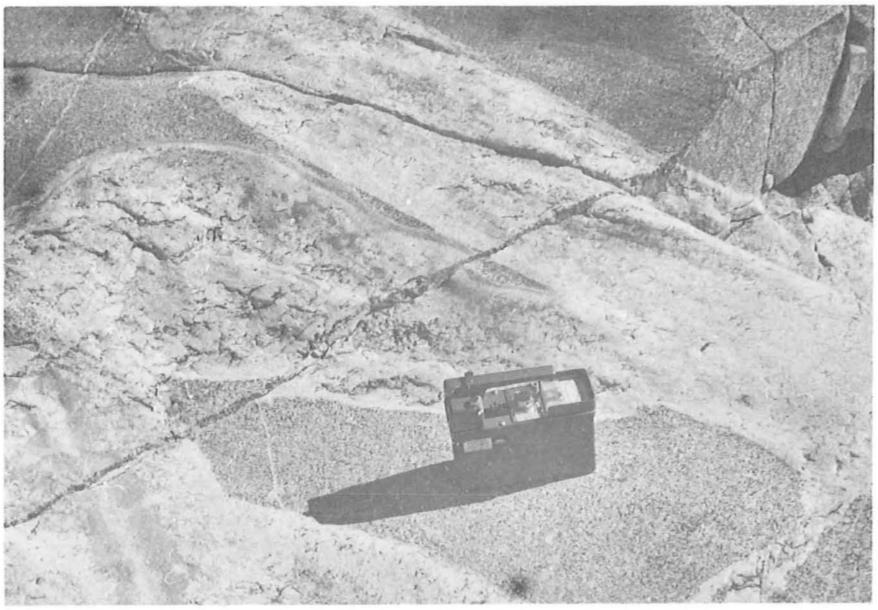


Fig. 60: Grey biotite granodiorite (Oak River Granodiorite) intruded by white-pink leucocratic aplite/pegmatite (Digger Creek Granite); Louis Creek (GR106062). 1669 (J.H.C.B.)

Fig. 61: Elongate xenoblastic quartz grain aggregates on weathered surface of foliated hornblende biotite tonalite; Oak River Granodiorite in Edmonds Creek (GR 7660-157980). GB137 (I.W.W.)

The granodiorite and tonalite were previously mapped as part of the Forsayth Granite (White, 1959b, 1962a & c, 1965), although they can be readily distinguished, both chemically and in hand specimen, from the redefined Forsayth Granite.

The topography developed on the granodiorite varies from subdued, almost flat areas with deep soil to rugged terrain with bouldery outcrops. There is no pronounced joint pattern.

Lithology

Grey medium-grained biotite granodiorite containing pink alkali-feldspar phenocrysts 1 to 2 cm long is the main rock type in the Sheet area (Fig. 60). A foliation, in places quite strong, is defined by alignment of biotite crystals; the feldspar phenocrysts are randomly oriented. Outcrops are commonly much weathered, the feldspars being white as a result of partial or total kaolinization, and the biotite being chloritized and epidotized.

Dark grey foliated hornblende-biotite tonalite is less common. The foliation is commonly more pronounced than that in the granodiorite and is defined by the alignment of biotite and hornblende crystals and elongate xenoblastic quartz and feldspar aggregates (Fig. 61).

Relationships and age

It was not possible to map the two rock types of the Oak River Granodiorite separately, and the relation between them is not known. However, both intrude middle? Proterozoic Einasleigh Metamorphics with sharp crosscutting, albeit regionally concordant, contacts, and both are intruded by middle? Proterozoic Digger Creek Granite (Fig. 60) and by Upper Palaeozoic rhyolite and microgranite dykes. Thus the granodiorite is middle Proterozoic. The western extent of the granodiorite beneath the overlying Carboniferous Newcastle Range Volcanics is unknown and thus its relation to the Forsayth Granite is also unknown.

Petrogenesis

Sheraton & Labonne (in press) have very few geochemical data for this unit, but it appears that the Oak River Granodiorite is not genetically related to the Forsayth Granite.

Mineralization

A minor occurrence of gold and copper in quartz-veined sericitized granodiorite adjacent to a rhyolite dyke at the Great Eastern mine is the only known mineralization in the unit.

Digger Creek Granite

General

Leucocratic muscovite granite, aplite, and pegmatite that intrude the Robertson River and Einasleigh Metamorphics and Oak River Granodiorite in the southern part of the sheet area are mapped as Digger Creek Granite (new name by Withnall et al., in press). In the Robertson River area the granite was formerly grouped with the Robin Hood Granodiorite whilst in the southeast quarter of the sheet area it was mapped, along with the Oak River Granodiorite, as Forsayth Granite (White, 1959b, 1962d, 1965). The largest body of Digger Creek Granite extends south and east of Beverly Hills homestead on the eastern side of the Newcastle Range for at least 10 km; the greatest concentration of small intrusions of Digger Creek Granite, especially pegmatite dykes, is in the type area (Digger Creek 14 km southwest of Robin Hood homestead), and to a lesser degree in the headwaters of the Oak River north of Fernhill outstation. The bulk of the pegmatites are confined to areas of middle to upper amphibolite facies rocks (indicated by the presence of sillimanite). Both concordant foliated and clearly discordant bodies are present, and although the latter predominate it is likely that the granite was formed and intruded during the main period of metamorphism in the Robertson River area (see p.). Thus the age of the granite is probably very similar to that of the Robertson River Metamorphics i.e. middle Proterozoic. As mapped, the larger bodies intruding metamorphics contain numerous xenoliths and roof pendants of the country rocks. The only known mineralization is in the Percyville goldfield - where linear, fracture-controlled quartz-sericite alteration zones contain complex Ag-Au-Cu-Pb ores. The granite typically exhibits a light colour on the airphotos, and commonly has greatest relief in the pegmatite stockwork areas. Scintillometer (Austral SG1) readings on outcrops range from 25-40 counts/second.

Lithology and Relationships

The Digger Creek Granite consists of white, to light grey, cream, and pink muscovite leucogranite containing sporadic biotite and garnet, and varying in grain size from

Fig. 62: Aggregates of plumose muscovite in muscovite granite; Digger Creek Granite 6 km west-northwest of Stars Well. 9465 (I.W.W.)

Fig. 63: Typical exposure of muscovite granite; Digger Creek Granite near Digger Creek, 4.5 km north of 'Old Robin Hood'. 9466 (I.W.W.)

aplitic to pegmatitic, commonly within the same outcrop; it is locally foliated. The distribution of primary mineral constituents is as variable as the grainsize and the variability of both is a characteristic of the units. Biotite is present in some of the fine even-grained rocks but is invariably absent from the pegmatite.

Cream and grey varieties of the Granite predominate in the Robertson River area and pink varieties are common near the southern edge of the sheet area, and in the headwaters of the Percy River and the hills between Beverly Hills homestead and Malcolms Creek. Cream and white varieties predominate northeast of 'Beverly Hills' and north and east of the abandoned Fernhill outstation. White fine-grained foliated biotite leucogranite is confined to the latter area. Most of the pegmatites are pink.

The granite (Fig. 62) forms small irregular bodies from a few tens of metres to 2 or 3 km across, (Fig. 63). Some of the small bodies are foliated; most of the large bodies contain numerous roof pendants and xenoliths of schist and amphibolite. In some places, notably near Percyville, they are cut by quartz-veined greisenized shear zones, some of which have been mineralized (see Withnall, in press).

Pegmatite occurs partly as segregations within the granite but more commonly as irregularly shaped dykes within the metamorphics. The larger bodies of pegmatite are complexly zoned- commonly with a massive white quartz core and quartz-muscovite and feldspar-muscovite outer parts. In some places the pegmatite dykes are so numerous as to form a stockwork - especially where the granite bodies are largest and most numerous (e.g. Digger Creek area). Although a great many dykes are clearly visible on the airphotos - at least three times as many as can be represented on the map - there are numerous small veins only a few centimetres wide that are visible only on the ground. Thus the density of pegmatite symbols on the map should be taken only as an approximation and a guide to the relative abundance of pegmatite throughout the metamorphics. Most of the dykes have been intruded along cleavage or foliation planes in the metasediments and are thus partly concordant. However, clear discordant intrusive relationships are also common.

A few small muscovite aplite and pegmatite dykes (presumably Digger Creek Granite) intrude the Forsayth Granite. Although the granite and pegmatite are slightly foliated and in places moderately deformed they are quite different from the deformed biotite- and garnet-bearing pegmatites in the Einasleigh Metamorphics e.g. in the Stockman Creek area.

Petrography

"The adamellites [+](68590416; 70571124) and granites (68590018A, B: 70571125, 8) are grey to pink and generally medium- to coarse-grained. The pink varieties (70571124, 5, 8) are leucocratic, being almost devoid of biotite, although up to 3 percent of muscovite is present. The other samples contain 1-2 percent of partly chloritized biotite. Quartz is usually granulate, particularly along grain boundaries, and often shows undulose extinction. Alkali feldspar is microcline perthite. Oligoclase (An_{24-28}) is partly sericitized. Myrmekite is common between adjoining grains of plagioclase, and microcline and plagioclase sometimes have corroded margins. Accessory minerals are not abundant but include sphene, apatite, zircon, opaque minerals and less commonly, garnet and fluorite." (Sheraton & Labonne, in press).

Age

The precise age of the granite is unknown but it is almost certainly Proterozoic, probably middle Proterozoic as it apparently intrudes middle Proterozoic Robertson River Metamorphics and Forsayth Granite and was intruded during or immediately after the second folding event in The Robertson River Metamorphics. A single K-Ar muscovite age of 1120 m.y. (previously assigned to the Robin Hood Granite) was obtained by Richards et al. (1966) and muscovite from the Digger Creek Granite in the type area has been dated by the Ar^{40}/Ar^{39} incremental heating method - a minimum age of about 1320 m.y. was obtained and total degassing gave an age of 1170 m.y. (D.C. Green, pers. comm.). These determinations should be treated with caution despite the fact that they are consistent with the known geological relations and are of the order of magnitude expected. Further isotopic studies are in progress.

Mineralization

The only known mineralization occurs in the old Percyville Goldfield and is outlined by Withnall (in press).

FAULTING IN THE PROTEROZOIC GRANITIC AND METAMORPHIC ROCKS

Numerous lineaments in the Proterozoic metamorphics and granite can be mapped from aerial photographs. They are shown as faults only where either shearing or displacement has been observed; because of the lack of distinct marker beds there is usually no observable displacement.

+ = granite (IUGS recommended terminology).

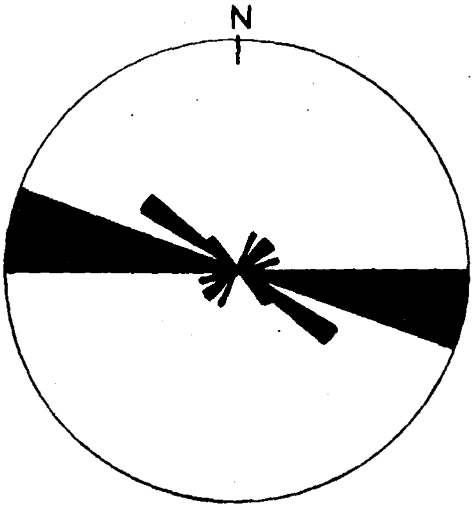


Fig. 64: Rose diagram of foliation directions in granite in the southern part of the Forsayth Granite. (24 readings)

Apart from the Delaney Fault, which is discussed separately, most of the faults and lineaments mapped in the Robertson River Metamorphics and Forsayth Granite define an apparently conjugate set indicating an approximately east-west principal stress direction. This stress direction may coincide with the direction of the stress responsible for the broad folding about north-south axes, one of the last phases, of folding recognized in the Robertson River Metamorphics. Other minor fault or lineament directions may be due to different stresses. Some of the faults were probably active in the late Palaeozoic, when the Newcastle Range Volcanics were downfaulted. Dykes of rhyolite, andesite, and dolerite were emplaced along several faults at this time.

Shear directions in the Forsayth Granite, particularly along its southern margin coincide with the major foliation direction of the granite. Many of the faults and fractures in and adjacent to the Forsayth Granite are marked by auriferous quartz reefs.

In the Einasleigh Metamorphics of the Stockman Creek area most of the faults and lineaments are parallel to the bounding-faults of the Newcastle Range Volcanics.

Most of the lineaments in the Einasleigh Metamorphics and the granites in the southeast corner of the Sheet area trend north-northeast although some trend north-northwest, northeast, east-northeast and east-southeast. The north-northeast trending set may be genetically related to the major northeast trending 'Gilberton Fault' which separates the Etheridge Formation and Einasleigh Metamorphics at Gilberton. Examination of ERTS photographs indicates that this structure may continue northeast towards Kidston and 'Carpentaria Downs'.

RELATIONS BETWEEN DEFORMATION, METAMORPHISM, AND GRANITE INTRUSION IN PROTEROZOIC ROCKS

The relations between deformation and metamorphism of the Robertson River Metamorphics has already been discussed in detail (see pp.35-36). In summary it appears that most of the metamorphism and growth of metamorphic minerals accompanied the two early periods of isoclinal folding; some mineral growth continued subsequent to this and possibly a minor amount took place during the major east-west folding, the third episode of folding. Temperatures were probably still relatively high during this event.

A conspicuous contact metamorphic aureole is lacking around the Forsayth Granite although in places there may be an increase in metamorphic grade towards the granite: sillimanite near granite contacts locally occurs as large needles rather than as fine-grained fibrolite. The lack of a conspicuous aureole suggests that there was only a relatively small temperature gradient across the contact, showing that the Forsayth Granite probably intruded hot country rocks. The foliation of the granite, defined by preferred orientations of the alkali-feldspar phenocrysts and biotite flakes and an alignment of xenoliths and biotite schlieren,is mainly the result of magmatic and post-magmatic crystallization under directed pressure. In the southern part of the Forsayth Granite outcrop, the dominant foliation direction is east to east-southeast (Fig. 64), approximately parallel to shears and faults both within the granite and in adjacent metamorphic rocks, to contacts with the metamorphic rocks, and to the strike of axial planes of the B_{S2}^{S3} folds. The parallelism of structures in the granites and in the country rocks suggests that the structures were produced by the same stress-field. The Forsayth Granite may therefore by synkinematic with the B_{S2}^{S3} folding. This is consistent with the conclusion that the complex was emplaced into relatively hot country rocks since, as pointed out previously, the temperatures were probably still high during this folding event. Alternatively it may have been emplaced during the B_{S0}^{S1} folding. The orientation of the axial planes of these older folds is also approximately east-west in the adjoining North Head 1:100 000 Sheet area to the west.

The Digger Creek Granite may also have had a synkinematic emplacement, as it is weakly foliated in places, for instance in the Welfern area, and it has no observable contact effects. Temperatures during its emplacement must have been relatively high to allow the formation of coarse muscovite pegmatites, some of which are many kilometres from the nearest known granite body. The pegmatites and muscovite granite seem to be restricted mainly to rocks of middle amphibolite facies (Fig. 28), indicating that they were formed during the main metamorphism, which was at its peak during the B_{S1}^{S2} folding.

The Oak River Granodiorite is associated with a large area of granite-gneiss and migmatite of comparable composition, and may have been formed at about its present level by anatexis of the Einasleigh Metamorphics. The foliation of the Oak River Granodiorite, in particular the tonalite, is generally more pronounced than that in the Forsayth Granite, In the south it generally has an approximately north-south trend, which suggests an east-west compression during crystallization; this may have been associated with the formation of B_{S1}^{S2} folds in the Einasleigh Metamorphics and the Robertson River Metamorphics. Metamorphism was at its peak during the formation of these folds, at least in the Robertson River Metamorphics, and it increased in grade eastwards, where granite-gneiss, migmatite, and possibly the granodiorite and tonalite of the Oak River Granodiorite were produced.

The Robin Hood Granodiorite is a post-tectonic batholith which is not regionally foliated, and clearly it postdates the Digger Creek Granite.

LOWER PALAEOZOIC GRANITIC ROCKS

General

The Robin Hood Granodiorite (Robin Hood Granite of White, 1959b, 1962d, 1965) is a stressed grey medium-grained hornblende-biotite granodiorite containing abundant small quartz phenocrysts (Fig. 64). It crops out over 200 km^2 on the south-western side of the Newcastle Range and extends south into the Gilberton 1:100 000 Sheet area. The type area as redefined by Withnall et al. (in press) is along the first 10 km of the track from Robin Hood homestead to Fish Hole. The granodiorite intrudes the Proterozoic metamorphics and is unconformably overlain by the mid-Carboniferous Newcastle Range Volcanics; it is probably Siluro-Devonian but its precise age is unknown. Muscovite granite, adamellite, and pegmatite previously included in the 'Robin Hood Granite' (White, 1959b, 1962d, 1965) are now assigned to the Digger Creek Granite on a basis of their lithology and geochemistry (Sheraton & Labonne, in press). The latter clearly shows that the granite and granodiorite are derived from different magmas. Mineral deposits are uncommon and only small. The topography developed on the granodiorite is subdued and characterized by low bouldery hills and extensive alluvial deposits near the main stream channels. Also characteristic are the deeply gullied slopes in the strongly weathered rock below Mesozoic sandstone-capped mesas. Where the granodiorite has been deeply weathered and outcrops are absent, the residual sand and gravel contains abundant distinctive small pea-sized quartz grains.

Lithology

The Robin Hood Granodiorite is characteristically uniform in rock type - stressed, medium-grained, porphyritic hornblende-biotite-granodiorite - although the colour varies from grey to pink depending on the degree of alteration of the plagioclase. It is further distinguished by the presence of small (1 cm) fractured, rounded quartz phenocrysts, and the virtually total absence of aplite and pegmatite dykes and veins. Scintillometer (Austral SG1) readings average 40 counts/sec. (range 35-45). There are some greisens (or quartz-

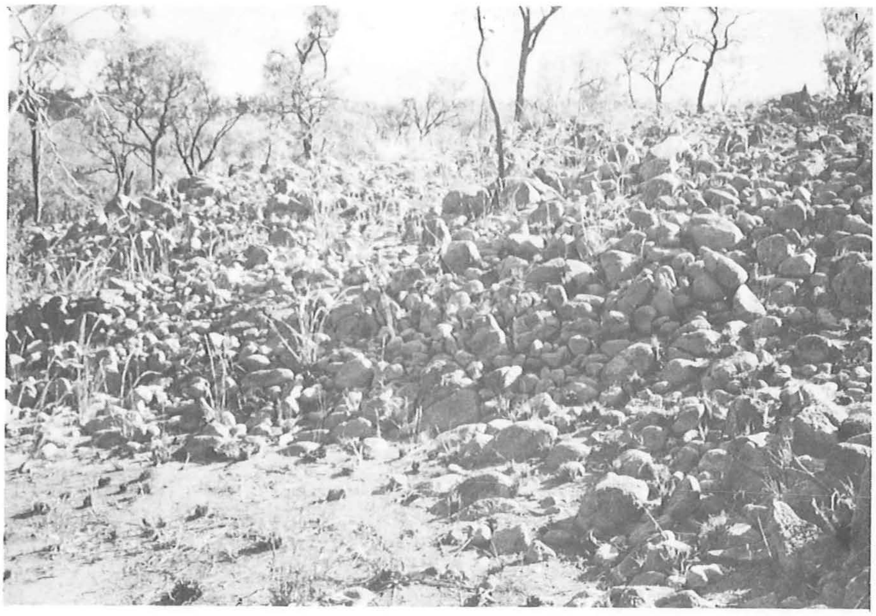


Fig. 65: Typical bouldery outcrop of Robin Hood Granodiorite north of Robin Hood homestead. 9441 (J.H.C.B.)

sericite alteration zones) and small quartz veins. The rock is well jointed and commonly forms rounded boulders 30 cm to 2 m in diameter (Fig. 65).

Petrography

The granodiorite consists of quartz (25-30 percent), andesine (45-50 percent), microcline (15-25 percent), and partly chloritized and epidotized biotite (5 percent) and hornblende (2 percent). Chlorite, epidote, sphene, zircon, apatite, muscovite, allanite, fluorite, and opaques are minor constituents. Most of the quartz occurs as subrounded aggregates (7-10 mm in diameter) of small grains with highly sutured boundaries and undulose extinction; a small amount is interstitial or graphically intergrown with microcline. The plagioclase is anhedral zoned andesine (1-5 mm) and much of it is sericitized, some of it intensely. The pink colour of the feldspar in some specimens is due to the intense sericitization. Microcline (1-3 mm) is slightly perthitic and is commonly unaltered. Some of the hornblende (0.5-2 mm) is pseudomorphed by biotite, chlorite, and epidote. Biotite (0.5-2 mm) is partly chloritized and epidotized and some flakes are bent.

Scattered small dark, fine-grained xenoliths are present locally; they consist of interlocking biotite and hornblende crystals, opaques, and some interstitial quartz.

The granodiorite is locally granulated and cut by many penetrative microshears and fractures. It is normally not foliated. Alteration, mainly sericitization and chloritization, accompanied or postdated the deformation. This is indicated by sericitized and chloritized microshears. 'Greisens' represent the most intense alteration, and they too appear to be closely related to shear zones. At the Jubilee-Plunger Ag-Au lode near Robin Hood homestead, altered granodiorite is pale green, except where iron-stained, and consists of quartz (60 percent), muscovite (40 percent), and opaques (1-2 percent). The quartz is even more strongly fractured than in the unaltered granodiorite, but the porphyritic texture is still evident. Muscovite is colourless and mostly fine-grained (0.05-0.2 mm). Some laths are grouped in rosettes, others form patches in which at least half the laths have a common orientation. The parallelism of these laths may be due to the growth of the muscovite along cleavage traces in the biotite and plagioclase in the original granodiorite.

Relationships and age

The granodiorite intrudes the Proterozoic Robertson River and Einasleigh Metamorphics, Cobbold Metadolerite and Digger Creek Granite. The intrusion has an irregular outline but contacts are sharp, relatively straight; and commonly have shallow outward dips. Contact metamorphic effects are slight. It is intruded by rhyolitic dykes and unconformably overlain by mid-Carboniferous Newcastle Range Volcanics, Permian Agate Creek Volcanics, and Mesozoic rocks. Therefore, purely on the basis of relations with other rock units its age could be anything from late Proterozoic to Lower Carboniferous. However, in view of the available isotopic data (Black, 1973 and pers. comm.) the most likely age is Silurian-Devonian (i.e. about 420-426 m.y.).

Previously (White, 1965) muscovite granite and pegmatite (Digger Creek Granite of this report) in the Robin Hood area were included in the 'Robin Hood Granite'. One of the only two specimens of 'Robin Hood Granite' that Richards et al. (1966) dated was from the Digger Creek Granite and it gave K-Ar muscovite age of 1120 m.y. The other specimen gave a K-Ar biotite age of 380 m.y. Thus the Robin Hood Granodiorite was cited as one of only two undoubted Proterozoic granites, but it now appears most likely to be Siluro-Devonian. Further isotopic dating is in hand.

Mineralization

Mineral deposits in the Robin Hood Granodiorite, at least within the sheet area, are very few and small and of the Ag-Pb and Au-Ag fissure vein type (Withnall, in press). Most important is the Jubilee-Plunger Au-Ag lode which was worked for very low gold values in the late 1890s and early 1900s. Recent geochemical studies (Armstrong, 1975) indicate the presence of anomalous Pb, Zn, Cu, Ag, and Au concentrations in the soil around this deposit. This probably represents lead, zinc, and copper sulphides at depth in the lode. A similar but smaller mineralized greisen (Bridle Track) containing Ag-Pb ore was prospected in the 1940s and early 1960s. Immediately south of the sheet area near Agate Creek two small high-grade Ag-Pb deposits (Big Hope and Big Surprise) were worked in the 1960s. These two are within altered granodiorite and of the fissure vein type. Detailed geochemical prospecting of the Robin Hood Granodiorite could reveal further small deposits of this type.'

There is a very small metatorbernite/autunite deposit (Limkins Prospect - see Withnall, in press) in a quartz-veined greisen on the southern edge of the Sheet area. No other mineralization of this type is known in the Sheet area.

UPPER PALAEOZOIC VOLCANIC ROCKS

Newcastle Range Volcanics

Introduction

The Newcastle Range Volcanics are of mid-Carboniferous age and consist mainly of rhyolitic ignimbrite with subordinate rhyolitic and andesitic lava, airfall tuff, agglomerate, and volcaniclastic and epiclastic sedimentary rocks. The unit was named from the Newcastle Range (White, 1959a), its main area of occurrence. The type area is Shrimp Creek, which is in the eastern Newcastle Range about 7 km north-northwest of Einasleigh (Mount Surprise 1:100 000 Sheet area) (White, 1959a; Branch, 1966).

Recent work in most of the area of Newcastle Range Volcanics indicates that the stratigraphy of the eastern Newcastle Range is different from that of the main range, the succession in the Shrimp Creek area being representative of only part of the eastern range sequence. Several units of formation rank, some of which are described below, are recognized in both parts of the range; they will eventually be formally defined and described, and the status of the Newcastle Range Volcanics raised to that of a group. At present, however, units constituting the Newcastle Range Volcanics are treated informally.

In the Forsayth 1:100 000 Sheet area the Newcastle Range Volcanics crop out mainly in two areas, totalling 400 km^2, in the upper reaches of the Robertson River and north of the main road and railway from Forsayth to Einasleigh (see map); the two areas are separated by Mesozoic and Cainozoic rocks. Rocks in these two areas belong to the main Newcastle Range sequence. A small area of Newcastle Range Volcanics shown in the northeastern corner of the map is part of the eastern Newcastle Range sequence, better developed in the Georgetown and Mount Surprise 1:100 000 Sheet areas.

General description of rock types

The dominant rocks in both the main and eastern range sequences of the Newcastle Range Volcanics are porphyritic rhyolites which are buff, pink, purple, grey, or green, and contain from 20 to 70 percent phenocrysts, commonly both beta-quartz and feldspars, up to 4 mm in maximum dimension. The groundmass is microcrystalline and quartzofeldspathic, and commonly has a eutaxitic (streaky and banded) texture formed by pseudomorphs of flattened glass shards and pumice, suggesting that the rocks originated as ignimbrites.

Beta-quartz phenocrysts in these rocks are euhedral to anhedral, and almost invariably corroded and embayed. Alkali feldspar occurs as euhedral to subhedral phenocrysts which are commonly microperthitic. High-temperature alkali feldspars (sanidine, anorthoclase) were probably originally present in the rocks, but none have been recognized in the present work despite the statement by Branch (1966, p. 23) that anorthoclase is relatively common in the Newcastle Range Volcanics. Euhedral to subhedral plagioclase ranges from oligoclase to andesine; optical properties are reported to indicate that it is transitional from a high- to low-temperature type (Branch, op. cit., p. 23), but this has not been verified. All feldspar phenocrysts are commonly altered (kaolinized, sericitized, and ironstained) to some, commonly great, extent, and some are corroded and embayed like the quartz. Biotite and hornblende phenocrysts, which are absent from most rocks and only relatively minor constituents of others, are euhedral to subhedral, up to 4 mm long, and invariably partly or wholly chloritized. Common accessory minerals are apatite, magnetite, and hematite, and secondary epidote; secondary calcite occurs sporadically.

Subordinate volcanic rock types in the Newcastle Range Volcanics of the sheet area are buff to purple aphyric rhyolitic lava?, green aphyric andesitic lava, airfall lithic-crystal-vitric tuff, and agglomerate. Relatively rare volcaniclastic sedimentary rocks are locally interbedded with the volcanic rocks; they are mainly lithic-crystal siltstones and sandstones and probably represent airfall tuff and ignimbrite material reworked under fluviatile conditions during sporadic lulls in volcanic activity.

Sedimentary rocks also lie below the volcanic rock-dominated sequence locally; they consist of quartzofeldspathic and lithic fluviatile siltstone, sandstone, and conglomerate containing subangular to rounded clastic material derived mostly from subjacent granitic and metamorphic rocks. The sedimentary rocks are commonly cemented by purple hematite, and locally contain clastic muscovite. Lacustrine shale and siltstone with rare limestone interbeds occur locally. These fluviatile and lacustrine epiclastic rocks grade upwards into volcaniclastic siltstone and sandstone, or are overlain by ignimbrites (Fig. 70).

Chemistry

The chemistry of the extrusive rocks in the Newcastle Range Volcanics has been discussed briefly by Branch (1966, 1969), and in more detail by Sheraton & Labonne (in press). In essence the rocks are calcalkaline, and commonly contain 70 percent or more silica. Alkali contents are variable, perhaps because of migration and redistribution of soda and potash during hydration and devitrification of originally glassy components (shards and pumice). The Newcastle Range Volcanics have similar Th contents to other Upper Palaeozoic volcanic rocks in northeastern Queensland, but are much lower in U, suggesting that they are depleted in the latter element; the significance of this is unknown.

Map units and stratigraphy

Mapping during the 1974 and 1975 field seasons in the Georgetown and Mount Surprise 1:100 000 Sheet areas, respectively north and northeast of Forsayth, suggested that there are two separate stratigraphic sequences in the Newcastle Range Volcanics, developed in the main and eastern parts of the Newcastle Range respectively. The Newcastle Range Volcanics in the Forsayth sheet area occur mostly in the lower part of the main range sequence. A small area of Newcastle Range Volcanics in the northeast is part of a unit (Cn_4) high in the eastern range sequence and more extensive in the Georgetown 1:100 000 Sheet area. A unit tentatively correlated with the uppermost unit of the eastern range sequence (Cn_6) overlies rocks of the main range sequence with apparent unconformity in the upper reaches of the Robertson River; if the correlation is valid then unit Cn_6 is the only one so far recognized which is common to the two Newcastle Range Volcanics sequences.

(a) Main range sequence

(i) Unit Cns (subunits Cns_a, Cns_b). Clastic sedimentary rocks developed sporadically below the lowest volcanic rocks in the main Newcastle Range sequence are assigned to unit Cns, within which two subunits, Cns_a and Cns_b, are differentiated. Rocks of the unit are thickest and most extensive north and south of Fish Hole (grid ref. 882264) (Figs. 67, 68), where they may be as much as 200 m thick. They also occur along Chinaman Creek northeast of Beverly Hills homestead (grid ref. 051218) on the eastern side of the range (see map), where they are probably less than 100 m thick.

Subunit Cns_a forms the lower part of the unit; it consists of coarse purple and green quartzofeldspathic and lithic fluviatile pebbly and cobbly sandstone and conglomerate (Fig. 68) with subordinate shale and siltstone and, near Fish Hole (at grid ref. 879262), grey lacustrine? sandy and algal limestone lenses. Clastic material consists mainly of subrounded to rounded fragments of subjacent granitic and metamorphic rocks; the volcaniclastic component is variable, but never dominant.

The upper subunit, Cns$_b$, consists mainly of thin- to medium-bedded volcaniclastic fluviatile sandstone and siltstone (Fig. 66), probably derived from airfall tuff and ignimbrite.

(ii) Unit Cna. Epidotized aphyric andesitic lava 50 m thick, designated Cna, occurs low in the sequence in the Chinaman Creek area, between 8 and 12 km northeast of Beverly Hills homestead. A similar, if not the same, lava occurs below agglomerate of subunit Cn$_{Ib}$ where the Forsayth-Einasleigh road crosses the eastern side of the range. A third occurrence of andesitic lave in a similarly low stratigraphic position is about 1 km southwest of Tenavute homestead (grid ref. 859453) on the western side of the range; here the andesite lies beneath rhyolitic ignimbrite of subunit Cn$_{IId}$.

(iii) Unit Cn$_I$ (subunits Cn$_{Ia}$, Cn$_{Ib}$). Unit Cn$_I$ is best developed in and south of upper Chinaman Creek, between 8 and 15 km northeast of 'Beverly Hills', where it lies conformably on, and interdigitates with, fluviatile clastic sedimentary rocks of unit Cns. Unit Cn$_I$, which is undivided in this area, contains buff to purple aphyric rhyolitic lava? which is commonly banded and autobrecciated, airfall tuff (elsewhere differentiated as subunit Cn$_{Ia}$), and agglomerate (elsewhere differentiated as subunit Cn$_{Ib}$). The maximum thickness of unit Cn$_I$ in upper Chinaman Creek is estimated to be about 100 m.

Along the Forsayth-Einasleigh road on the eastern side of the Newcastle Range agglomerate (Cn$_{Ib}$) lies on aphyric andesitic lava (Cna). Airfall crystal-lithic-vitric tuff (Cn$_{Ia}$) which underlies ignimbrite of unit Cn$_{II}$ between 1 and 12 km west of 'Beverly Hills' is at the same stratigraphic level as chaotic boulder agglomerate (Cn$_{Ib}$) (Fig. 69) which crops out in the bed and lower slopes of the Robertson River gorge upstream from Fish Hole. The airfall tuff may be a distal equivalent of the agglomerate; the latter is cut locally by tuffisite veins and is interpreted as a vent accumulation.

A small outlier of airfall tuff, tentatively assigned to subunit Cn$_{Ia}$, occurs 1 km west of the Georgetown-Forsayth road in the northwestern corner of the map area; it is intruded by rhyolite.

(iv) Unit Cn$_{II}$ (subunits Cn$_{IIa}$ to Cn$_{IIf}$). Unit Cn$_{II}$ consists of a variety of porphyritic rhyolitic ignimbrites, all of which contain corroded beta-quartz and feldspar phenocrysts, and relatively rare interbeds of volcaniclastic sedimentary rocks. The unit overlies units Cns and Cn$_I$ and is the most areally extensive one in the Newcastle Range

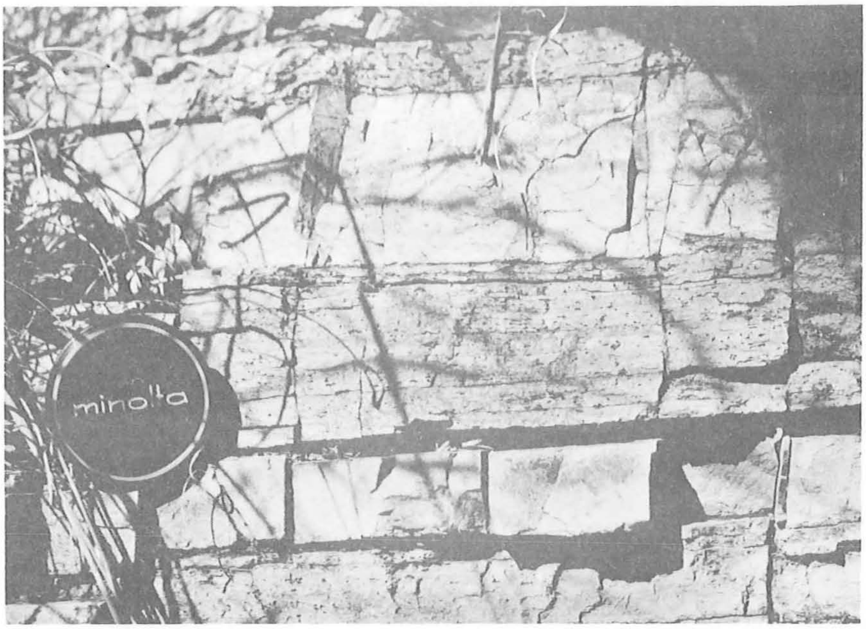


Fig. 66: Volcaniclastic siltstone, Newcastle Range Volcanics (unit Cns_b). Exposed in the western front of the main Newcastle Range about 6 km north-northwest of Fish Hole (grid ref.865308). M9445 (I.W.W.).

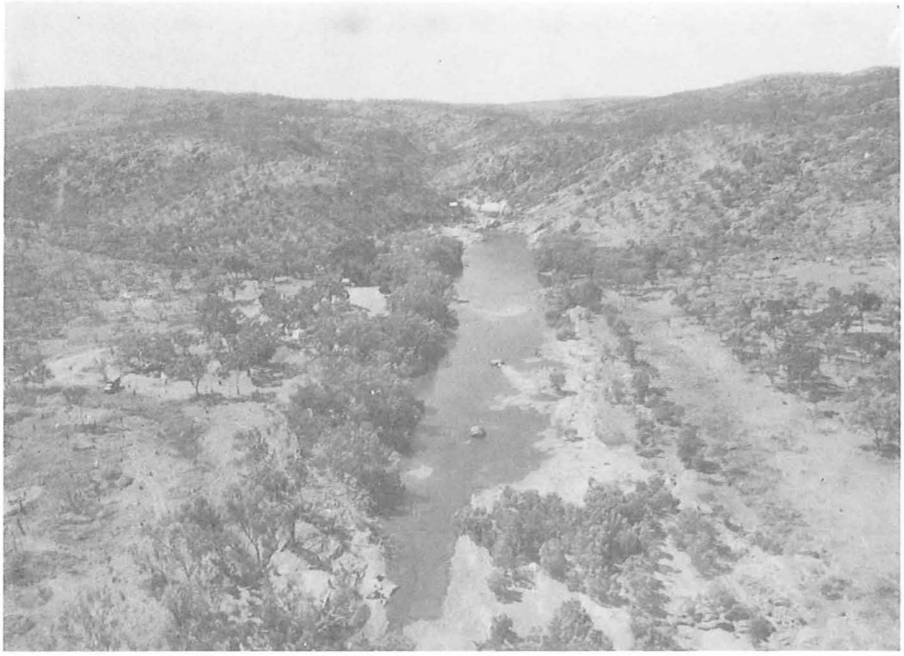


Fig. 67: Newcastle Range Volcanics at Fish Hole on the Robertson River; view upstream(northeast) towards the front of the main range. The low relief area in the foreground is underlain by fluvial epiclastic sedimentary rocks (unit Cns_a). The break in slope in the middle distance which defines the topographic edge of the Newcastle Range is occupied by a high-angle fault separating the sedimentary rocks from ignimbrite (unit Cn_{IIb}) in the background. The bed and lower slopes of the gorge above Fish Hole expose chaotic boulder agglomerate (unit Cn_{Ib}) beneath the ignimbrite; this agglomerate is interpreted as a vent accumulation. The flat top of the Newcastle Range is close to the Mesozoic erosion surface. The 1973 base camp can be seen on the left hand (northwestern) side of Fish Hole. M1510 (J.H.C.B.).

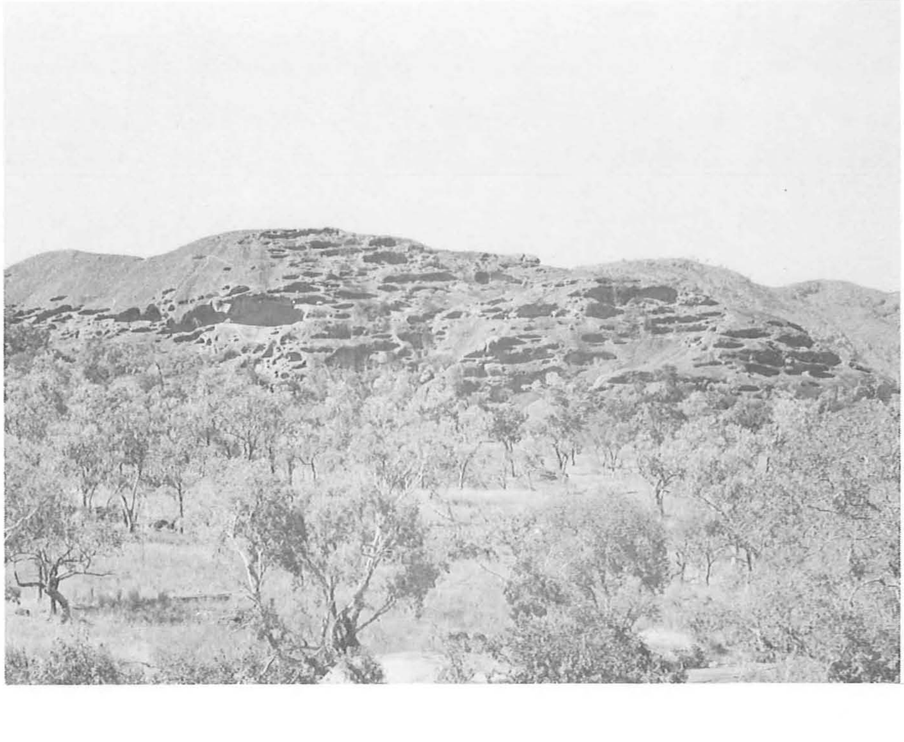


Fig. 68: Hill exposing pebbly and cobbly coarse quartzofeldspathic and lithic sandstone (unit Cns_a) in the lowermost part of the Newcastle Range Volcanics south of Fish Hole (grid ref. 906223). M1510 (J.H.C.B.).

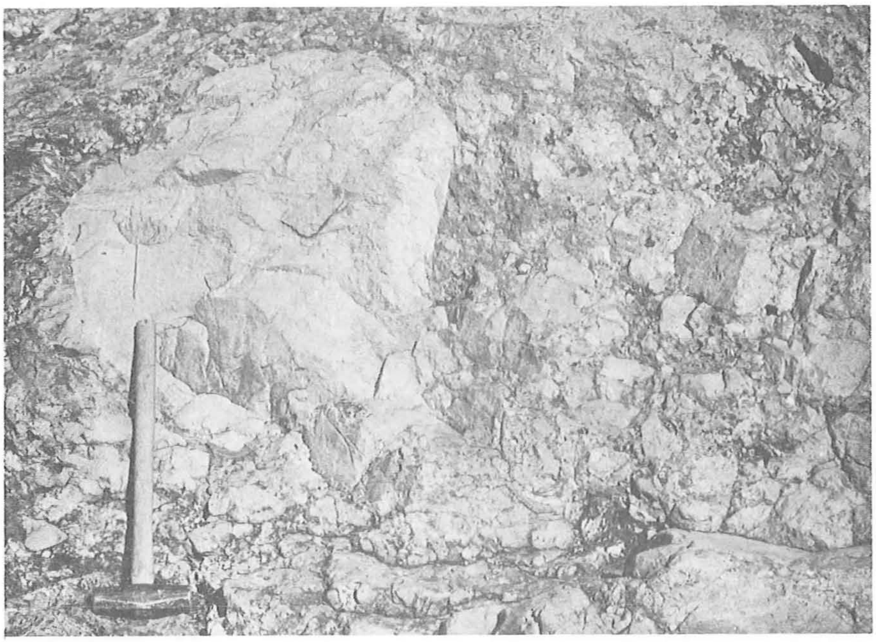


Fig. 69: Boulder agglomerate (subunit Cn_{Ib}) in the gorge of the Robertson River upstream from Fish Hole (grid ref. 885270). The agglomerate is cut locally by tuffisite dykes and probably accumulated in or near a vent area. GA9486 (I.W.W.).

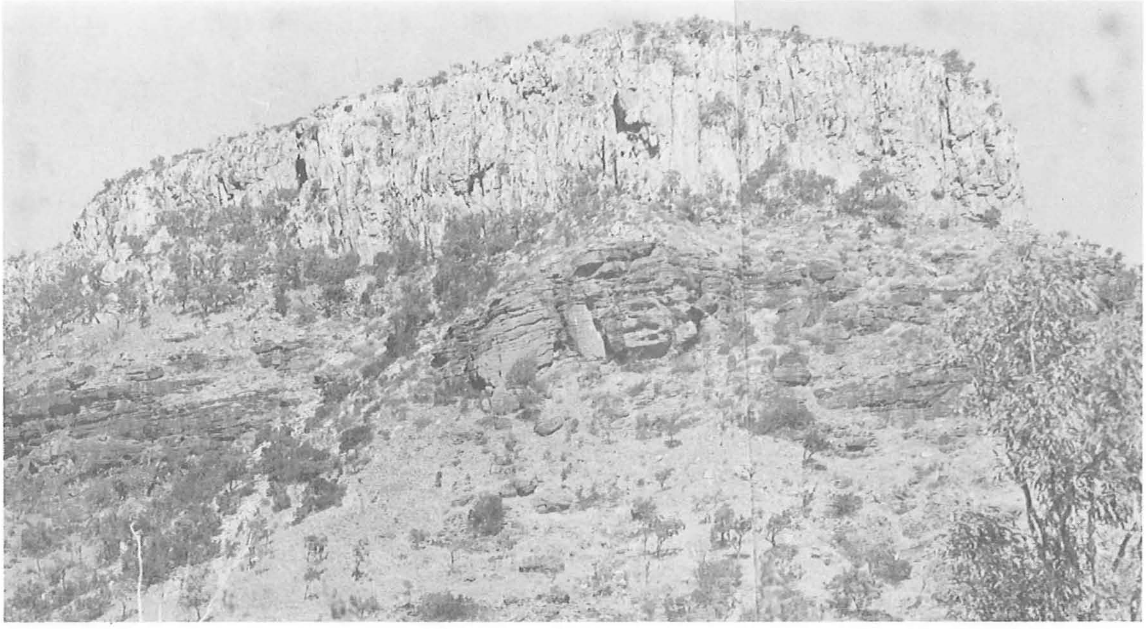


Fig. 70: Cliff-forming ignimbrite of subunit Cn_{IIb}, Newcastle Range Volcanics, main range sequence. The ignimbrite overlies fluviatile clastic sedimentary rocks (unit Cns), exposed in the dark cliff and benches. View west from grid ref. 898220. M1510 (J.H.C.B.).

Volcanics of the Forsayth Sheet area. Six subunits (a to f) are differentiated on a basis of gross lithology; some of these subunits are stratigraphically superimposed, others are laterally equivalent. The maximum thickness of unit Cn_{II} is estimated to be about 150-200 m.

Subunit Cn_{IIa} contains grey to green rhyolitic ignimbrite with 40 percent phenocrysts 2 to 4 mm across. It crops out only in the Chinaman Creek area where it overlies unit Cn_{I} and apparently interfingers with, and is overlain by, subunit Cn_{IIb}.

Subunit Cn_{IIb} consists of buff to purple rhyolitic ignimbrite; phenocrysts about 2 mm across form 25 percent of the rock. The subunit crops out throughout the upper Robertson River area, and commonly forms a conspicuous cliff (Fig. 70). On the western side of the Newcastle Range it lies on clastic sedimentary rocks of unit Cns (Fig. 70), except west of Beverly Hills homestead where it overlies airfall tuff (Cn_{Ia}), and in the Robertson River gorge near Fish Hole where it overlies agglomerate (Cn_{Ib}) (Fig. 67). On the eastern side of the range it interfingers with and overlies Cn_{IIa} as noted above.

Subunit Cn_{IIc} is probably a grey variety of Cn_{IIb}; it occurs on the eastern side of the main Newcastle Range near the Forsayth-Einasleigh road.

Subunit Cn_{IId} is a buff to purple rhyolitic ignimbrite containing 25 percent phenocrysts about 4 mm across. It lies either on basement rocks, or on clastic sedimentary rocks (Cns); its stratigraphic position is thus the same as that of Cn_{IIb}, to which it is probably laterally equivalent. Subunit Cn_{IId} is more widespread in the Georgetown 1:100 000 Sheet area than in the Forsayth Sheet area.

Subunit Cn_{IIe}, which consists of buff rhyolitic ignimbrite with 20 percent phenocrysts about 4 mm across, overlies subunit Cn_{IIb} and crops out over a fairly wide area in the upper Robertson River. Lenses of volcaniclastic siltstone and sandstone (Cns_{b}) occur at the contact between the two subunits.

IIe ?

Subunit Cn_{IIf} is lithologically similar to Cn_{IIb} but overlies subunit Cn_{IIf}. Sporadic lenses of volcaniclastic sedimentary rocks (Cns_{b}) occur within the subunit.

Rocks stratigraphically higher in the main Newcastle Range sequence than those of unit Cn_{II} do not occur in the Forsayth Sheet area; they crop out extensively in the Georgetown and Galloway 1:100 000 Sheet areas to the north.

(b) Eastern range sequence

The Newcastle Range Volcanics in the eastern part of the Newcastle Range (which mostly lies in the Georgetown and Mount Surprise 1:100 000 Sheet areas) have been divided into six units, designated Cn_1 to Cn_6 to distinguish them from units in the main range sequence. Most of the eastern range sequence cannot be correlated with that in the main range, although unit Cn_6 is tentatively recognized in the main range in the Forsayth Sheet area, where it overlies Cn_{II} unconformably.

(i) Unit Cn_4. This unit, which consists of buff rhyolitic ignimbrite containing 40 percent corroded beta-quartz and feldspar phenocrysts about 4 mm across, crops out in the northeastern Forsayth Sheet area. It is better developed in the adjacent Georgetown and Mount Surprise Sheet areas, where it has a maximum estimated thickness of about 1000 m.

(ii) Unit Cn_6? (subunits Cn_{6a}?, Cn_{6b}?). Rocks tentatively assigned to this unit overlie those of subunits Cn_{IIe} and Cn_{IIf} with apparent unconformity in the upper reaches of the Robertson River.

The lower subunit, Cn_{6a}, consists of buff to purple rhyolitic ignimbrite containing 50 percent corroded beta-quartz, feldspar, and rare hornblende phenocrysts, all about 4 mm across.

Subunit Cn_{6a} apparently grades upwards with increase in phenocryst content into buff to grey porphyritic rhyolite of subunit Cn_{6b} which contains 70 percent corroded beta-quartz, feldspar, and hornblende phenocrysts about 4 mm across. Rocks of subunit Cn_{6b} do not have a eutaxitic texture, and no pseudomorphs of glass shards or pumice have been seen in the groundmass. In view of the fact that they probably grade down into ignimbrites of subunit Cn_{6a}, however, they are assumed to be ignimbrites also.

Source of volcanic rocks

The only possible major vent area associated with the Newcastle Range Volcanics of the Forsayth Sheet area is that occupied by the coarse chaotic boulder agglomerate (Cn_{Ib}) in the Robertson River gorge upstream from Fish Hole. Tuffisite dykes cut the agglomerate locally, and some of them extend into the overlying ignimbrite (Cn_{IIb}), suggesting that gas streaming continued after accumulation of the agglomerate.

Rhyolite and microgranite in dykes and intrusive bodies in and near the main Newcastle Range do not have fragmental textures; consequently it is unknown whether they represent volcanic feeders or not. Certainly, the intrusive microgranite in the range (Map) occupies large magma chambers whose contents might have been extruded as ignimbrites at some period of time.

Age

The Newcastle Range Volcanics are unconformable on, or faulted against, middle? Proterozoic granitic and metamorphic rocks; they are overlain unconformably by Mesozoic and Cainozoic rocks.

Isotopic data by Richards et al. (1966) did not yield an unambiguous age for the Newcastle Range Volcanics; of the two ages obtained, about 377 and 333 million years, the former (Early Devonian) was believed the more likely. Additional data (Black, 1973) produced a total-rock Rb/Sr isochron age of 318 ± 5 m.y., i.e. close to the Early/Late Carboniferous boundary and here designated mid-Carboniferous. A recent reappraisal of the data (Black, 1974) indicates that the samples from the main and eastern range sequences are isotopically distinct, although they do not give statistically different ages. Additional samples from both parts of the range are being processed.

A plant stem from subunit Cns$_b$ near Fish Hole (grid ref. 878267) has been tentatively identified as *Lepidodendropsis*, possibly of Tournaisian (Early Carboniferous) age (N. Morris, pers. comm.).

Alteration and mineralization

Groundmass and phenocryst feldspars in the Newcastle Range Volcanics ignimbrites are almost invariably kaolinized and sericitized, and commonly ironstained. Locally intense alteration of this kind has produced white to pink rocks which consist of little else but quartz and kaolinite. Presumably alteration of the rocks was brought about in the first place by hydration and devitrification of originally glassy components and inversion of high-temperature feldspars to low-temperature types. Areas of intense alteration may have been produced by locally abnormal concentration and migration of fluids within and through the volcanic pile.

Mineralization is rare in the Newcastle Range Volcanics of the Forsayth Sheet area. Chemically the rocks do not contain abnormal concentrations of metallic elements in comparison with other calcalkaline suites; they may be depleted in uranium, as noted above (p. 163) (Sheraton & Labonne, in press). Minor fluorite occurs in epiclastic sedimentary rocks and limestone near Fish Hole (grid ref. 877262).

Agate Creek Volcanics

Introduction

The Agate Creek Volcanics, of Permian age, contain mainly andesitic, trachyandesitic, and basaltic lavas, rhyolitic ignimbrite? and agglomerate, and locally developed sedimentary rocks. The unit was named from Agate Creek (White, 1959a), and crops out mainly in the Gilberton 1:100 000 Sheet area, which was mapped in 1975.

In the Forsayth Sheet area the Agate Creek Volcanics crop out in several small areas in the southwest. These areas are on the northeastern edge of the main occurrence of the unit, and basic extrusive rocks are less well developed than to the south in the Gilberton Sheet area. The stratigraphy of the Agate Creek Volcanics in the Forsayth Sheet area is basically the same as that farther south, however.

Units described below are informal; they will eventually be formally defined and described as formations, thus raising the Agate Creek Volcanics to the status of a group.

Map units and stratigraphy

The lowermost subunit of the Agate Creek Volcanics in the Forsayth Sheet area, Pas, consists of probably fluviatile conglomerate and sandstone containing clastic material from subjacent granitic and metamorphic rocks. Breccia in Dry Pocket, 1 km west of Bald Mountain (grid ref. 655125), is tentatively assigned to the subunit. The breccia, which contains angular clasts of schist (Robertson River Metamorphics) and may represent a talus deposit, is probably no more than about 50 m thick.

An unknown thickness of undivided rhyolitic volcanic rocks, mainly ignimbrite? and agglomerate, assigned to subunit Pa, overlies Pas or lies unconformably on basement rocks.

An aphyric basaltic lava about 10 m thick (Pab) is locally interbedded with rhyolites low in the Pa sequence.

Age

The Agate Creek Volcanics in the Forsayth Sheet area lie unconformably on middle? Proterozoic Robertson River Metamorphics and Siluro-Devonian Robin Hood Granodiorite; they are overlain unconformably by Mesozoic rocks.

Fossil plants from the unit in the Gilberton 1:100 000 Sheet area are probably of Early Permian age (White, 1965; Branch, 1966). No fossils have been found in the Forsayth Sheet area.

Alteration and mineralization

Rhyolitic rocks in the Agate Creek Volcanics have kaolinized, sericitized, and ironstained feldspars like those in the Newcastle Range Volcanics (p. 171); the alteration presumably originated in the same way. No mineralization occurs in the Agate Creek Volcanics.

UPPER PALAEOZOIC HYPABYSSAL ROCKS

Introduction

Dykes and intrusive masses of rhyolite, microgranite, dolerite, and quartz-diorite occur throughout the Forsayth 1:100 000 Sheet area, those of rhyolite being the most common. These hypabyssal rocks are most abundant in and near the Newcastle Range and the areas of Agate Creek Volcanics; this, and their composition and mineralogy, suggest that they are genetically related to the volcanic rocks of these areas.

Rhyolite

Aphyric to porphyritic rhyolite (rh) is the most common of the hypabyssal rock types; it is similar in composition to the rhyolitic ignimbrites in the Newcastle Range and Agate Creek Volcanics. Phenocrysts, when present, are corroded anhedral beta-quartz and subhedral alkali feldspars (including rare anorthoclase) and plagioclase (oligoclase-andesine) up to 4 mm across. The rhyolite is commonly flow-banded, and some intrusions have columnar joints developed perpendicular to their margins (Fig. 71).

Microgranite

Microgranite intrusions are common in the sheet area; four main lithological varieties are recognized, all having a granular quartzofeldspathic groundmass. The most common type, mg_1, is probably compositionally close to the rhyolites described above; it is commonly pink or red, less commonly grey, and contains about 25 percent phenocrysts consisting of corroded anhedral beta-quartz, subhedral to euhedral feldspars and sporadic minor (less than one percent) subhedral hornblende. The hornblende phenocrysts are up to 1 cm long and commonly partly or wholly chloritized.

A probable variant of this microgranite, designated mg_2, has only about 3 percent quartz and feldspar phenocrysts.

Microgranite containing 25 percent phenocrysts of subhedral to euhedral feldspar and sporadic minor anhedral beta-quartz and chloritized subhedral hornblende is assigned to mg_3.

The fourth microgranite type, mg_4, occurs only in the upper reaches of the Robertson River (grid square 0332). This type contains 50 percent subhedral to euhedral feldspar and subsidiary, mainly chloritized, hornblende phenocrysts 1.5 mm long, and less than one percent euhedral feldspar phenocrysts about 1 cm long.

Age relations among most of the various hypabyssal rocks, and between them and associated volcanic rocks, are variable; evidently the different intrusive types were introduced repetitively throughout Late Palaeozoic time. Microgranite mg_4 might either intrude or be intruded by an adjacent body of mg_1. Xenoliths of the latter microgranite occur in unit Cn_6 of the Newcastle Range Volcanics suggesting that the unit is younger than at least that one body of mg_1.

Dolerite, quartz-diorite, and andesite

Intrusions of aphyric dolerite (do), quartz-diorite (di), and andesite (ad) are relatively uncommon in the Forsayth Sheet area; they are cut locally by intrusive rhyolites, suggesting that they are relatively early like their extrusive equivalents (andesite and basalt) in the Newcastle Range and Agate Creek Volcanics.

Dolerite dykes near Frasers Well (grid ref. 953019) and Carpentaria Gully, close to the southern edge of the sheet area, contain quite fresh rocks. The dolerites contain about 50 percent randomly oriented plagioclase laths normally zoned from oligoclase to labradorite, 35 to 45 percent intergranular to subophitic augite, some of which has olivine cores and rims of secondary hornblende, and about 5 percent opaques. Minor graphic intergrowths of quartz and alkali feldspar form a mesostasis. The average grainsize ranges from less than 0.5 mm to about 1 mm.

Quartz-diorite occurs in dykes and small bosses along the Delaney Fault, about 12 km west of the Newcastle Range (Map). The rock contains up to 10 percent quartz, which is interstitial to plagioclase and is locally intergrown with microperthitic alkali feldspar, and up to 50 percent augite-cored uralite aggregates rimmed by hornblende. Opaque minerals, mainly skeletal ilmenite rimmed by sphene or leucoxene, make

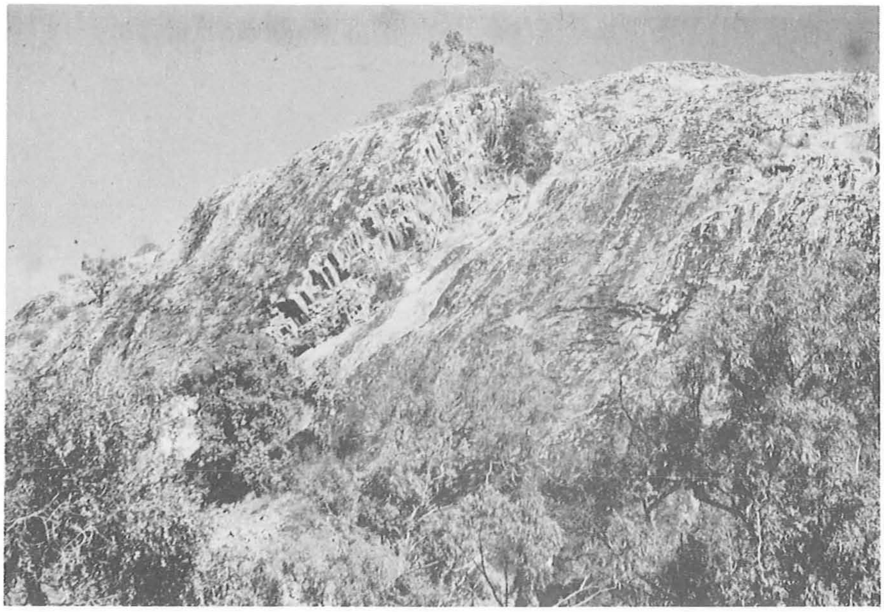


Fig. 71: Columnar rhyolite (rh) marginal to a small boss (1 km^2) 5 km southwest of Fish Hole (GR 842237). GA 9444 (I.W.W.)

up from 5 to 10 percent of the rocks. The average grainsize is between 0.5 and 1.5 mm.

Mineralization

Part of a small rhyolite dyke on the south side of the Forsayth-Robin Hood road (grid ref. 791178) contains veins and patches of fluorite. The area of mineralization has been taken up as a Mining Lease (Robertson no. 3) and tested by costeans; it is too small to have any economic significance.

STRUCTURE OF THE UPPER PALAEOZOIC ROCKS

Dips in the Newcastle Range Volcanics of the main range in the Forsayth 1:100 000 Sheet area are commonly 20 degrees or less, except locally adjacent to marginal faults, where dips are up to 45 degrees. The overall structure of the volcanics at the present level of exposure is that of a shallow basin with concentrically distributed units dipping inwards towards the central area, which is underlain by Cn_6. The structure at depth is unknown; an attempt was made to resolve this by means of detailed gravity traverses during the 1975 field season, but preliminary results suggest that no useful information has been obtained because of a lack of density contrast between the volcanic rocks and basement (D.R. Wilson, pers. comm.).

Major faults marginal to, and within, the Newcastle Range Volcanics are steep, commonly dipping at more than 60 degrees, and are commonly inclined inwards towards the central part of the range. Linear faults commonly strike west-northwest to northwest; this trend is also followed by many joints and lineaments. Other linear faults strike north to north-northeast. Curvilinear faults are made up of various combinations of linear fault segments. Rhyolite and microgranite dykes occur locally along many of the faults (see also Delaney Fault below).

Displacements on most faults are not well known; they are probably dip-slip and relatively small (100 m or less). The available data suggest that the rocks, at least in the main Newcastle Range, probably did not accumulate in a major well-defined fault-bounded rift. This is contrary to Branch's (1966) interpretation that the Newcastle Range Volcanics were essentially restricted to a cauldron subsidence area - a marked topographic depression formed by faulting and collapse consequent on withdrawal of magma from a chamber in the crust. If a cauldron subsidence-like area did exist it was probably a wider and more diffuse (both spatially and temporally) structure than that envisaged by Branch.

No useful information on the structure of the Agate Creek Volcanics can be gained from the Forsayth sheet area. Preliminary interpretation of the 1975 data from the Gilberton sheet area suggests that the unit accumulated in a topographic basin which was probably not fault-controlled, except perhaps locally.

Delaney Fault

The Delaney Fault is a large north-south fracture which has been traced from near 'Old Robin Hood' for almost 100 km. Although in many places it is represented by a Shear zone up to 500 m wide there is little observable displacement; most movement was probably vertical. The Delaney Fault is unmineralized although near Forsayth, adjacent east and east-southeast trending shears contain auriferous quartz reefs. This suggests that is is a relatively young structure, perhaps formed during late Palaeozoic time in association with the Newcastle Range's bounding faults, to which it is parallel and of comparable length. As a prominent photo-lineament, the fault stops at the edge of the Robin Hood Granodiorite, but a rhyolite dyke cutting the granodiorite 3 km south of 'Old Robin Hood' is in line with the projected continuation of the fault, indicating that the Delaney Fault probably continues south into the Robin Hood Granodiorite. Rhyolite dykes (Fig. 72) and small intrusions of quartz-diorite occur along the Delaney Fault. The quartz-diorite is much weathered and iron-stained and accounts for the brown photo-pattern characteristic of the fault in many places.

MESOZOIC SEDIMENTARY ROCKS

Remnants of thin but previously extensive Mesozoic quartzose marine and terrestrial sedimentary rocks cover parts of the Newcastle Range, the Ropewalk Range, and the country in the southwest corner of the sheet area, commonly forming mesas. These Mesozoic outliers consist of Middle? to Upper Jurassic Eulo Queen Group (quartzose sandstone, siltstone, and minor shale and conglomerate), Upper Jurassic to Lower Cretaceous Gilbert River Formation (quartzose sandstone, with minor conglomerate, siltstone and shale), and possibly, near the head of the Percy River, some Lower Cretaceous Wallumbilla Formation (mudstone and sandstone). These units have been described by Needham (1971). On the Forsayth 1:100 000 Preliminary edition map the various Mesozoic units have been grouped together as undivided Mesozoic, as they were not examined in sufficient detail to permit subdivision.

Fig. 72: Rhyolite (rh) dyke injected into part of the Delaney Fault 10 km south-southwest of Forsayth (GR 708330). The slope between the vehicle and foot of the dyke is underlain by grey microgranite (mg_1) probably injected earlier along the same line. GA 9442 (I.W.W.).

POST-PALAEOZOIC FAULTING

A set of downfaulted blocks of Mesozoic sandstone (the Jurassic Hampstead Sandstone of Smart et al., 1971) occurs west of Cave Creek in the southwest of the Forsayth Sheet area. Basement rocks form topographically higher country than the downfaulted sandstone (Fig. 68). Dragging against the faults produced dips of up to 10° in the normally flat-lying sandstone.

This faulting is at the southern end of a structural feature named the Robertson Structure by Needham (1971), identified on the basis of structural contours. The greatest movement along this structure was in the region of Agate and Cave Creeks. This region coincides with the intersection of the Robertson Structure with lineaments and faults which are continuations of the Cork Fault and Wetherby Structure of the Eromanga Basin (Doutch, 1973).

Doutch et al. (1970) and Needham (1971) suggested that most movement on the Robertson Structure occurred in Pliocene times.

CAINOZOIC SEDIMENTS

The Cainozoic sediments are mapped as three units following Needham (1971). They are Czs, mainly quartzose sand and gravel (soil and colluvium), Qa, sand and silt (inactive floodplain alluvium), and Qh, sand (active stream bed alluvium). Only the larger deposits are shown.

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FORSAYTH

QUEENSLAND

AUSTRALIA 1:100 000 GEOLOGICAL SERIES

SHEET 7660

Geological boundary

Fault (D,U indicate relative movement down, up)

Where location of boundaries, folds and faults is approximate line is broken; where inferred, queried; where concealed, boundaries and folds are dotted, faults are shown by short dashes

Shear zone

50 Plunge of crest of minor fold

20 Strike and dip of strata, facing known or inferred

Strike and dip of strata, facing known or inferred, dip unmeasured

75 Strike and dip of strata, facing not known

Strike and dip of strata, facing not known, dip unmeasured

Vertical strata, facing not known

Dip < 5°
Dip 5°–15°
Dip 15°–45°
Dip > 45°
Horizontal strata
Vertical strata
Trend line
Joint pattern
Lineament (includes minor faults in Newcastle Range)
} airphoto interpretation

80 Strike and dip of joints

Vertical joints

60 Strike and dip of foliation

Strike and dip of foliation, unmeasured

70 Strike and dip of second generation folding

Horizontal foliation

Vertical foliation

60 Strike and dip of cleavage

Vertical cleavage

50 Direction and plunge of undivided lineation

50 Direction and plunge of mineral elongation

50 Direction and plunge of crenulation

Horizontal lineation (crenulation)

65 Dyke (dip indicated where known) unless stated otherwise all dykes are pegmatite
a–amphibolite, ad–andesite, di–diorite, do–dolerite
mg–microgranite, q–quartz, rh–rhyolite

Quartzite (Pmr_2) bed

PD Percussion drill hole

2 Location of isotopically dated sample; numbers refer to list of isotopic ages

9 Abandoned mine

10 Abandoned prospect or mine with little production

31 Abandoned alluvial workings

Mill and treatment plant

Site of former battery or mill, ± treatment plant

Bore with windpump

Well with windpump

W Well

Windpump

E Earth tank or dam

Dam on stream

Spring

Erosion surface

Road

Vehicle track

Railway with station

Robin Hood Homestead

Building

Yd Yard

Fence

. 685 Elevation in metres

abd Abandoned

p.a. Position approximate

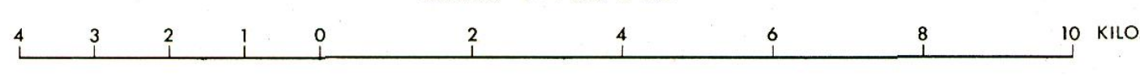
ISOTOPIC AGES⁺

Locality	Unit	Age(x10⁶yr)	Source*
1	Pmf	1490 700	M B
2	Pmf	390 594	b B
3	Pme	415 430 1727 723	b m M B
4	Pmr	1436 1423 1451	M B m
5	Pmr₁	1500 1500	M T
6	Pmd	1120	m
7	SDr	380 426	b M
8	SDr	420 405	B b

* b – biotite K–Ar
m – muscovite K–Ar
b – biotite $Ar^{40}–Ar^{39}$
m – muscovite $Ar^{40}–Ar^{39}$
B – biotite Rb–Sr
M – muscovite Rb–Sr
T – total rock Rb–Sr

\+ Data from Richards et.al., 1966 (BMR Bull. 88); Black, 1973 (BMR Record 1973/50); Black (pers. comm., 1975); D.C. Green (pers comm, 1975). Ages are preliminary only, and subject to amendment and refinement

Scale 1: 100 000



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ESMERALDA 7460	NORTH HEAD 7560	FORSAYTH 7660	EINASLEIGH 7760	CONJUBOY 7860	VALLEY OF LAGOONS 7960
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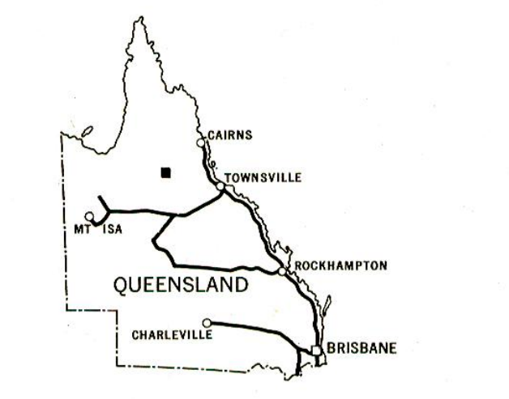
GEORGETOWN
EINASLEIGH
GILBERTON
CLARKE RIVER
18°00'
19°00'
20°00'
142°30'
144°00'
145°30'



MINERAL OCCURRENCE AND PRODUCTION OF METALS

	MINOR OCCURRENCE, NO PRODUCTION OR PRODUCTION UNKNOWN	OCCURRENCE WITH PRODUCTION. AMOUNT OF RECORDED OR INFERRED PRODUCTION SHOWN BY SIZE OF SYMBOL			
GOLD – SILVER	▨	▨ < 30 kg	▨ 30–300 kg	▨ 300–1000 kg	▨ > 1000 kg
SILVER	▨	▨ < 30 kg	▨ 30 – 300 kg	▨ 300 – 1000 kg	
LEAD	●	● < 200 tonnes	● 200–400 tonnes		
COPPER	▲	▲ < 50 tonnes	▲ 50 – 100 tonnes		
TIN		▲ < 10 tonnes			
URANIUM	Ⓤ				
FLUORITE	Ⓕ				

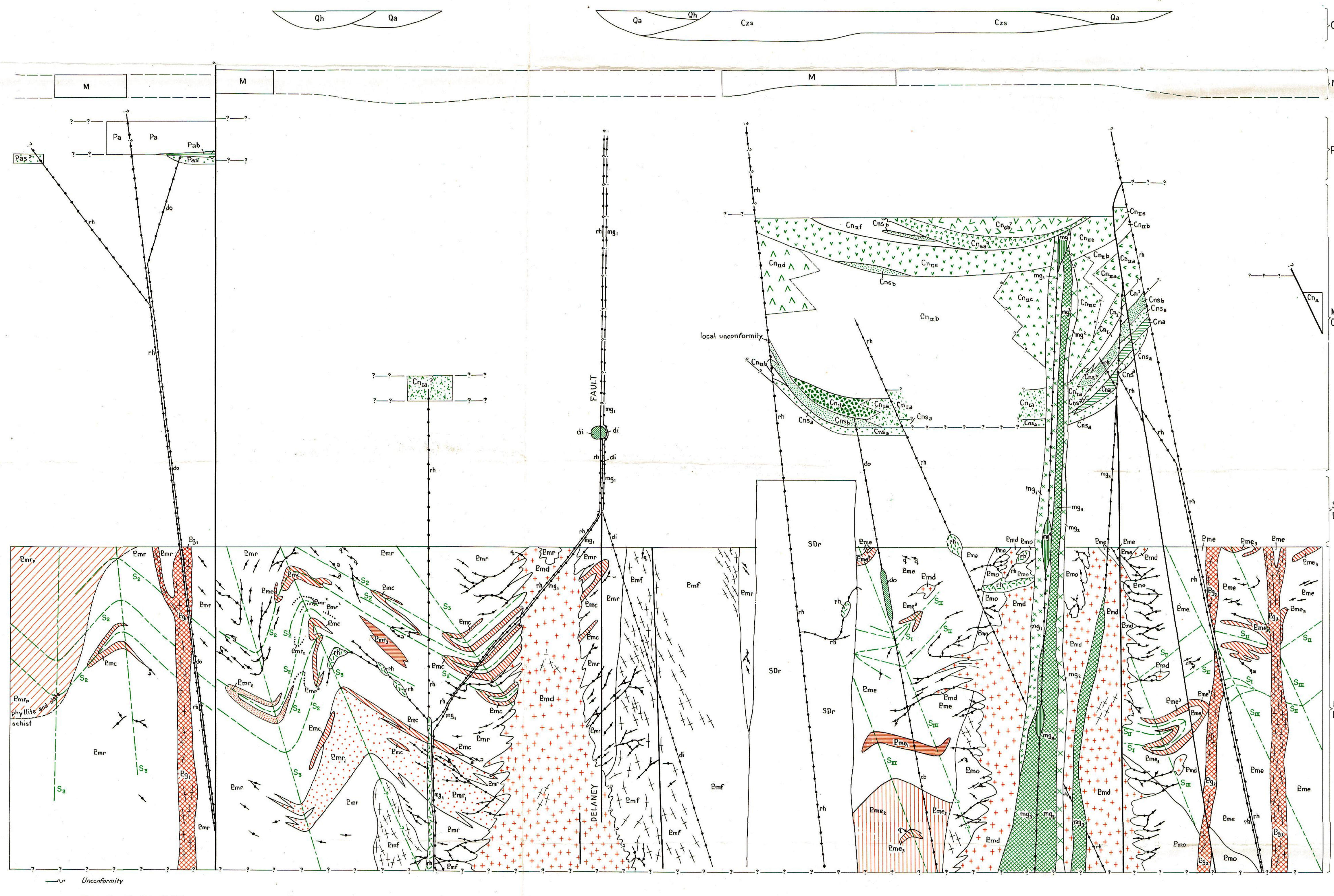
KNOWN OR ESTIMATED PROPORTIONS OF GOLD (BROWN) AND SILVER (GREEN) INDICATED

Note : Symbols are over locality or associated with appropriate mine or prospect

MINES AND PROSPECTS

1 (p.a) Wet Leader
2 (p.a) Stockholm Comet
3 Eureka
4 (p.a) Commune
5 Dry Hash
6 (p.a) Stockman Central
7 (p.a) Enigma
8 Desert Rose
9 Locos
10 By Chance
11
12 Edinburgh
13 (p.a.) Coolibah?
14 Marquis
15
16
17 Little Queenslander
18 Queenslander – Shamrock
19 Trafalgar
20 (p.a) Rusty Knoll
21 Nil Desperandum – Fox's
22
23 (p.a.) Cora
24 (p.a.) Loch
25 (p.a.)
26 (p.a.) Dell's
27 Meteor
28 Mountaineer – Melba
29 Struggle – Pinnacles
30
31
32 (p.a.)
33 (p.a.)
34
35
36 (p.a.) Saturn
37 (p.a) Bookall
38 (p.a) Valentine
39 (p.a) Forget-me-not
40 (p.a) Settler
41 Havelock – Last Hope
42 Dreadnaught
43 Mount Misery
44 (p.a) Tartan
45 (p.a) City of Carlisle
46 Pig's Eye
47 Crows Nest
48 (p.a.) Leo
49 Monte Christo
50
51 (p.a.) Grand Flaneur
52 Mount Jack Group
53
54 (p.a.) Federation
55
56 Republic
57 Balmoral
58 (p.a.) Ironbark
59 Tunnel
60
61 Big Reef
62 Victory
63
64 (p.a) Lucky Hit
65
66
67
68
69 Two Micks
70 Goldsmiths Creek
71 (p.a.) Tweedside
72 (p.a.) Clydesdale
73
74 (p.a.) Eugene
75 (p.a.) Flemings
76 (p.a.) Sunburst
77 (p.a.) Milky Way
78 (p.a.) Black Jack
79 Canadian
80
81 Caledonia (Goldsmiths)
82 All Nations
83 Lady Franklin
84 Ropewalk
85 Just in time
86
87 Comet
88 Tin Mine Gully
89 Robertson 3
90 Bridle Track
91 Black Blow
92 Jubilee Plunger – Lady Mary
93
94 Great Eastern
95 Moonbeam (Lucky Strike)
96 Cindy Lou
97 (p.a.) The Diggings
98 (p.a.) Thorns Find
99
100 Perseverence
101
102 Union – Walker's – Cranky Dick's
103
104
105
106
107 Limkin's
108
109 Bernadette
110
111

(p.a.) position approximate



Unconformity

Trace of axial plane of fold
S_2, S_3 – Second and third generation axial planes in Robertson River Metamorphics;
S_I, S_{II}, S_{III} – First, second and third generation axial planes in Einasleigh Metamorphics
} Relationships between structures in different units (Robertson River Metamorphics, Einasleigh Metamorphics, Forsayth Granite and Oak River Granodiorite are not known, e.g. S_2 is not necessarily the same as S_{II}

Foliated granite

Other symbols as in key above

SPATIAL, TEMPORAL AND STRUCTURAL RELATIONSHIPS
OF ROCK UNITS SHOWN SCHEMATICALLY (Not to scale)

CAINOZOIC
- Qh Holocene, mainly sand; active alluvium
- Qa Quaternary, mainly sand and silt; mainly inactive alluvium
- Czs Soil and colluvium

MESOZOIC M Mainly quartz sandstone and conglomerate

PERMIAN Agate Creek Volcanics
- Pa Undivided, mainly rhyolite breccia and agglomerate and rhyolitic ignimbrite?
- Pab Aphyric basaltic lava
- Pas Epiclastic sedimentary rocks; conglomerate and sandstone with clasts of subjacent rocks; probably fluviatile. Local talus? breccia

MID-CARBONIFEROUS Newcastle Range Volcanics¹
- Cn_{6b}? Buff to grey rhyolitic ignimbrite, 70% phenocrysts (β-quartz, feldspar, subsidiary hornblende) 4 mm across
- Cn_{6a}? Buff to purple rhyolitic ignimbrite 50% phenocrysts (β-quartz, feldspar, rare hornblende) 4 mm across
- Cn_4 Buff rhyolitic ignimbrite, 40% phenocrysts (β-quartz, feldspar) 4 mm across
- Cn_{IIf} Buff to purple rhyolitic ignimbrite, 25% phenocrysts (β-quartz, feldspar) 2 mm across
- Cn_{IIe} Buff rhyolitic ignimbrite, 20% phenocrysts (β-quartz, feldspar) 4 mm across
- Cn_{IId} Buff to purple rhyolitic ignimbrite, 25% phenocrysts (β-quartz, feldspar) 4 mm across
- Cn_{IIc} Grey rhyolitic ignimbrite, 25% phenocrysts (β-quartz, feldspar) 2 mm across
- Cn_{IIb} Buff to purple rhyolitic ignimbrite, 25% phenocrysts (β-quartz, feldspar) 2 mm across
- Cn_{IIa} Grey to green rhyolitic ignimbrite, 40% phenocrysts (β-quartz, feldspar) 2 - 4 mm across
- Cn_{Ib} Agglomerate
- Cn_{Ia} Airfall crystal-lithic-vitric tuff
- Cn_I Buff to purple aphyric rhyolite (lava?), airfall tuff; minor volcaniclastic sediment and agglomerate
- Cna Green aphyric andesitic lava
- Cns_b Volcaniclastic sedimentary rocks; sandstone and siltstone representing reworked airfall tuff; probably fluviatile
- Cns_a Epiclastic sedimentary rocks; conglomerate, sandstone and siltstone with clasts of subjacent rocks and ignimbrites, minor limestone; mainly fluviatile, locally lacustrine

CARBONIFEROUS-PERMIAN
- rh Intrusive aphyric to porphyritic rhyolite
- mg_4 Porphyritic microgranite, 50% phenocrysts (feldspar, subsidiary hornblende) 1·5 mm across, <1% phenocrysts (feldspar) 1 cm across
- mg_3 Porphyritic microgranite, 25% phenocrysts (feldspar, rare β-quartz, sporadic minor hornblende) 1 cm across
- mg_2 Porphyritic microgranite, 3% phenocrysts (β-quartz, feldspar) 1 cm across
- mg_1 Porphyritic microgranite, 25% phenocrysts (β-quartz, feldspar, sporadic rare hornblende) 1 cm across
- di Aphyric diorite
- do Intrusive aphyric dolerite, commonly uralitized
- ad Intrusive aphyric andesite

SILURIAN–DEVONIAN? Robin Hood granodiorite² SDr Pink to grey hornblende-biotite granodiorite with quartz phenocrysts

MIDDLE ? PROTEROZOIC
- Cobbold metadolerite² Pmc Metadolerite and amphibolite (a–amphibolite)
- Robertson River Metamorphics¹
  - Pmr_p Phyllite, slate
  - Pmr_3 Banded calc-granofels
  - Pmr_2 White and dark grey quartzite
  - Pmr_1 Quartzite ± calc-silicate minerals, mica schist
  - Pmr Mica schist ± garnet-staurolite, andalusite, sillimanite: graphitic schist, quartzite; minor calc-silicate-bearing rocks
- Einasleigh Metamorphics
  - Pme_3 Amphibolite (a–amphibolite dykes)
  - Pme_2 Porphyroblastic granite-gneiss, migmatite
  - Pme_1 Banded calc-granofels, commonly with diopside and hornblende
  - Pme Gneiss, schist, quartzite, banded calc-granofels, migmatite, amphibolite, granitoid and pegmatite veins

PROTEROZOIC
- Pg_1 Dark pink foliated medium-grained biotite granite
- Pg_2 Pale grey to pink foliated medium-grained biotite granite, locally porphyritic

- Digger Creek granite³ Pmd White, grey and pink aplitic to pegmatitic muscovite leucogranite with sporadic biotite and garnet; locally foliated. Most pegmatites probably related to this granite
- Forsayth Granite¹ Pmf Grey, locally pink leucocratic to melanocratic biotite granite ± minor muscovite (partly secondary), equigranular to porphyritic (feldspar megacrysts 2-7 cm long), commonly foliated; minor biotite microtonalite, pegmatite and aplite
- Oak River granodiorite³ Pmo Grey medium-grained granodiorite with pink potassium feldspar megacrysts (porphyroblasts?) 1-2 cm long, locally foliated; subordinate grey foliated hornblende biotite tonalite with quartz and white feldspar megacrysts

q : quartz, genetic affiliation/s unknown

1 Previously published name, unit to be redefined
2 Variation of published name
3 New name, unit to be defined
} Registered with Stratigraphic Nomenclature committee, not published

Other names published and defined by previous workers
Nomenclature of plutonic rocks follows current I.U.G.S. recommendations (N. Jb. Miner Mh, H4, 149-164)
Nomenclature of other igneous rocks is consistent with these recommendations

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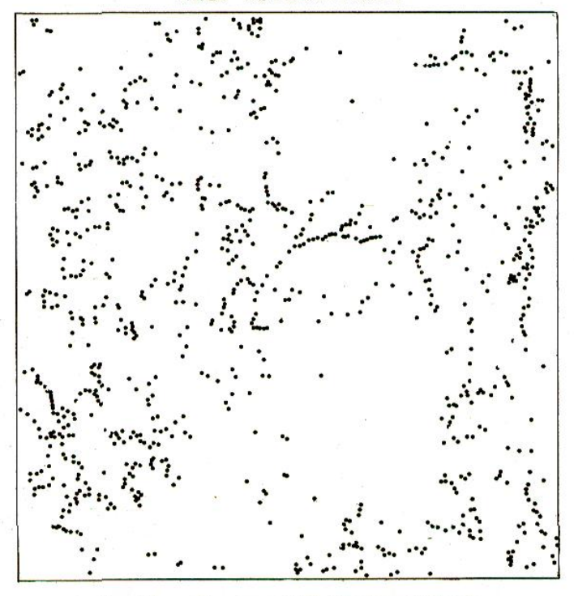
Base map compiled by the Royal Australian Survey Corps from aerial photography at 1: 80,000 scale

Geology 1972–1974 by J.H.C. Bain, B.S. Oversby (BMR)
I.W. Withnall (GSQ)
Compiled 1973 by J.H.C. Bain, I.W. Withnall, D.M. Pillinger
1974–1975 by J.H.C. Bain, B.S. Oversby, I.W. Withnall, P.L. Blythe
Cartography by Geological Branch, BMR
Drawn by P.L. Blythe

Initial geological airphoto interpretation, mapping and field compilation based on 1:25 000 (approx) scale colour airphotographs taken May 1972, with local supplementary airphoto interpretation based on 1:80000 (approx) scale RC-9 and 1:24 000 (approx) scale Queensland Lands Department black and white airphotographs

FIELD OBSERVATIONS



• Location of recorded field observation/s

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. ⁷64⁰⁰⁰

SAMPLE POINT: • Robin Hood

1. Quote this 1: 100 000 map sheet: 7660
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: 85
3. Estimate tenths from grid line to point: 3
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: 14
5. Estimate tenths from grid line to point: 7

SAMPLE REFERENCE: 7660 853 147

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GRID VALUES ARE SHOWN IN FULL ONLY AT THE SOUTH WEST CORNER OF THE MAP
TRANSVERSE MERCATOR PROJECTION

PRELIMINARY EDITION 1975
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FORSAYTH
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