GSB47

STRUCTURE AND PETROLOGY
OF
THE RAGLAN RANGE

by

R. D. GEE, B.Sc. (Hons.)

Raglan Range, looking westward, with Joyce Creek in left foreground and West Coast Range in background.

PREFACE

This Bulletin is a technical study of a restricted area which will be included eventually in the Map Sheet of the Lyell Quadrangle, K/55-10-58. This area lies to the east of one of the most important mineral districts in the State and, though it is not itself a mineral field, the detailed study of its structure has added greatly to our understanding of the environment and mechanics of mineralization, as well as the Precambrian stratigraphy and tectonic history of Tasmania.

Most of the work of this Bulletin was carried out while the author held a Geological Scholarship of the Department of Mines at the University of Tasmania and was working for the degree of B.Sc. (Hons.). This Bulletin represents a condensation and adaptation of a thesis submitted for that degree.

It is hoped that it may be possible to publish detailed studies of other structurally important areas in the future.

J. G. SYMONS,
Director of Mines.

Department of Mines,
Hobart, March, 1963.

CONTENTS

INDEX OF FIGURES

FIGURE 1.—Locality Map.

STRUCTURE AND PETROLOGY OF THE RAGLAN RANGE

by R. D. GEE

ABSTRACT

The Raglan Range consists dominantly of pelitic schist and quartzite with minor ortho-amphibolite, generally of garnet grade. This is the Franklin Group, which overlies chlorite phyllite and quartzite of the Mary Group. All are Precambrian.

Two Precambrian deformations are recognizable. A bedding schistosity was formed during the first deformation phase. Associated with the first phase is the regional metamorphism producing chlorite, biotite and almandine in a zonal arrangement. Kyanite is also present, but not in sufficient quantities to delineate a zone. The biotite isograd is taken as the upper limit of the Mary Group. The second deformation phase was accompanied by retrograde metamorphism and large scale recumbent folding, during which the metamorphic zones were inverted and the Franklin Group was transported over the Mary Group. The Governor River Phyllite, herein defined, resembles a phyllonite and is a wide zone of dispersed movement related to the second phase of deformation. Quartz, muscovite, chlorite and amphibole recrystallized during the second phase of deformation. Albite of possible metasomatic origin crystallized in the interval between the two phases.

The quartz fabric in a fold in quartzite is homogeneous, irrespective of tectonic position and is not capable of being unrolled, but the mica fabric is unrollable. The two deformations are approximately coaxial, and the microfabric shows monoclinic symmetry with slight tendencies toward triclinic symmetry.

The Precambrian structures show a slight, regional departure from homoaxiality due to a rotation about an axis trending 301° (true) and plunging 24°. This is an expression of the Tabberabberan folding. Approximately coaxial relationships between the Precambrian axes and the Tabberabberan axis permit construction of a tectonic profile of the Raglan Range by axial projection.

Lamprophyre dykes of Tabberabberan age intrude the schist.

8

SKETCH MAP

RAGLAN RANGE–MT. MARY–MT. FINCHAM AREA

0   1   2   D GEE
                          GEOLOGIST

MILES

FINCHAM GP.
FRANKLIN GP.

GOVERNOR R.
PHYLLITE

MARY GROUP

JOYCE GROUP

FIGURE 2.

5 cm
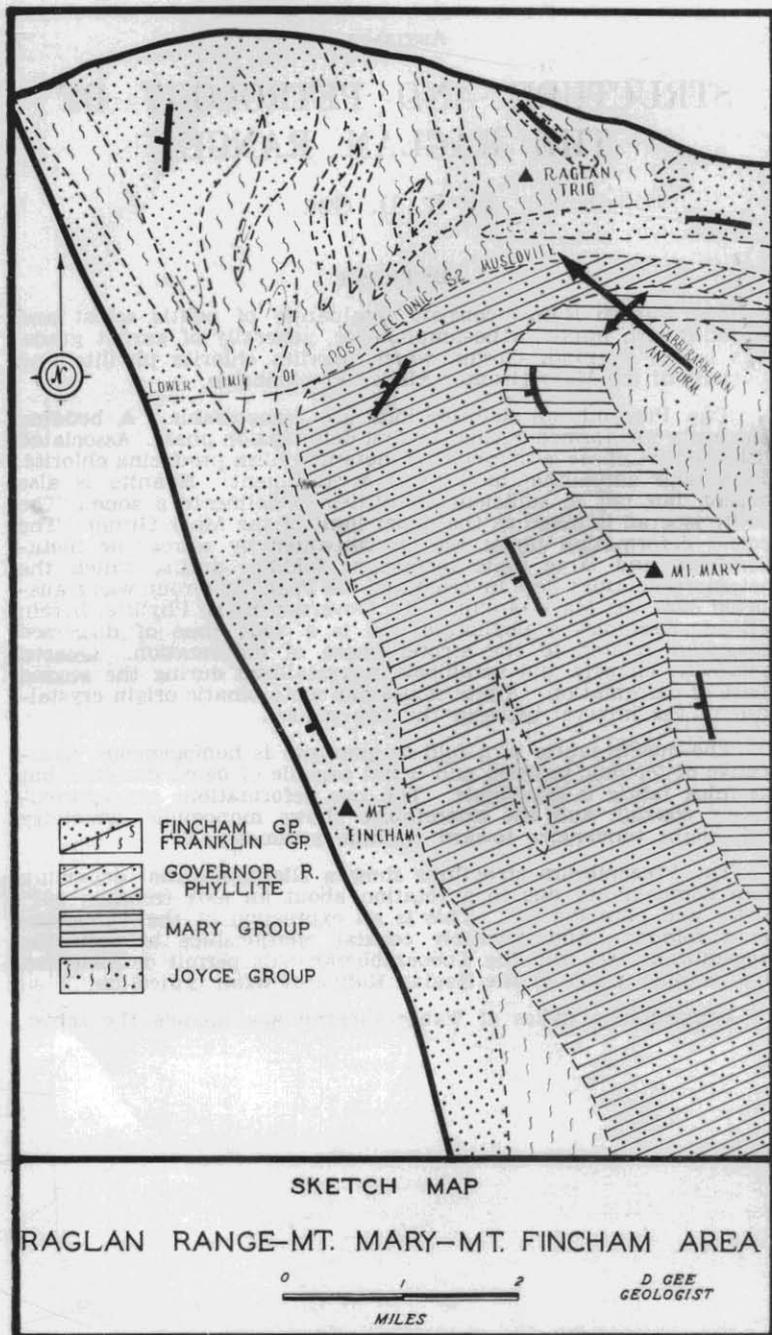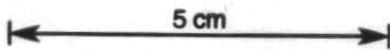
INTRODUCTION

This Bulletin is concerned with the structural petrology of a small portion of the Precambrian basement of central western Tasmania (See Figures 2 and 10). The area, of approximately 27 square miles, is located at the centre of the Lyell Quadrangle and encompasses the Raglan Range, Lat. 42° 8' S, Long. 145° 46' E. Access to the centre of the area is by the timber track which branches south from the Lyell Highway, 14 miles from Queenstown.

No previous work has been done on the Raglan Range, and the little that has been done on the Precambrian rocks in the Frenchmans Cap area is largely of reconnaissance standard. Adjoining areas to the SE and S have been investigated by McLeod (1955) and Spry (1957b).

The area was mapped on a scale of 8 inches : 1 mile but as this Bulletin represents only one year's work, it is by no means a complete study. Two coaxial phases of penetrative deformation in the Precambrian are postulated, mainly on textural studies and microfabric work. Although the mesoscopic evidence is not completely absent, it is somewhat deficient. However, it is hoped that this Bulletin will serve as a useful framework for further studies of a similar nature in the Precambrian rocks of central-western Tasmania.

PRECAMBRIAN STRATIGRAPHY

(See Figure 10)

The present tentative proposal of group stratigraphy in the Precambrian of the Mt Mary-Mt Fincham area is after Spry (1957b).

> Fincham Group: quartzite and phyllite of chlorite grade.
>
> Franklin Group: garnet-mica schists, quartzite, and amphibolite of garnet grade.
>
> Mary Group: quartzite, quartz-muscovite schist and phyllite of chlorite grade.
>
> Joyce Group: garnet-mica schists, quartzite, and amphibolite of garnet grade.

This is strictly a division into metamorphic facies and does not necessarily have any time significance. The term " group " is used for an assemblage of diverse metamorphic rocks having the same metamorphic facies. Consequently, correlations between the Raglan Range and the Mt Mary-Mt Fincham area are made on petrological grounds. It is probable that time-rock units pass from one group to the other, for example the Fincham Quartzite in the Mt Maude area (McLeod, 1955) is structurally continuous with typical quartzite of the Franklin Group at the western edge of the Raglan Range. However, many of the iso-facial correlations can also be made on grounds of structural continuity. The divisions therefore may have some stratigraphic significance.

The tectonic succession of the Raglan Range is:—

(Tectonically higher) Franklin Group: {quartzite and schists (unnamed) Governor River Phyllite

Mary Group: quartzite and schist

Unnamed: biotite-albite phyllite.

The small patch of biotite-albite phyllite, underlying the Mary Group, is mineralogically similar to the Governor River Phyllite, and also similar to the Joyce Group which underlies the Mary Group in the Mt Mary area.

Governor River Phyllite

The lowermost unit of the Franklin Group, the Governor River Phyllite, is here defined as that phyllite lying structurally above the Mary Group, and below the remaining portion of the Franklin Group, occurring on the northern slopes of the Governor River valley, Raglan Range. Both its upper and lower boundaries are gradational, and the thickness varies between 1,000 and 4,000 feet. Rather than a stratigraphic unit, it is a tectonic slice which received its distinctive lithology and fabric when the Franklin Group moved over the Mary Group. It resembles a phyllonite in texture and structural setting. The Governor River Phyllite is similar in lithology and structural position to the Canyon Creek type schist of McLeod (1955) in the Mt Fincham area.

PETROLOGY

Mary Group

Fine grained quartzite, quartz-muscovite schist and phyllite comprise the Mary Group in the area. Mineralogically the group is simple, containing quartz, muscovite, chlorite, and accessory rutile, zircon and tourmaline

The quartzite is saccharoidal, grey in colour and finely banded. This banding is parallel to a layering seen in Plate I C. Ripple marks and current bedding have been observed in the adjacent Mt Mary area (Spry, 1957b). In thin section it commonly has a mortar texture, consisting of large quartz grains, 0.1 mm in diameter, with feathery edges having undulose extinction and deformation lamellae, separated from each other by a cloudy mass of very fine sericite, granular quartz and broken muscovite flakes. Generally the muscovite is oriented in the plane of the banding. The banding is due to trails of graphite.

The phyllite is extremely fissile, medium to dark grey lustrous rock, and is contorted on all scales. The folded surface is designated S_1, and successively later surfaces S_2 and S_3. The S_1 surface in the finer grained phyllites is expressed by the alignment of muscovite flakes parallel to the banding. Plate IV A, B illustrates the style of microscopic folding. Minor inflections and fold axes persist along the axial planes for varying distances before dying out or converging, but the style is generally similar. On the limbs of the microfolds, the muscovite flakes are rotated to assume an echelon arrangement in a plane parallel to the axial plane of the folds. This is a potential plane of movement, allowing more differential slip and facilitating the recrystallization of muscovite. There is an associated migration of quartz into the crests of the micro-crenulations producing a metamorphic banding. A new transposed foliation S_2 is formed, with remnants of S_1 still clearly visible as curved trails of muscovite flakes preserved in the quartz-rich layers (Plate IV B). The S_2 surface is a crenulation cleavage as defined by Rickard (1961). Coupled closures are not present in Plate IV suggesting that the crenulations closing one way are dynamically different from crenulations closing the opposite way.

A third and later surface S_3, which is not penetrative, is commonly found in the phyllite. It takes the form of micro-fracture cleavage, sub-parallel to the axial planes of the micro-folds that deform S_2 (Plate V A)

Franklin Group

This assemblage consists mainly of thick slabs of intensely internally folded quartzite and quartz-muscovite-albite-garnet schist in approximately equal proportions. Minor rock types include biotite schists, knotted amphibole schist, garnet-chlorite quartzite and ortho-amphibolites.

Between the Mary Group and the coarse schist of the Franklin Group is the Governor River Phyllite of distinctive lithology. It consists of fine grained, dark grey to black phyllite with minor bands of fine-grained banded quartzite. Quartz, muscovite, and albite are the major constituents. Biotite and garnet are present

in quantities not more than 10% and tourmaline, graphite, zircon and pyrite are the accessory minerals. Secondary chlorite and limonite are present, replacing garnet. The lower part of the formation is devoid of garnet. Its fabric is described on page 14.

The quartzite of the Franklin Group is massive or schistose, dirty brown in colour and pitted with limonite cavities representing altered garnet. The schist is coarse grained, grey to light brown in colour and often knotted. Both schist and quartzite are colour banded, the banding being due to variations in the proportions of muscovite, iron-oxides, garnet and albite. This is the folded surface, S_1. In the quartzite S_1 is the most conspicuous microscopic and mesoscopic surface. A preferred dimensional orientation of muscovite is parallel to this surface. Rarely is the axial surface S_2 microscopically developed. The schists possess a conspicuous axial plane foliation which is expressed by the concentration of platy minerals into layers, and the parallel arrangement of the cleavage planes within these layers. In thin section, S_2 is rarely a planar continuous surface because of mimetic recrystallization of mica, the bending of S_2 around the porphyroblastic minerals, and the effect of S_1 which is still visible. S_1 is represented by cross laminae of muscovite folia.

Muscovite occurs in flakes which define the various tectonic surfaces. It is optically negative, with a 2V of 33°-38°. It has a 2M structure and there is no evidence of it being the paragonite end member. Four types can be differentiated on size and habit—

    (i) Helicitic inclusions in albite are small flakes 0.05-0.6 mm in length. Graphitic muscovite is usually found in those porphyroblasts in the Governor River Phyllite, and clean muscovite occurs in the upper portion of the Franklin Group. This muscovite is pre-albite in age.

    (ii) Where still remaining, the muscovite of the actual S_1 surface occurs as very small splintered flakes 0.03 mm in length. This type is more common in the phyllite of the Mary Group. In the Franklin Group, this muscovite is mostly recrystallized.

    (iii) The dominant surface in the Governor River Phyllite is defined by stringy layers of muscovite flakes averaging 0.3 mm long (Plate VI A, B). The flakes are often curved and graphitic inclusions and iron staining are common. This is syntectonic to the deformation that produced the S_2 surface.

    (iv) In the coarse schist of the Franklin Group the muscovite defining S_2 occurs in thick, tabular, clear crystals, ranging from 0.4 mm to 10 mm in length. The individual crystals are bent only where they are affected by the still later S_3 surface. Where the muscovite bands curve around porphyroblasts, the crystals are smaller, unbent, and sub-idioblastic (Plate VII B). The flakes form interlocking and fan-shaped aggregates (Plate VII A). This muscovite is post tectonic to the deformation that produced S_2, and is mimetically recrystallized type-3 muscovite.

Biotite is a common but minor constituent of the schist, but in the more uncommon knotted amphibole schist, the biotite content is as much as 20% and takes the place of muscovite. The biotite

is strongly dichroic from dark reddish brown to almost colourless and slightly biaxial. Two generations of biotite are recognized. Plate VIA illustrates the porphyroblastic habit. The porphyroblasts are relatively free of inclusions, sub-idioblastic and wrapped by the main foliation S_2. This is pre-tectonic to the S_2 deformation. Helicitic biotite inclusions in albite are also probably of this generation. The second generation occurs as small irregular flakes (0.1 mm in length) which help delineate the S_2 foliation.

Garnet is a common constituent of both schist and quartzite, where it may comprise as much as 30% of the rock. It is porphyroblastic, and usually partially or wholly replaced by limonite and chlorite. The garnet is close to the almandine end member, since it has a pink colour when cleaned with acid, a refractive index of 1.801, and a cell size of 11.55 $\overset{\circ}{\text{A}}$. (Compare 1.830 and 11.526 $\overset{\circ}{\text{A}}$ for pure almandine, Skinner, 1956).

Two main textural types of garnet are recognized. Garnet with inclusions or quartz grains arranged in symmetrical, sigmoidal lines are one type. In some cases the included material amounts to as much as 90% of the porphyroblast. Although the internal surface is not continuous with the surface outside the crystal, the recurring " snowball " arrangement indicates these are syntectonic garnets. The second type occurs as idioblastic crystals (when intact) which have a rectangular system of fractures and are often broken and strung out along the S_2 foliation. There are few or no inclusions.

All combinations of these two types exist. The syntectonic garnets occasionally have an euhedral rim which has few inclusions with no orderly arrangement. More rarely, garnets are converse to this combination, i.e., the core is idioblastic and almost devoid of inclusions, whilst the rim has abundant quartz inclusions arranged parallel to the circumference of the porphyroblast.

Garnet porphyroblasts are invariably wrapped by the S_2 foliation, and thus were present before the latest penetrative movements. Rectangular cracks that do not keep the same orientation from crystal to crystal, and broken and strung-out crystals bear testimony to a post crystalline deformation.

Albite is a common porphyroblastic constituent of the schist. The plagioclase is twinned according to the Albite Law, and the absence of CaO from the analyses indicates that it is albite. In the coarse knotted albite schist in the upper Franklin Group it comprises about 60% of the rock and has a maximum diameter of 10 mm. It is abundantly included with elongate quartz, and also with muscovite, biotite and garnet. The inclusions are arranged in straight lines or gentle curves which are not necessarily parallel to the twin planes. In the Governor River Phyllite, the albite porphyroblasts are smaller (2 mm diameter), are lozenge shaped, and have helicitic inclusions of dusty graphitic trails (Plate V B). These trails are gently curved, sigmoidal or contorted, and represent the remnants of a pre-existing folded surface enclosed and preserved in the growing porphyroblast.

In the transition zone between the Governor River Phyllite and the remainder of the Franklin Group, both types of inclusions can be found in the one porphyroblast. The two internal surfaces are always parallel, and there is nothing to suggest they are not

genetically the same. The quartzose inclusions represent an enveloped surface which is structurally more evolved over the graphitic surface. In some of the albite bearing micaceous quartzite, where S_1 is folded but in no way obliterated, it can be seen that the internal surface of the albite is equivalent to the S_1 surface.

Similarly to the garnet, the main foliation wraps around the albite porphyroblast, so that it is post-tectonic to the first phase of deformation and pre-tectonic to the second phase.

Primary chlorite occurs both as a porphyroblast in the Governor River Phyllite, and as a co-existing mineral with garnet in the schist and quartzite of the Franklin Group. The former type has a habit similar to that of the porphyroblastic biotite and is pre-tectonic S_2. The latter occurs in subidioblastic flakes which form interlocking and fan-like aggregates. These are similar to the post-tectonic S_2 muscovite but with a lesser degree of preferred orientation.

This chlorite is pale yellow-green, non-pleochroic, weakly birefringent (n_γ-n_α is 0.008), biaxially positive, with a 2V of about 10°. It has the properties of prochlorite.

Secondary chlorite is an alteration product of garnet. It occurs in small equidimensional or hexagonal flakes. It is pleochroic from apple green to colourless, has anomalous " Berlin Blue " interference colours and is optically negative. It has the properties of penninite.

Clusters of small fragmentary kyanite are fairly rare. The fragmentary nature is taken to indicate a pre-S_2 age; it is probably synchronous with the garnet or closely follows it.

Fabric of the Governor River Phyllite

The fabric of the Governor River Phyllite is structurally more advanced than that of the Mary and Franklin Groups. S_2 is the dominant surface, being defined by a banding foliation and is more continuous than that in the Franklin Group. S_1 is still visible as a weak cross lamination though in places it is completely obliterated. The phyllite is finer grained than in the overlying portion of the Franklin Group. The garnets are fractured and smeared out, and the occasional biotite porphyroblasts are bent and broken. If the amount of obliteration of the earlier surface is a criterion of the degree of deformation, then the Governor River Phyllite is an intensely sheared rock sandwiched between two less deformed quartzose assemblages. During this shearing the earlier fabric was broken down and a chlorite-muscovite assemblage was superimposed upon the biotite-garnet assemblage. The Governor River Phyllite can therefore be regarded as a phyllonite, although the second metamorphism was not strictly cataclastic since there was a recrystallization of quartz and muscovite.

Both the upper and lower contacts of the Governor River Phyllite are gradational. The lower contact is marked, in thin section, by the first appearance of biotite. This also corresponds to the first appearance of albite. In the field the lower contact is located by the change from phyllite above to the more psammitic rock types below.

The upper limit is more difficult to locate precisely. It is determined in the field by the gradual change from aphanitic black phyllite to phanitic brown schist. This corresponds in thin section to the first appearance of mimetic S_2 muscovite, and to the change in the textural type of albite.

Amphibolite

Amphibolite constitutes less than 1% of the rocks of the Franklin Group. It occurs either in small isolated rounded boudin bodies (Plate I A) up to 5 feet in diameter, or as tabular masses concordant with the foliation in the enclosing schist. The boudin bodies are generally massive whilst the tabular bodies are foliated.

The amphibolite contains about 60% amphibole, 20% almandine garnet, 10% quartz with the remainder biotite, albite, sphene, ilmenite. The amphibole occurs in sub-idioblastic, broad poikilitic prisms 3 mm long. The inclusions are quartz, garnet and sphene. It is optically negative, with a 2V of approximately 70°, and a maximum extinction angle ($Z \hat{C}$) of 20°. The pleochroic formula is X = pale green, Y = yellow green, Z = light blue-green. More rarely Z is a darker blue. It is actinolite.

Parallel alignment of these prisms defines the foliation, which corresponds to S_2 in the enclosing schist. The foliation is knotted with " snowballed " and sheared garnet. Quartz is interstitial, and also occurs as a coating around the garnet. Biotite, when present, is idiomorphic and has no preferred orientation. The amphibole is later than the syntectonic S_1 garnet, and there is a good dimensional orientation of amphibole parallel to S_2. This probably represents a recrystallization of earlier amphibole during or after the S_2 movements.

A chemical analysis of a massive amphibolite is given in Table I, No. 8. On the ACF diagram (Figure 4) the amphibolite (and the knotted amphibole schist) falls within the hornblende-zoisite (in place of epidote)-almandine-biotite field, of the basic assemblage, of the upper greenschist facies, deficient in potash.

The norm calculated from the analysis, and the mode for this rock are given below:—

Norm	%	Mode	%
orthoclase	2.8	amphibole	64
labradorite	41.7	garnet	20
clinopyroxene	12.3	quartz	8
orthopyroxene	22.7	biotite	2
olivine	8.9	ilmenite	4
magnetite	3.5	sphene	1
ilmenite	5.3	apatite	1
apatite	1.0		

Field relations of the amphibolite bodies are not sufficiently clear to designate them as ortho- or para-amphibolites. Spry (1957b) mentioned intrusive amphibolites near the Franklin River, which were dyke-like in form. It seems unlikely that the amphibolite could have resulted from the lime-magnesia metasomatism of the pelitic metasediments of the Franklin Group, which contain on the average only 0.5% CaO. The norm is in agreement with a typical olivine basalt. The 4% ilmenite present in the mode also points to the amphibole having been derived from an intrusive, basic igneous rock.

At coordinates 376550E/812500N, in a creek bed are exposed several small tabular and spherical amphibolite bodies, together with knotted amphibole schist and biotite-albite schist. The knotted amphibole schist is a mottled pink rock with metacrysts of green amphibole up to 10 mm in length. A chemical analysis is given in Table I, No. 9.

The amphibole is a pale green hornblende, occurring in sub-idioblastic prisms which are poikilitically included with zoisite and quartz. The schist-matrix is composed of biotite, quartz, zoisite and amphibole fragments in segregated layers forming the S_2 foliation. Both the amphibole and the albite are wrapped by the S_2 foliation, and are thus older.

TABLE 1

Chemical Analyses of Precambrian Rocks from the Raglan Range

			1	2	3	4	5	6	7	8	9
SiO_2	..	..	68.00	68.46	69.28	67.20	73.70	71.60	49.92	44.78	58.18
Al_2O_3 ..	..	..	17.00	15.72	15.64	17.67	11.62	14.72	16.76	13.44	15.36
Fe_2O_3 ..	..	..	1.96	0.92	0.57	2.30	2.95	1.04	4.21	2.41	0.79
FeO	..	..	2.54	3.02	0.61	2.72	3.69	2.62	8.84	16.22	5.31
MnO ..	..	..	0.02	0.02	..	0.02	0.04	0.02	0.05	0.86	0.09
TiO_2	..	..	0.69	0.76	0.45	0.94	0.45	0.69	2.44	2.81	0.61
P_2O_5 ..	..	..	0.06	0.06	..	0.40	0.03	0.05	2.24	0.40	0.15
CaO ..	..	..	0.60	0.32	0.68	0.32	0.04	0.16	0.72	9.12	5.00
MgO ..	..	..	1.16	1.16	1.48	1.19	2.00	2.56	6.91	7.01	6.72
Na_2O ..	..	..	1.31	1.31	1.93	0.98	0.09	0.71	2.12	1.65	1.69
K_2O ..	..	..	3.64	3.64	3.42	3.47	2.47	3.02	1.61	0.47	2.95
H_2O^- ..	..	..	0.19	0.12	0.10	0.18	0.36	0.14	0.58	0.07	0.49
H_2O^+ ..	..	..	2.93	2.79	1.96	3.06	2.96	2.95	6.33	1.58	2.61
FeS_2 ..	..	..	..	1.29	..	..	..	..	..	..	..
SO_2 ..	..	..	..	0.14	..	..	..	..	..	..	..

1. Specimen 30149   Garnet-albite-muscovite schist from beneath quartzite at Raglan Bluff.
2. Specimen 30108   Governor River Phyllite containing albite, muscovite and no garnet from Joyce Creek.
3. Specimen 6275   Garnet-albite schist collected by A. H. Spry, from near Raglan Bluff.
4. Specimen 30114   Albite-muscovite-garnet schist from old timber mill.
5. Specimen 30125   Chloritized garnet-muscovite schist from thin band within quartzite at western end of
                Raglan Range.
6. Specimen 30150   Muscovite-chlorite schist from western end of Raglan Range.
7. Specimen 30115   Biotite-chlorite-albite schist from creek bed 3,000 feet NW of timber mill.
8. Specimen 30132a   Garnet amphibolite from 378500E/812000N.
9. Specimen 30132b   Knotted amphibole schist with biotite from 376500E/813000N.

Analyst: W. St. C. Manson

Numbers refer to specimens in the rock catalogue in the Geology Department, University of Tasmania

LAMPROPHYRE DYKES

In addition to the regionally metamorphosed and deformed ortho-amphibolite there are unmetamorphosed basic intrusive rocks, which were first noted by Spry (1957a, b). These were tentatively correlated with the Precambrian Cooee Dolerite of North-West Tasmania of Precambrian age. The lamprophyre forms tabular and steeply dipping bodies discordant to the foliation in the intruded schist. They vary from 1 to 15 feet in thickness and their horizontal and vertical extent is not known. Because of extreme susceptibility to weathering, fresh exposures are only found in creek beds and track cuttings, and elsewhere the lamprophyre is reduced to a tan coloured clayey mass. The dykes occur as an ill-defined swarm alongside a major NW-SE Tabberabberan fault and trend in the same direction.

When fresh, the lamprophyre is dark green, fine grained, and speckled with varying proportions of black pyroxene and amphibole phenocrysts. Specimen No. 30103 has a mineral composition of quartz 3.2%, plagioclase 23.6%, clinopyroxene 28.3%, amphibole 12.9%, biotite 2.3%, ilmenite 3.9%, all of which are primary, and talc 5.8%, calcite 4.0%, chlorite 15.6% and leucoxene which are secondary. The chemical analysis and norm of this specimen are given below:—

	%		%
SiO_2	46.16	quartz	2.9
Al_2O_3	12.7	orthoclase	5.0
Fe_2O_3	1.58	plag. Ab_3An_7	25.3
FeO	9.51	corundum	2.9
MgO	12.79	hypersthene	49.4
CaO	6.12	magnetite	2.3
Na_2O	0.94	ilmenite	1.4
K_2O	0.80	apatite	0.3
H_2O	5.61	calcite	4.2
CO_2	1.93		
TiO_2	0.71		
P_2O_5	0.13		
MnO	1.31		

The proxene is colourless, optically positive, with a 2V of approximately 60°, and an extinction angle ($Z \wedge C$) of 54°. This is indicative of the augite variety which is probably deficient in CaO. The amphibole is pleochroic from brown-yellow to green-yellow. It is optically negative, with a 2V of approximately 50°. It is characterized by third order maximum interference colours and an extinction angle varying from 0° to 5°. It resembles lamprobolite. A labradorite-bytownite plagioclase is indicated by the norm.

Specimen No. 30103 is porphyritic, phenocrysts of amphibole and clusters of clinopyroxene are scattered in a fine grained ground mass of plagioclase, quartz and chlorite. Clinopyroxene occurs in subhedral to euhedral short prisms with 9-sided cross sections. They range in size from 0.2 mm to 1 mm in diameter and form clusters of crystals up to 2 mm in diameter. Along fractures and crystal faces, pyroxene is replaced by secondary green amphibole. Phenocrysts of amphibole average 0.8 mm in diameter, and range up to 2.3 mm. The larger phenocrysts show reaction rims of talc.

the medium sized crystals are usually skeletal remains whilst the smaller crystals are completely replaced and appear as fluffy patches of fine fibrous talc. Compared with the amphibole, pyroxene is relatively fresh. Phenocrysts comprise 45% of the slide.

The ground mass consists of interlocking small laths of plagioclase, subhedral pyroxene and anhedral chlorite flakes with interstitial quartz. The average length of the plagioclase is 0.1 mm. Biotite occurs in ragged shreds, partially chloritized, up to 0.3 mm in length. Minute grains and aggregates of grains of calcite are clustered around small pyroxene crystals. The plagioclase laths have a flow texture around the phenocrysts, and the biotite is usually bent. Ilmenite and magnetite are ground mass accessory minerals.

Specimen No. 30104 is a different variety, in that hornblende is the dominant phenocryst. It contains hornblende 32.7%, clinopyroxene 7.8%, actinolite 5.7%, all of which occur as phenocrysts, and chlorite-sericite ground mass 49.0%, calcite 2.6% and iron oxides 2.2%.

Hornblende phenocrysts are subhedral slender prisms up to 2 mm long. It is a coloured variety (X = light greenish yellow, Y = light olive green, Z = dark olive green), optically negative with a 2V of about 60° and $\overset{\wedge}{Z\,C}$ of 21°. There is no alteration of the hornblende. Fibrous aggregates of serpentine form equidimensional phenocrysts up to 2 mm in diameter. The serpentine is slightly pleochroic between pale green and yellow-green and has upper first order interference colours. The fibres tend to be arranged in two lines at 60° and may represent pseudomorphs after amphibole. Phenocrysts of clinopyroxene (augite variety) are present. These are fractured and fragmented crystals but chemically unaltered.

The ground mass is more altered than in specimen No. 30103 and it consists of an interlocking mesh of sericitized plagioclase, quartz, chlorite, microlithic hornblende with a little biotite, magnetite and ilmenite.

Features of the lamprophyres from the Raglan Range are the common association of both altered and fresh ferromagnesian phenocrysts, the variation in type and amount of phenocrysts, and the fragmentation of the phenocrysts. These may indicate a hybrid origin of the lamprophyres. The rocks belong to the camptonite-spessartite series of the lamprophyre classification of Johannsen (1938), since they are characterized by the presence of plagioclase, with pyroxene and amphibole in varying proportions. Field indications are that the lamprophyre dykes intrude parallel to a major Tabberabberan fault. The nearest lamprophyres outside the Raglan Range occur at Mt Lyell, 15 miles to the NW, and are Tabberabberan in age. The lamprophyres of the Raglan Range are texturally and mineralogically more similar to those on Mt Lyell, than to Cooee Dolerite of the North West Coast of Tasmania, and so appear Devonian in age.

METAMORPHISM

The time relations between mineral crystallization and the tectonic movements are deduced from the previously outlined petrographic features of the individual minerals. In this way the mineralogical and textural evolution of the metamorphic rocks can be followed step by step. Figure 3 is a diagrammatic presentation of the fields of crystallization in relation to deformation for the whole of the Franklin Group.
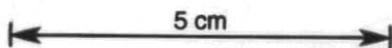
	S_1			S_2		S_3
	PRE TECTONIC	SYN TECTONIC	POST PRE TECTONIC	SYN TECTONIC	POST TECTONIC	
QUARTZ						
MUSCOVITE						
BIOTITE						
GARNET						
ALBITE						
KYANITE						
AMPHIBOLE						
ZOISITE						
CHLORITE						
TOURMALINE						

CHRONOLOGICAL RELATIONS BETWEEN CRYSTALLIZATION & DEFORMATION IN SCHISTS OF THE FRANKLIN GROUP, RAGLAN RANGE.

FIGURE 3.

The schist and quartzite of the Franklin Group are meta-sediments of pelitic and psammitic composition. They are poly-metamorphic, with two periods of mineral crystallization, related to the two main tectonic phases. The earlier deformation was accom-panied by syntectonic crystallization of biotite, garnet, kyanite, muscovite and amphibole. The second period of metamorphism, during which muscovite and chlorite crystallized, is syntectonic and post-tectonic to the second stage of deformation. In Table I are given chemical analyses of representatives of the Franklin Group rocks.

The Mary Group has a chlorite grade, the lower part of the Governor River Phyllite has a biotite grade, and the upper portion of the Franklin Group has reached garnet grade.
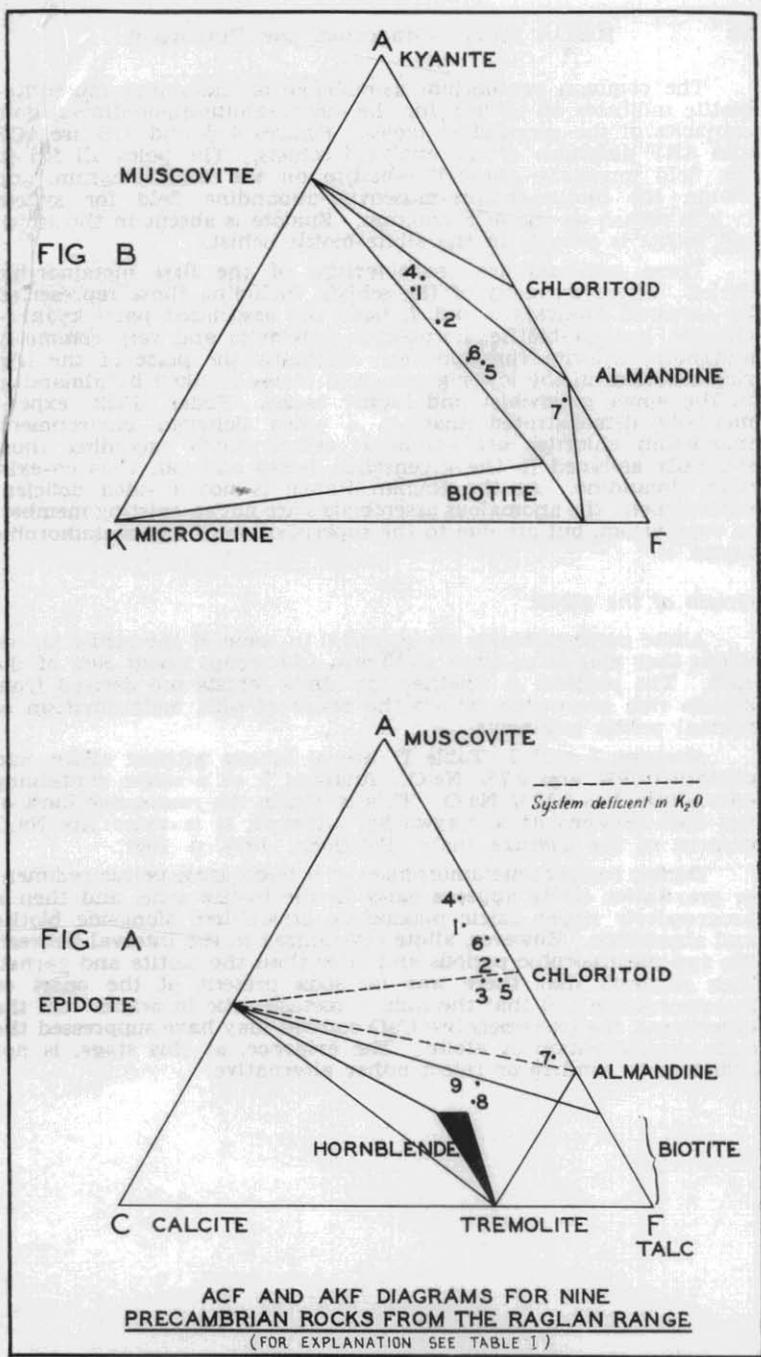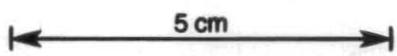
|← 5 cm →|

ACF AND AKF DIAGRAMS FOR NINE
PRECAMBRIAN ROCKS FROM THE RAGLAN RANGE
(FOR EXPLANATION SEE TABLE I)

Figure 4.

The common equilibrium assemblage of almandine-muscovite-biotite indicates an affinity for the quartz-albite-almandine-epidote subfacies of the greenschist facies. Figures 4 A and 4 B are ACF and AKF diagrams of the analysed schists. The poles all fall in the field muscovite-almandine-biotite on the AKF diagram, and within the biotite-epidote-muscovite-almandine field for system rich in potash on the ACF diagram. Epidote is absent in the schist, but zoisite is present in the albite-biotite schist.

These minerals are characteristic of the first metamorphic period. However, many of the schists, including those represented by chemical analyses 6 and 7, have the associated pairs kyanite-chlorite, kyanite-biotite, hornblende-muscovite and very commonly almandine-chlorite (prochlorite). Normally the place of the iron rich chlorites in the lower greenschist facies is taken by almandine in the upper greenchist and higher facies. Yoder (1952) experimentally demonstrated that in a silica deficient environment, magnesian chlorites are stable at temperatures exceeding those normally assigned to the greenschist facies and can thus co-exist with almandine. As the Raglan Range is not a silica deficient environment, the anomalous assemblages are not co-existing members in equilibrium, but are due to the superposition of two metamorphic facies.

Origin of the Albite.

Albite porphyroblasts are plentiful in some of the schist layers, where they may be as large as 10 mm and occupy about 50% of the rock. The problem is whether the albite schists are derived from a soda rich greywacke, or are the result of soda metasomatism of normal pelitic sediments.

Analyses 5 and 6 (Table I) are of schists without albite, and contain 0.09% and 0.7% Na_2O. Analysis 7, of a schist containing 44% albite, has 2.12% Na_2O. This is within the reasonable limit of the soda content of a greywacke, although it is twice the Na_2O content of the average shale (Pettijohn, 1957, p. 106).

During regional metamorphism of a feldspathic pelitic sediment or greywacke, albite appears early in the biotite zone, and then a progressively richer calcic plagioclase crystallizes alongside biotite and almandine. However, albite crystallized in the interval between the two metamorphic periods and later than the biotite and garnet. This suggests that there was no soda present at the onset of metamorphism and that the soda is metasomatic in origin. On the other hand, the extremely low CaO content may have suppressed the early crystallization of albite. The evidence, at this stage, is not sufficient to confirm or reject either alternative.

ACF AND AKF DIAGRAMS FOR NINE
PRECAMBRIAN ROCKS FROM THE RAGLAN RANGE
(FOR EXPLANATION SEE TABLE I)
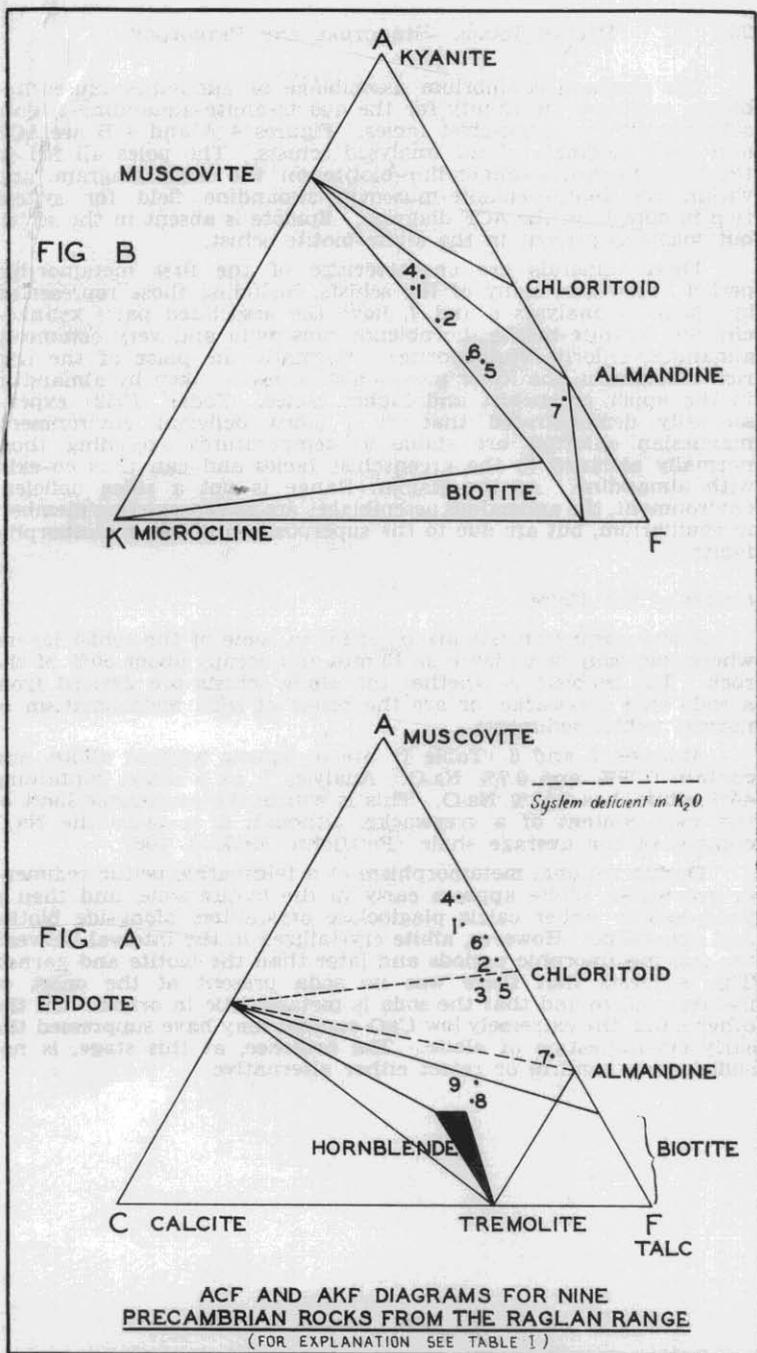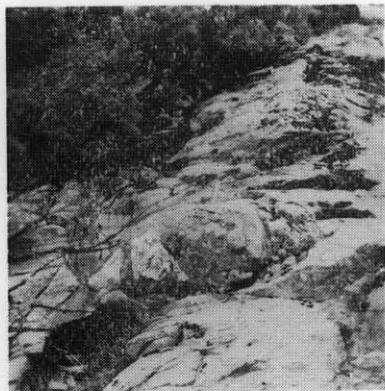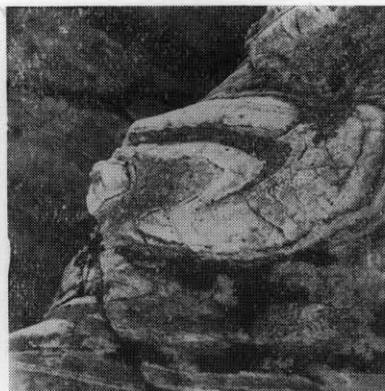
FIGURE 4.

5 cm

PLATE I

A

AMPHIBOLITE BODY IN
SCHIST, FRANKLIN GROUP.

B

REFOLDED QUARTZITE BAND
IN SCHIST, FRANKLIN GROUP.

C

LAYERING AND BOUDINAGE
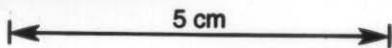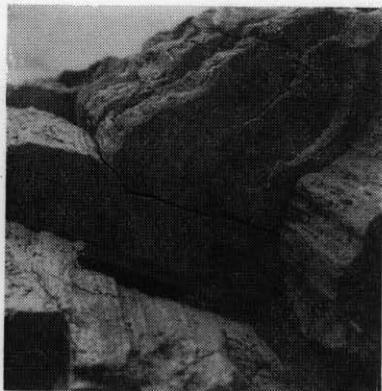IN QUARTZITE, MARY GROUP.

5 cm

PLATE II

A

RUDIMENTARY DEVELOP-
MENT OF AXIAL PLANE
SURFACE IN QUARTZITE,
FRANKLIN GROUP.

B

FOLD MULLIONS IN
QUARTZITE, FRANKLIN
GROUP.
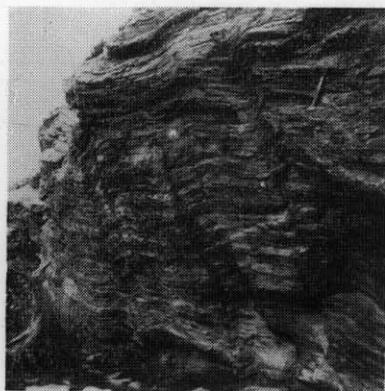
C

TABBERABBERAN FOLDS
IN QUARTZITE, FRANKLIN
GROUP.

5 cm

PLATE III

A

FOLDING IN SCHIST,
FRANKLIN GROUP.
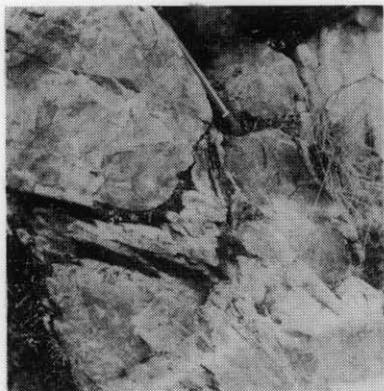
B

FOLDS IN QUARTZITE,
FRANKLIN GROUP.
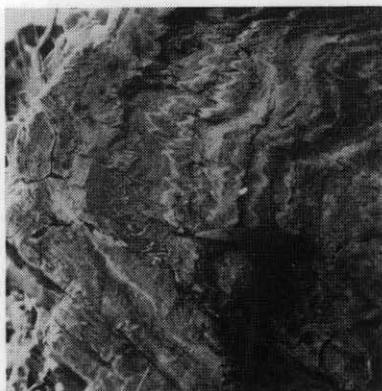
C

FOLDS IN QUARTZITE,
FRANKLIN GROUP.

5 cm

PLATE IV

A
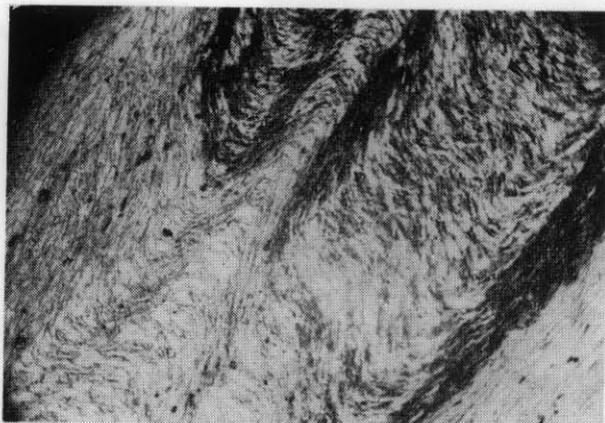
EARLY STAGE IN DEVELOPMENT OF CRENULATION
CLEAVAGE IN PHYLLITE, MARY GROUP.

B
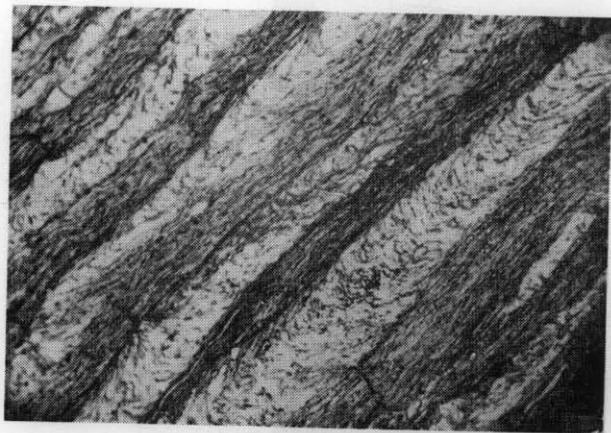
FOLIATION IN PHYLLITE, MARY GROUP, RESULTING
FROM TRANSPOSITION OF AN OLDER
TECTONIC SURFACE.

|←————— 5 cm —————→|
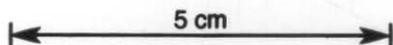
PLATE V

A
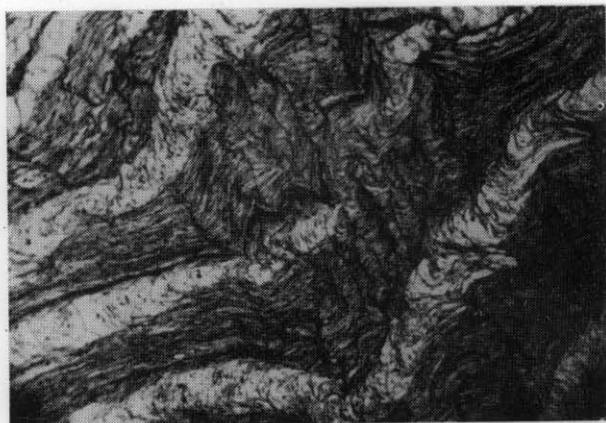
FOLIATION IN PHYLLITE, MARY GROUP, FURTHER
DEFORMED BY S₃ SURFACE.

B
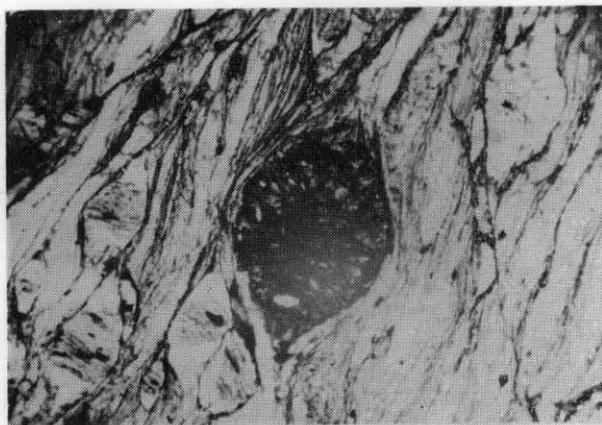
GOVERNOR RIVER PHYLLITE. GRAPHITIC ALBITE
WITH HELICITIC INCLUSIONS, STRINGY
S₂ MUSCOVITE.

5 cm

PLATE VI

A
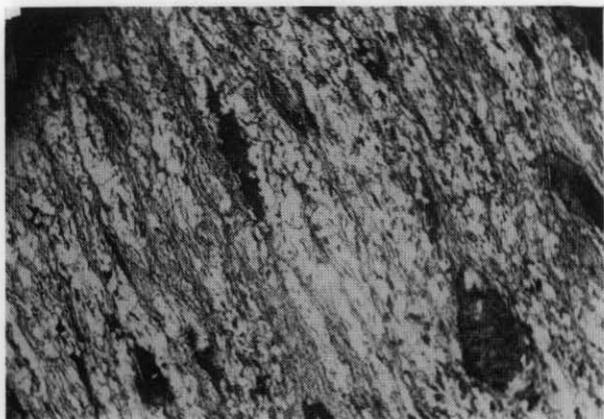
PORPHYROBLASTIC BIOTITE IN
GOVERNOR RIVER PHYLLITE.

B

REMNANTS OF S₁ IN GOVERNOR RIVER
PHYLLITE.

|← 5 cm →|
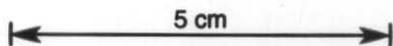
PLATE VII

A

SCHIST, FRANKLIN GROUP SHOWING COARSE
POST-TECTONIC S2 MUSCOVITE.

B
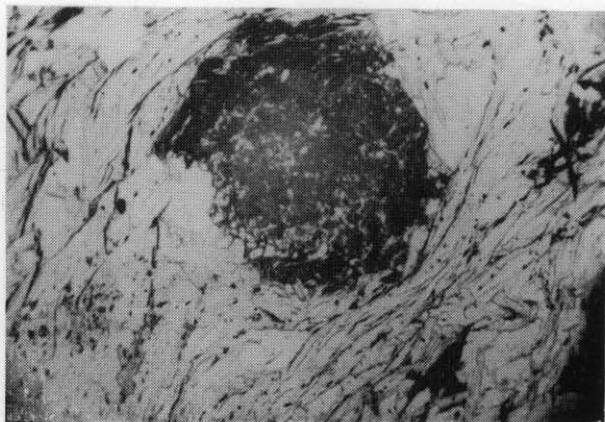
SCHIST, FRANKLIN GROUP. ZONED GARNET
WRAPPED BY POST-TECTONIC S2 MUSCOVITE.

5 cm

MESOSCOPIC STRUCTURE

In this paper, the terms *microscopic* and *mesoscopic* accord with the usage of Weiss and McIntyre (1957) namely:—

(i) *Microscopic*: the field of a thin section.

(ii) *Mesoscopic*: the field ranging in size from a single hand specimen to a single continuous exposure.

The mesoscopic structures can be divided into two categories. Firstly, those related to the penetrative movements of the Precambrian orogeny, and secondly the structures that deform the regional lineation and foliation, and are thus younger.

Precambrian Structures

These include minor folds with axial plane foliation, lineation, and boudinage. Two surfaces are present in the schist of the Franklin Group. The older surface, S_1, which is a tectonic surface, is folded into abundant similar style recumbent folds (Plate III A). Points of inflection persist for many feet along the axial plane foliation and the limbs are attenuated. Minor folds are rare in the Governor River Phyllite due to S_1 having been mostly obliterated.

Folds in the quartzite have a variable style. In profile they are disharmonic, ptygmatic, Z-folds or isoclinal (Plate III, B, C). The S_1 surface has the appearance of a bedding-schistosity. Generally it retains its orthogonal thickness in the crests, but is attenuated in the limbs. Rarely is there a discrete axial plane foliation in the quartzite, but there is often a rudimentary parting, for example, Plate II A. Deformation is by both flexural slip and plastic flow.

Intersection of S_1 and S_2 is the main type of lineation in the schist. Micaceous quartzite in the crests of larger recumbent folds is intensely contorted into miniature chevron folds which impart to the rock a fibrous rather than a platy appearance.

Lineation in the quartzite is manifested by fine striations and small steps on the foliation, quartz and muscovite elongation, minor fold axes, fold mullions in the cores of larger recumbent folds, quartz rods and the intersection of S_1 and the rudimentary S_2 surface. The small steps on the S_1 foliation surface are due to the intersection of S_1 with a slightly oblique compositional banding which is designated S_0. Lineation in quartzite is of two different generations which are indistinguishable on orientaton.

Lineation is parallel to the fold axis, although rare instances of lineation slightly oblique (about 8°) to the fold axis have been observed. More attributable to two deformations are the refolded minor folds (Plate I B), a number of which are found in the quartzite and schist in the creek bed at 376410E 812910N. These are the mesoscopic features to be expected from two coaxial deformations. The two fold generations are similar in style and orientation. On the mesoscopic scale the fabric has monoclinic symmetry.

Later Structures

Minor folds are common along the crestal line of the postulated Tabberabberan antiform (page 31). There is no development of a new lineation or cleavage, and the types of folds are accordian-like, asymmetrical ripples and irregular crumpling of the foliation (Plate IIC). Wave lengths vary from 20 feet to a few inches. Regular and irregular jointing, joint drags, brecciation and silification are common accompaniment to these folds. The axial planes of these folds strike NW-SE and are vertical.

Included in this category is the microscopic S_3 surface of uncertain age.

PETROFABRICS

Petrofabric Analysis of a Fold

In order to investigate the effects of two deformations on the quartz and muscovite orientation, a petrofabric study of a homogeneous fold in quartzite was undertaken. The mesoscopic fabric of this fold near the old timber mill is described later. Three oriented specimens were taken from the positions indicated on Figure 8 B. Quartz and muscovite diagrams were prepared from thin sections cut normal to the lineation. The petrofabric diagrams are presented in Figure 5. For ease in comparison the petrofabric diagrams are oriented so that the axial planes on all diagrams are mutually parallel, and so that the observer looks down the plunge of the lineation.

Mica Fabric

The mica diagrams (Figures 5 A, C, E) are the poles to the 001 cleavage planes of muscovite. The lineation is seen to be an axis of rotation and an axis of a partial girdle. Figure 5 E, prepared from the lower limb of the fold, has a high concentration maximum of 34%, and a symmetrical spread in the plane normal to the lineation. The maximum defines the S_2 surface.

In the hinge of the fold (Figure 5 C) the mica surface is rotated clock-wise through 110° which is consistent with the dip of S_1 having changed from 24° W on the limb to 80° SW and overturned in the hinge. There is a greater girdle spread, but there is still a distinct break in the foliation plane. This greater spread is due to slight microscopic undulation of S_1. There is no indication of the development of a surface parallel to the axial plane of the major fold.

A common feature of the specimens illustrated by Figures 5 C and 5 E is a colour and composition banding which is oblique by 15° to S_1. As the surface was folded, the inclination of this surface to S_1 remained the same. The intersection of these two surfaces produced the fine streaming lineation.

The micaceous quartzite in the crest of the fold is crumpled on all scales into zig-zag folds. The average axial plane of the minor folds is marked on the mica diagram, Figure 5 A. It has two maxima (M^I and M^{II}) of 10% and 6% respectively, defining a pair of statistical planes symmetrically disposed about S_2. A number of micro-folds, drawn from the slide, are inset in Figure 5 A in their correct orientation. The predominance of mica on the limb of the folds accounts for the two maxima. A third maximum M^{III} of 8% is centered on the pole of the axial plane of the micro-folds, representing the occasional isoclinal fold.

Quartz Fabric

The quartz fabric is fundamentally different from the mica fabric in that it maintains approximately the same orientation irrespective of the tectonic position. The quartz (0001) diagrams (Figure 5 B, D, F) are all strikingly similar in the following respects:—

1. There is a sharply defined girdle of 0001 poles, with an axis slightly inclined to the mesoscopic lineation. Consequently, the

girdles are not strictly in the plane normal to the lineation, but are inclined at up to 10°. The symmetry is broadly monoclinic with a tendency toward triclinic.

2. A single, unusually strong, peripheral maximum is present in each diagram. The point-maxima of Figure 5 B, D, F, are respectively 13%, 8% and 8%.

3. The q-lines joining the point-maxima to the centre of projection make angles of 15° in 5 B, and 20° in 5 F, with the axial plane of the fold. The positions of the maxima remain more or less constant. Such a fabric is not capable of being unrolled and is homogeneous.

4. A break or a distinct weakness in the girdle in the region 90° from the maxima is common to all three diagrams. The weakness also has a constant orientation, and again points to the homogeneity of the quartz fabric. The sharp girdle and peripheral maxima cause the quartz diagrams to imitate mica diagrams in general.

The inhomogeneity of the mica fabric and the homogeneity of the quartz fabric appear incompatible. Considering the muscovite, the fabric is capable of being unrolled about the lineation giving a homogeneous fabric for the unwound fold. At the two positions of the fold, the tangent to the folded surface is given by the mica plane. This is a criterion of concentric folding (Knopf and Ingerson, 1938, p. 48; Ball, 1960). However, the quartz fabric in a concentric fold will be identical in pattern but all points on the fabric diagram will have an identical relationship to the tangent of the fold. Taking the fold as a whole the quartz fabric will be inhomogeneous because of the inhomogeneous stress field and is unrollable. For a similar fold the fabric of the quartz grains will be identical in all parts of the fold and the maxima retain the same positions (Ball, 1960). The fabric is homogeneous and cannot be unrolled. This is the relationship portrayed by the quartz fabric of the fold under discussion.

Crampton (1958) described a folded specimen of Moine Schist, Scotland, in which the quartz fabric is homogeneous but the mica fabric is unrollable (i.e., capable of being unrolled to a planar surface). He interpreted this as due to the reorientation of a previously existing quartz fabric by a homogeneous strain, with the muscovite failing to reorientate and retaining its unrollable fabric. This interpretation could not be applied to this fold because there is no evidence of any movement later than the S_2 folding which could reorientate the quartz fabric. Tabberabberan movements are certainly incapable of such penetrative reorientation.

It is expected that at the onset of folding, the quartzite would initially deform in a concentric manner in view of the pre-existing potential slip surface S_1, and in view of the vastly differing competencies of schist and quartzite. This produces the concentric and disharmonic profiles of some folds in quartzite.
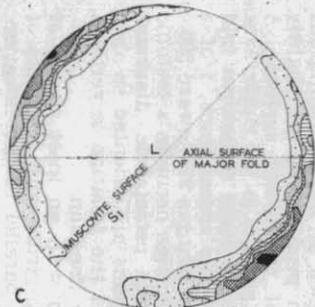
The quartz fabric is consistent with the greater part of deformation taking place by flow folding. The flow surfaces in the fold under discussion are defined by the flattening of the individual quartz grains in the axial plane of the fold. The dimension ratios in the limb of the fold are a = 2.9, b = 2.4, c = 1, where b is the
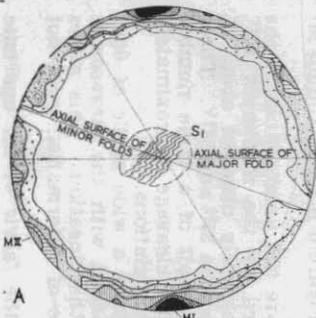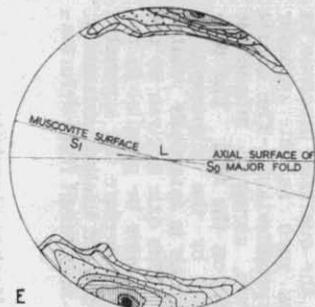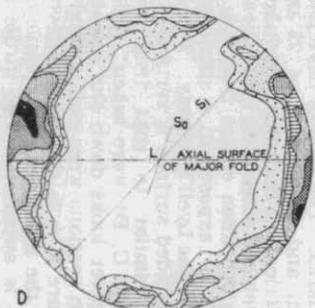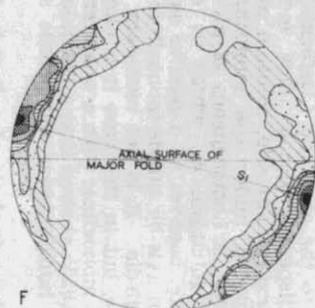
FIGURE 5 (see also Figure 8 B),

fold axis, a is normal to b and lies in the axial plane, and c is normal to the ab plane. Deformation in the quartzite proceeds by finely dispersed viscous flow movements such as intergranular slip, intragranular slip, solution and recrystallization. The quartz is orientated under the monoclinic strain, giving a monoclinic fabric that is homogeneous at all positions on the fold. The pre-existing foliation, S_1, which is expressed by the alignment of muscovite, behaves as a passive surface which is internally rotated about an axis by simple monoclinic shear. This axis is given by the quartz girdle. It is not necessary that this axis be parallel to the fold axis, but in this case it is almost so. Therefore the symmetry remains monoclinic with a weak tendency toward triclinic symmetry. Weiss (1955) showed that a triclinic fabric may result from deformation by homogeneous monoclinic strain.

Petrofabric Analysis of a Pseudo-Ripple-Marked Quartzite.

Quartz and muscovite petrofabric diagrams were prepared from a slab of quartzite on which are structures resembling sedimentary ripple marks. The ripples have parallel axes, an average amplitude of 5 mm and wavelength of 25 mm. In profile they are slightly asymmetrical, cylindroidal undulations of the folded surface. A well developed streaming type lineation is parallel to the ripple axis.

The specimen comes from the hinge of a large recumbent fold (Plate II B) exposed in a small quarry in the access track, ¾ of a mile from the Lyell Highway. The lineation plunges 22° toward 305°, and the folded surface is vertical. The specimen occupies a tectonic position similar to that from which the petrofabric diagrams (Figures 5 C, D) were taken. The diagrams are oriented so that the observer looks down the lineation and the foliation is vertical. The thin sections were cut normal to the lineation.

Figure 6 A is the muscovite diagram with an inset sketch of part of the specimen. A complete, sharp girdle with four sets of maxima is apparent. The girdle axis is parallel to the lineation. In thin section the folded surface is disclosed by a banding which is due to varying quartz grain sizes and slight variation in the muscovite content. Parallel to this banding is S_1 which is defined by the parallel arrangement of a small number of large muscovite flakes. The surface S_1 is represented on Figure 6 A by maximum M^I of 4% concentration.

Approximately perpendicular to S_1 are the axial planes of the undulations. This surface is represented by the maximum M^{II}, and is possibly the S_2 surface. Symmetrically disposed about S_2 are two mica surfaces corresponding to maxima M^{III} and M^{IV}. These three closely adjacent maxima are the result of a large number of small muscovite flakes oriented with 001 cleavage approximately parallel to the axial planes of the minor undulations.

The quartz diagram, Figure 6 B, shows a wide girdle of 0001 poles. The axis of the girdle is not coaxial with the megascopic Lineation L, but is 15° removed from the lineation. This arises from the fact that the S_1 and S_2 phases of deformation were not exactly coaxial.

Comparing this quartz fabric with the fabric of the quartzite from the core of the recumbent fold described previously, it is seen that the fabrics are very similar in pattern and orientation. This strengthens the conclusion reached above that the quartz fabric is homogeneous irrespective of the tectonic position.
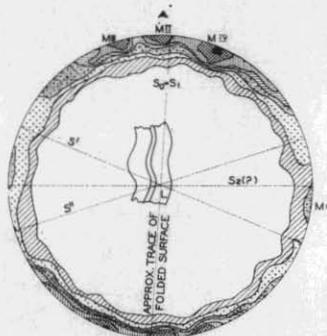
A   200 MUSCOVITE POLES FROM A PSEUDO
    RIPPLE MARKED QUARTZITE

B   250 QUARTZ OPTIC AXES FROM A
    PSEUDO RIPPLE MARKED QUARTZITE

C   250 QUARTZ OPTIC AXES FROM A
    QUARTZITE AT WESTERN END OF THE
    RAGLAN RANGE

D   200 MUSCOVITE POLES FROM QUARTZITE
    FROM MARY GROUP

E   250 QUARTZ OPTIC AXES FROM A
    QUARTZITE FROM MARY GROUP

FIGURE 6,

Miscellaneous Diagrams

Included for comparison are a quartz diagram from the quartzite at the extreme western edge of the Raglan Range (Figure 6 C), and a muscovite and quartz diagram from a quartzite in the Mary Group from the Governor River (Figure 6 D, E). The quartz diagram from the western edge of the Raglan Range is similar to the previously described quartz diagrams and again points to the homogeneity of the quartzite fabric. The quartzite from the Mary Group is very fine grained and the quartz diagram cannot be classed as reliable. However, it shows that the lineation is a quartz girdle axis, and the concentrations of the maxima are considerably lower. The significance, if any, of the crossed girdles is not known.
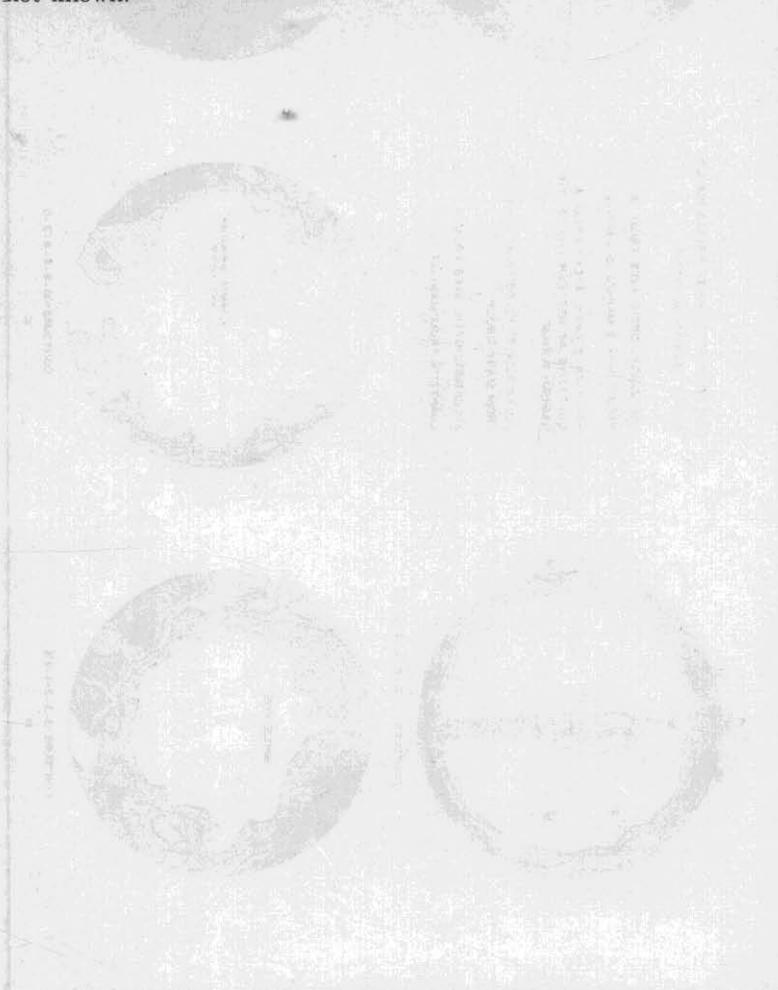
MAJOR STRUCTURES

Tabberabberan Structures

Figures 7 A and 7 B are equal area projections of 600 poles to the foliations and 600 lineations taken from the whole of the area. The significant feature is a 25% maximum of lineations plunging 25° toward 301° (true), and a broad great circle of foliation poles whose axis coincides with the lineation maximum. No distinction is made between the types of foliation. The axial plane foliation S_2, conspicuous in the schists, contributes mainly to the foliation maximum, and the folded surface S_1, conspicuous in the quartzites, is responsible for the completion of the girdle. If these features only are considered then the area is homoaxial.

However, the lower concentration contours of the lineation diagram (Figure 7 B) have two spreads. The more pronounced is due to an apparent rotation of lineations about a near vertical axis, and is manifest by those lineations which plunge WSW, NW and NE. No such axis is known in the Precambrian rocks, but such lineations, almost without exception, occur in the strip three miles long and half a mile wide, along the NE border of the Precambrian rocks, adjacent to Bubbs Hill. This area is termed the "fault complex". It is cut by several systems of faults and also marks the crestal line, in quartzites, of a large Tabberabberan antiform.

The second spread is a symmetrical dispersion about the maximum, and is due to a rotation of lineations (and also foliations) about a NW plunging axis. This inhomogeneity is due to a systematic variation of the attitude of foliations and lineations over the whole of the area. In the western part of the Raglan Range the foliation dips about 60° to the west, and the lineation plunges 50° to the WNW, whereas in the east, the foliation dips 40° to the NNE and the lineation plunges 0°-5° to the WNW. This is the expression of a NW trending antiform developed in the once overlying Junee Group, reflected in the Precambrian rocks by an axis of rotation trending 326° and plunging 24°.

This Tabberabberan folding, and its regional effect on the orientation of the Precambrian structures, is the substance of another paper (Spry and Gee, in press). It is shown in this paper that most of the Precambrian shows a slight departure from homoaxiallity.

This generalization does not apply to the inhomogeneous "fault complex" which may have impressed upon it a post-Precambrian, pre-Tabberabberan deformation, as well as a Tabberabberan deformation. Evidence for this intermediate deformation is given by a considerable departure of the lineations from a rectilinear arrangement beneath the Owen Conglomerate at the Bubbs Hill exposure. No minor folds are visible in the conglomerate. Furthermore, the foliation in the schist beneath the conglomerate steepens in dip on flattening the bedding in the conglomerate. This means that, prior to the deposition of the Owen Conglomerate, this region was not homogeneous within itself, and not homogeneous with the rest of the Raglan Range.

The SE half of this complex has a backbone of a thick slab of quartzite dipping steeply NE. In the NW half is another slab dipping moderately NW. Within these slabs are typical Precambrian folds whose axes plunge gently into the sector 260°-080°. Both easterly and westerly plunging folds can be seen in the one outcrop. Superimposed upon these are non-cylindroidal, brittle style folds. The crestal line of the large Tabberabberan antiform passes through this complex, and is probably related to these brittle folds. Figures 7 C and 7 D are equal area projections of foliations and lineations from within the " fault-complex ".

Trending parallel to the complex are two high angle NW trending faults of unknown but large displacement. The fault zones are characterized by sheared and unsheared breccias, granulation, silicification, dragging on nearly horizontal axes and slickensiding. The isolated maximum of lineations plunging steeply to the east (Figure 7 F) is the expression of this dragging. These are the oldest faults in the area, and are approximately parallel to the crestal line of the Tabberabberan antiform.

Two sets of Tabberabberan faults, an earlier NNE set and a later NW set, contribute to the structural complexity. These are high angle, normal faults, and are accompanied by close jointing and silicification.

In summary, there appear to be three deformations, superimposed upon the Precambrian structures, which produce this complex.

(1) Folding which disorientates the Precambrian lineations so that the fabric is not homogeneous on flattening the bedding in the overlying Ordovician sediments.

(2) The major Tabberabberan antiform and related minor folds.

(3) Faulting.

A detailed structural analysis, with particular attention given to the pattern of disorientation of lineations and axial planes, is required to confirm these movements.

Block Faulting

The Raglan Range is strongly block faulted: this makes difficult the interpretation of the Precambrian structures since structural continuity is the only method of correlation within iso-facial rock types. Small faults of insignificant displacement are numerous, and only those that affect the Precambrian major structures are mapped. All are Tabberabberan.

Three dominant trends, in chronological order, are:—

(1) Set trending 300°-310°, found in the fault complex as described previously.

(2) Set trending 000°-030°; these have small displacements.

5 cm
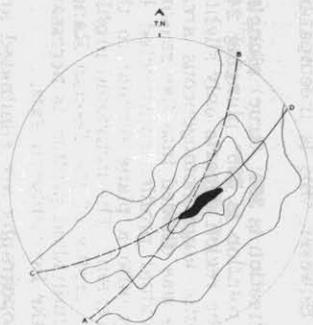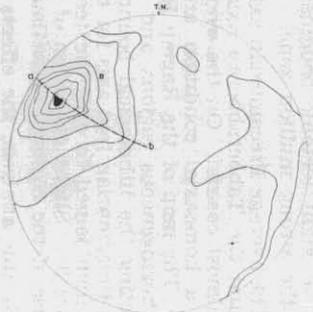
A   600 POLES TO FOLIATION FOR WHOLE AREA

B   600 POLES TO LINEATION FOR WHOLE AREA

C   FOLIATIONS IN FAULT COMPLEX

D   LINEATIONS FROM FAULT COMPLEX

12-8-4-2-0%

25-20-15-10-8-5-1-0%
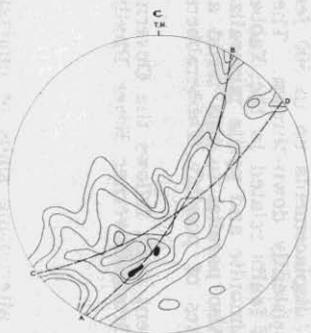
10-8-6-3-1-0%

20-15-10-5-3-2-0%

FIGURE 7.

(3) set trending 330°, which are vertical or high angle reverse faults having displacements up to 500 feet. The east side is consistently down-thrown. These are longitudinal crest faults related to the Tabberabberan antiform. Limonite and pyrite mineralization is associated. Also parallel to this trend are the lamphophyre dykes of possibly Tabberabberan age.

A major E-W dextral transcurrent fault follows the Governor River. This displaces the Mary Group-Governor River Phyllite contact by 3,500 feet.

Precambrian Structures
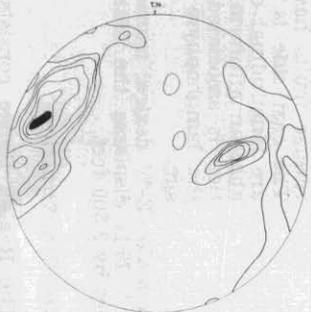
The Raglan Range consists of alternating slabs of quartzite and schist, dipping moderately to the north and west. Rapid variations in thickness of these slabs occur, and many of the slabs are completely attenuated. Two characteristics of the mesoscopic fabric at the point of complete attentuation are a well developed fold mullion zone and the vertical attitude of the folded surface.

One such quartzite body, that immediately NW of the old timber mill, is the nose of a recumbent fold impressed into the side of a hill of garnet schist (Figure 8 A, B). Between the quartzite and schist is a layer of micaceous quartzite which is intensively crumpled into cylindroidal, concertina folds. A weakly developed surface, parallel to the axial plane of the minor folds is sub-parallel to the axial plane of the major fold. In the surrounding schist, the dominant foliation is the axial plane foliation, S_2. Near the quartzite the orientation of S_2 is controlled by the shape of the quartzite, although further away it assumes a uniform orientation.

Figure 8 C is a stereographic projection of the poles to the folded surface S_1 and the lineation in the quartzite. The gap in the foliation girdle is due to most of the upper limb having been eroded away. On this scale, the area is homogeneous.

These terminated quartzite slabs may all represent fold crests, but they could also indicate lobate fold crests detached from their limbs, or giant tectonic boudinage. However, this is incompatible with the strong mullion zone.

The average Precambrian axial direction is 300° (true) plunging 24°, and the Tabberabberan axis of rotation is 326° plunging 24°, and almost coaxial. On the whole, the region departs only slightly from a homoaxial condition and quite large homogeneous areas exist. The map of the Raglan Range was divided into five reasonably homogeneous regions and individual profiles constructed by projecting the lithological boundaries onto a plane normal to the mean Precambrian fold axis for that region. The individual profiles were then joined to give the tectonic profile of the Raglan Range (Figure 9). Slight distortion of the individual profiles is necessary because of the regional distortion of the Precambrian axis.

By this analysis, the effects of topography are eliminated and the regional structure is viewed by looking down the fold axis. Faulting makes axial projection difficult, but most of the faults can be corrected once the individual profiles are drawn. The fault which is sub-parallel to the axial plane of the Tabberabberan

5 cm

MAP OF FOLD N.W. OF MILL

(a)

5 A
5 B

5 C
5 D

5 E
5 F

S.W.   N.E.

(b)

FOLD IN PROFILE

QUARTZITE.

MUSCOVITE QUARTZITE.

SCHIST.

0   100   200   300   400 FT.

TIMBER   TRACK

MILL

(c)

T.N.

APPROXIMATE AXIAL SURFACE
OF MAJOR FOLD.

•   POLES TO LINEATIONS.

×   POLES TO S₁.

○   AXIAL SURFACE OF
    MINOR FOLDS.

**ANALYSES OF LINEATIONS & FOLIATIONS IN HINGE OF RECUMBENT
FOLD NEAR OLD TIMBER MILL**

R. D. GEE.
GEOLOGIST 1963.

FIGURE 8.

TECTONIC PROFILE
RAGLAN RANGE

MEAN AXIS OF PROJECTION 301°, PLUNGE 24°

FRANKLIN GROUP   MARY GROUP

QUARTZITE   QUARTZITE

SCHIST   PHYLLITE

PHYLLITE

———— MAJOR FAULT.

‒ ‒ ‒ MAJOR FAULT APPROX.

〜〜〜 UNCONFORMITY.

0   1000   2000   3000 FT.

S.W.

N.E.

FAULT
COMPLEX

GOVERNOR RIVER PHYLLITE (PHYLLONITE)
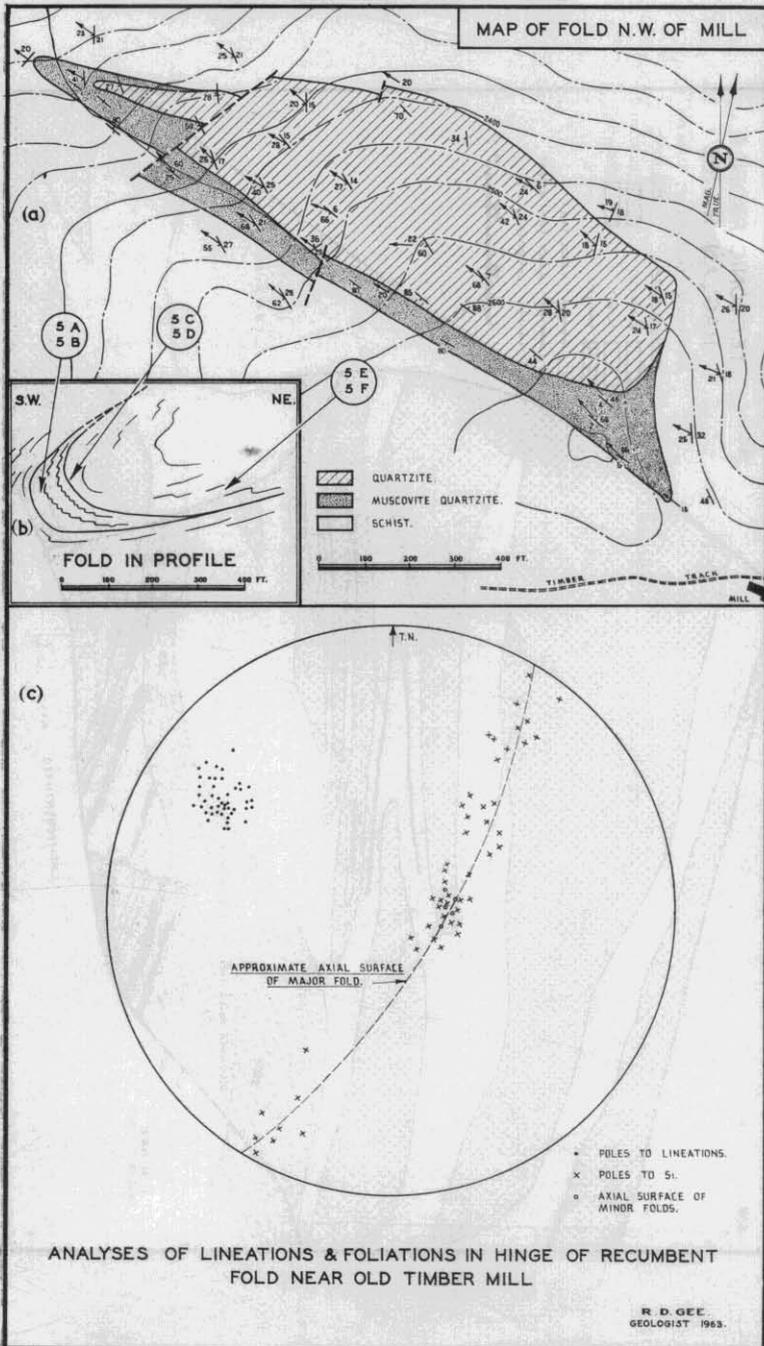
R.D. GEE
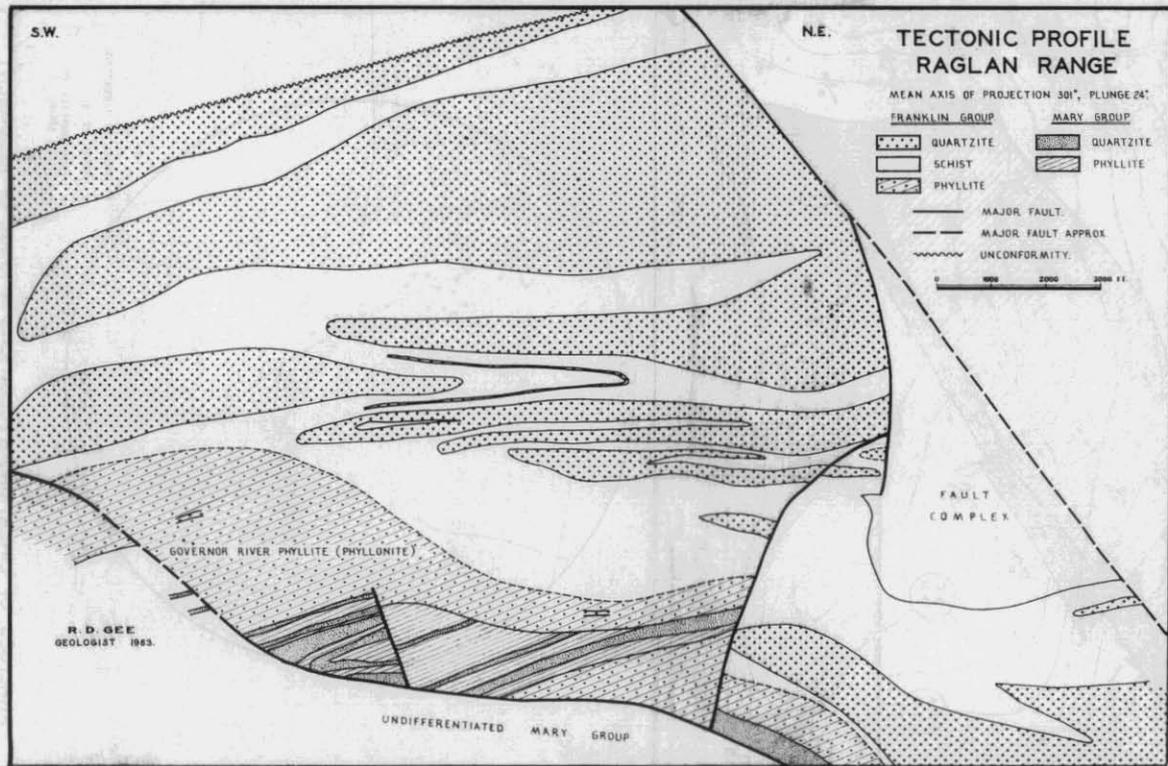GEOLOGIST 1963.

UNDIFFERENTIATED   MARY   GROUP

FIGURE 9,

5 cm

antiform has been left uncorrected. It should be noted that the projection of the trace of the fault on the ground surface on any plane does not give the true attitude of the fault. For example, the major fault along the Governor River projects as a near horizontal line although actually it dips steeply. Where faulting is complex, construction of a profile is technically impossible, hence the fault complex is left unprojected.

The profile demonstrates the ptygmatic style of folding that is evident on the smaller scales. The Franklin Group consists of quartzites and schists, piled up into recumbent folds, which have overridden the Mary Group. The major lithological boundaries defining the folds probably represent the original bedding. No firm indication of two phases of folding is apparent from the shape of these folds, although the second-lowermost quartzite slab may be a hooked fold. Such features are to be expected if the mesoscopic fabric typifies the major structure.

During the overriding of the Mary Group by the Franklin Group, shearing did not take place on one discrete surface, but was dispersed in a thick zone corresponding to the phyllonite. The direction of tectonic transport, whether from SE to NW or vice-versa, is not clear. Most of the minor and major folds are related to this deformation, and very little is known of the first generation folds.

The area mapped is not sufficiently large to disclose a major, coherent structure. The Governor River Phyllite is similar in lithology, and is structurally continuous with the Canyon Creek type schist of McLeod (1955). The quartzite at the extreme western end of the Raglan Range is structurally continuous with the quartzite of the Fincham Group. This would make the Fincham Group and the Franklin Hut type schist of McLeod (1955) equivalent to the schist and quartzite of the Franklin Group in the Raglan Range. Figure 2 is a sketch map, combining the essential features of the Raglan Range with the (reconnaissance) rock distribution map of the Mt Fincham area, assuming the above correlations. All faults are eliminated, and mostly minor changes are made to McLeod's map.

The Franklin Group appears to form large recumbent folds pushing southward, and becoming larger at higher tectonic levels, finally culminating in the Fincham Group of nappe dimensions.

RELATION BETWEEN METAMORPHISM AND STRUCTURAL DEFORMATION

First Metamorphic Period

In the first metamorphic period appeared those metamorphic minerals which are normally connected with the regional metamorphism of a sediment of pelitic composition. The index minerals in their order of appearance are chlorite, biotite and garnet. The areal distribution of these minerals is zoned from chlorite in the Mary Group, biotite in the lower part of the Governor River Phyllite, and garnet in the upper portion of the Franklin Group. Kyanite is also present but not in sufficient quantities to delineate a kyanite zone. The biotite and garnet isograds, determined by the first appearance of S_1 biotite and garnet respectively, are drawn on the map (Figure 10). These isograds must be interpreted carefully, since there has been a later phase of tectonic movement which must have considerably modified the positions and width of the zones. The important feature is that the garnet isograd is tectonically higher and roughly parallel to the biotite isograd.

Normally a zone of higher grade metamorphism underlies a zone of lower grade metamorphism. This position may become inverted by subsequent deformations (Harker 1932, p. 185). Elles and Tilley (1930) interpreted an inverted zoning in the South West Highlands of Scotland where a garnet zone overlies a chlorite zone as due to metamorphism followed by recumbent folding of the zoning. However, some workers, notably Read (1957), have attributed zoning in general to metasomatism by advancing fronts. In this case, inversion of zones does not necessarily demand regional overturning since metamorphism can "increase downward, upward or sideways" (Read, 1957, p. 295).

However, the Raglan Range is not a metasomatic environment, and there is clear evidence of major transport subsequent to the first metamorphic period. It is postulated that the second Precambrian deformation is responsible for the overturning of the isograds.

The other minerals of the first metamorphic period are amphibole and zoisite. The close spatial relationship between first and second generation amphibole, and the association with zoisite (which is definitely S_1 in age) suggests that the knotted amphibole schist and the amphibolites are genetically related. It appears that the basic intrusion was related to the first metamorphism. The post-tectonic S_2 amphibole in the amphibolites consequently would simply represent re-crystallization during the second metamorphic period.

Second Metamorphic Period

Prochlorite was the only new mineral to appear in the second metamorphic period. It involved mainly the redistribution and re-crystallization of quartz, muscovite, biotite and amphibole. The S_2 biotite is largely related to the re-crystallization of amphibole. The metamorphism in the whole of the Franklin Group was retrograde. Garnet, kyanite and albite were sheared, fractured, granulated or twinned. Syntectonic S_2 muscovite crystallized along the new shear

planes in the schist, whilst in the quartzite, the muscovite grew
mimetically in the bedding schistosity. The amphibolite bodies
were remoulded into spherical and tabular masses during which the
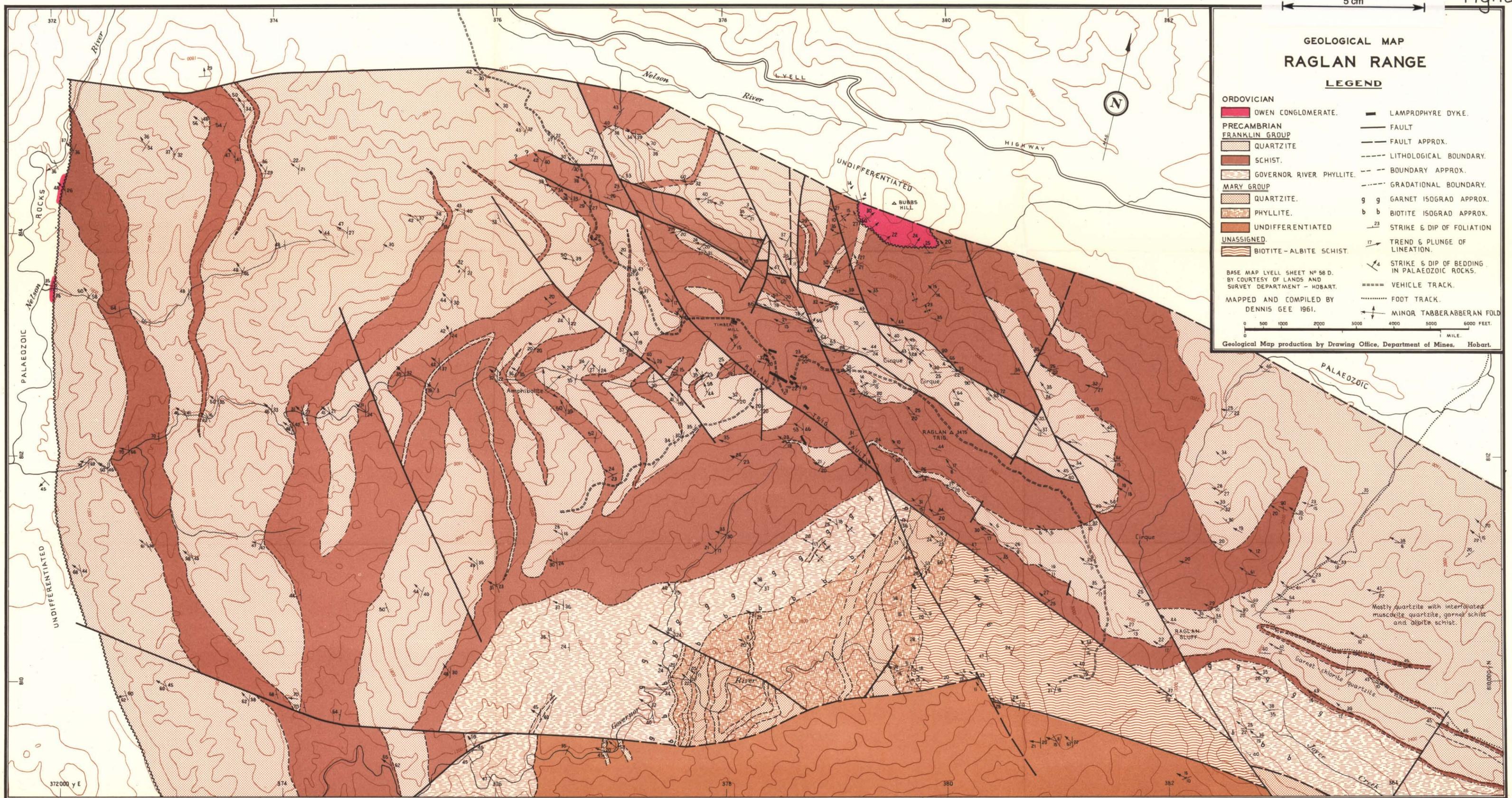amphibole assumed a new direction of preferred orientation.

Phyllonitization occurred in the zone above the Mary Group
as it was over-ridden by the Franklin Group. The bedding in the
Mary Group is truncated obliquely by the biotite isograd. There
are no direct structural equivalents of the quartzites of the Mary
Group in the Governor River Phyllite, and there is quite an abrupt
change from psammitic rock type below to pelitic rock type above.
This contact is a metamorphic boundary oblique to bedding, that
has been dislocated by the later tectonic movements.

At a later stage, muscovite and chlorite again re-crystallized in
the upper part of the Franklin Group. These processes did not
affect the phyllonite zone, thus giving the Governor River Phyllite
its distinctive lithology. First appearance of mimetic S_2 muscovite
may not be a necessary marker of the upper contact of the Governor
River Phyllite, and probably does not apply in McLeod's area
to the south of the Raglan Range. Schist contained within the
Fincham Group does not contain post tectonic S_2 muscovite (writer's
observation of McLeod's specimens). This muscovite horizon prob-
ably continues to the SW, and does not swing to the south along with
the Fincham Group as shown in Figure 2. It is suggested that this
is one of the important differences between the Franklin Group and
the Fincham Group. The effect of the first metamorphism on the
Fincham Group is not known, but McLeod reported garnet schist
associated with the quartzite.

REFERENCES

BALL, T. K., 1960.—A petrofabric analysis of a fold. *Amer. J. Sci.*, 258, 274-281.

CRAMPTON, C. B., 1958.—Muscovite, biotite, quartz reorientation. *J. Geol.*, 66, 28-34.

ELLES, G. L. AND TILLEY, C. E., 1930.—Metamorphism in relation to structure in the Scottish Highlands. *Trans. Roy. Soc. Edinburgh*, 56, 621-646.

GEE, R. D., 1962.—Structure and petrology of the Raglan Range. *Thesis, Univ. of Tas.* (unpublished).

HARKER, A., 1932.—Metamorphism. *Methuen*. London.

JOHANNSEN, A., 1938.—Descriptive petrography of the igneous rocks. Vol. 4. *Univ. Chicago Press.*

KNOPF, H. G. AND INGERSON, H., 1938.—Structural Petrology. *Mem. Geol. Soc. Amer.*, 6.

McLEOD, I. R., 1955.—Geology of the Mt Fincham Map Square. *Rep. H.E.C. Tas.* (unpublished).

PETTIJOHN, F. J., 1957.—Sedimentary Rocks. *Harper*, New York.

READ, H. H., 1957.—The Granite Controversy. *Thomas Murby*, London.

RICKARD, M. J., 1961.—A note on cleavage in crenulated rocks. *Geol. Mag.*, 98, 324-332.

SKINNER, B. J., 1956.—Physical properties of end-members of the garnet group. *Am. Min.*, 41, 428-436.

SPRY, A. H., 1957a.—Precambrian rocks of Tasmania, Part 1. Dolerites of the North-West Coast. *Proc. Roy. Soc. Tas.*, 91, 81-93.

————, 1957b.—Precambrian Rocks of Tasmania, Part 2. The Mt Mary area. *Proc. Roy. Soc. Tas.*, 91, 95-98.

SPRY, A. H. AND GEE, R. D.—Some effects of Tabberabberan refolding of the Precambrian basement in Tasmania. *In press.*

WEISS, L. E., 1955.—Fabric analysis of a triclinic tectorite and its bearing on the geometry of flow in rocks. *Amer. J. Sci.*, 253, 225-236.

WEISS, L. E. AND McINTYRE, D. B., 1957.—Structural geometry of Dalradian rocks at Loch Leven, Scottish Highlands. *J. Geol.*, 65, 575-602.

YODER, H. S., 1952.—The MgO-Al_2O_3-SiO_2-H_2O system. *Amer. J. Sci. Bowen Mem. Vol.*, pp. 569-627.

Fig. 10

GEOLOGICAL MAP
RAGLAN RANGE
LEGEND

ORDOVICIAN

▆ OWEN CONGLOMERATE.

PRECAMBRIAN
FRANKLIN GROUP

▢ QUARTZITE.

▆ SCHIST.

▢ GOVERNOR RIVER PHYLLITE.

MARY GROUP

▢ QUARTZITE.

▢ PHYLLITE.

▢ UNDIFFERENTIATED

UNASSIGNED.

▢ BIOTITE-ALBITE SCHIST.

— LAMPROPHYRE DYKE.

— FAULT

– – FAULT APPROX.

– – – LITHOLOGICAL BOUNDARY.

– – – BOUNDARY APPROX.

– – – GRADATIONAL BOUNDARY.

g g GARNET ISOGRAD APPROX.

b b BIOTITE ISOGRAD APPROX.

⌐23 STRIKE & DIP OF FOLIATION

17 TREND & PLUNGE OF LINEATION.

⌐4 STRIKE & DIP OF BEDDING IN PALAEOZOIC ROCKS.

----- VEHICLE TRACK.

········· FOOT TRACK.

—··— MINOR TABBERABBERAN FOLD

BASE MAP LYELL SHEET Nº 58 D.
BY COURTESY OF LANDS AND
SURVEY DEPARTMENT - HOBART.

MAPPED AND COMPILED BY
DENNIS GEE 1961.

Geological Map production by Drawing Office, Department of Mines. Hobart.