THE GEOLOGY

of an area

EAST OF ANGASTON, SOUTH AUSTRALIA

by

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ABSTRACT

The stratigraphy, metamorphic petrology and structural geology of a small area of amphibolite facies rocks have been investigated. A non-stratigraphic boundary separates the two major rock units in the area.

Mineral assemblages in pelitic rocks of the younger unit indicate that the area has undergone andalusite-staurolite metamorphism. No general conclusions can be drawn regarding either the metamorphism of the marbles of the same unit, or of the scapolitised pelitic schists of the older group.

Three main phases of deformation have been recognised in rocks of the area. Macroscopic and most mesoscopic folding is a result of the first phase deformation. Second and third phases have involved a crenulation cleavage movement, but do not appear to have had a controlling effect on the macroscopic geometry.

INTRODUCTION

The initial object of the present study was to contribute to the existing knowledge of the stratigraphy of the Angaston - Truro region on the eastern side of the Mount Lofty Ranges. As the work progressed it became apparent that some of the stratigraphic relations could be understood only with a comprehensive knowledge of the structural relations of the various rocks in the region. Consequently, the present work involves certain aspects of the stratigraphy, petrology and structural geology of the area selected for study.

An area of about 19 square miles was investigated, extending from about 1 mile to 4 miles east of Angaston, and from about 3 miles to 9 miles south of Truro (Fig.1).

A number of workers, including Hossfeld (1935) and Campbell (1945), have investigated the area on a regional scale; the northern half of the area has been described on the Truro (1 inch to 1 mile) Geological Sheet by Coats and Thomson (1959). The Sheet depicts the area as containing a broad anticline exposing a core of Proterozoic age, flanked and unconformably overlain by Lower Cambrian rocks, which on the eastern margin of the area are in turn unconformably overlain by steeply dipping rocks of the Kanmantoo Group. The Proterozoic core was assigned to the Sturtian Series of the Adelaide System. On the basis of a total of some 8 weeks field work carried out by the writer in the area, a critical reappraisal of some aspects of the local and regional stratigraphy has been made.

The topography has a relief variation of about 300 feet, a number of the hills in the area being close to the maximum elevation of just over 1400 ft. Much of the area is moderately undulating. In some parts the moderately hilly terrain gives way to the low alluvial areas of the more major water courses. Drainage is towards the north-west corner of the area, and is provided by several meandering creeks draining tributaries which dissect the more hilly regions. Weathering products of the old uplifted Tertiary peneplain are exposed as remnants on some of the higher hills.

Outcrop over most of the area is poor, probably caused at least in part by the dominantly micaceous nature of the rocks together with the near-vertical attitude of their well-developed foliation. Even in the limited areas of denser outcrop, few individual beds could be traced with reasonable confidence for more than a few tens of yards.

To aid the reader unfamiliar with the area to assess the evidence from which past and present interpretations of the general geological relationships have been made, a fact map (Fig.1) has been presented with this report; within the limits imposed by drafting techniques, only the actual extent of surface outcrop have been represented. Some interpretation has been presented on Fig.2 (overlay).

In the text or in Plate descriptions, reference to any specific locality is given as a national grid reference drawn on the Cambrai (1940) and Truro (1940) 1: 63,360 Sheets.

SECTION A : STRATIGRAPHY

It would appear from field evidence that the current interpretation of the stratigraphic succession in the area studied must be held in doubt. The uncertainty arises mainly because of the nature of the boundary between the two major groups of rocks (Units 1 and 2 on Fig.1). For this reason, before a discussion on the stratigraphic succession is presented, the boundary is discussed in the light of field evidence.

1. The boundary between the two major rock units in the area.

(a) Field relations

Although a more detailed discussion of the structural geometry in the area is presented in Section C, a study of the bedding attitudes, the form of geological boundaries, and the distribution of rock units, suggests an anticlinal structure whose fold axis trends north-south. The anticlinal core exposed is seen to separate two groups of rocks which in the field are similar, and have been assigned to the same rock unit (Rock Unit 2, see below). This unit, then, overlies Unit 1 in the core. Sedimentary facings confirm the expected relative ages: that is, Unit 2 is younger than Unit 1. The nature of the geological boundary between Unit 1 and Unit 2 must now be sought.

The field evidence concerning the nature of the boundary is listed below for convenience.

(i) In the area studied, the actual boundary (whatever its nature) between 1 and 2 was not observed by the writer. In fact, along the zone where the boundary might have been expected outcrop is poor or completely lacking.

(ii) Rocks in and around the boundary zone show evidence of varying degrees of crushing and brecciation. This can take the form of micro-faulting (e.g. A263-148), partial mylonitisation in marbles (A263-812), and crushing such that the form of the original material is obscure. (A263-434).

(iii) Mineralization appears to be commonly located along the boundary zone.

Although the rocks of Unit 2 in general are initially iron rich, many of the outcrops of both units close to the boundary zone have been indurated with iron oxides (A263-153a); small outcrops of gossan are not uncommon.

Quartz reefs in areas of no outcrop and quartz-veining in rocks can be seen in a number of places along the boundary zone (e.g. between 082360 and 082368). At 082361 quartz veining is associated with small-scale faulting and intense tourmalinization (A263-153b).

(iv) The strike directions of beds adjacent to the boundary zone can be discordant with the trend of the boundary zone. This can be seen particularly well on the western side of the area, between grid lines -340 and -350 where beds of Unit 2 (in particular the interbedded quartzites) strike into the trend of the boundary zone.

An examination of Figs. 1 and 2 will reveal similar discordances, such as the apparent discordance of the boundary zone with beds of Unit 1 around 081326.

It should be noted that not only are beds discordant with the trend of the boundary, but strike directions on opposite sides of the boundary zone are discordant. This can be seen around 345076 where the discordance between quartzites of Unit 2 and rocks of Unit 1 is about 20° (Plate 2).

(v) The distribution of bedding attitudes across the major anticlinal structure suggests that this structure may not be as simple as appears at first sight. Beds of Unit 1 have smaller apparent thicknesses on the western side of the fold axis compared with the apparent thicknesses on the eastern side. In addition the dips of Unit 1 beds on the western side of the fold axis are steep west, whilst dips immediately to the east are shallow and then within a short distance east become very steep to the east;

these steep dips continue to the eastern margin of the area.

(vi) The interpreted trend of the boundary zone in the south-eastern portion of the area is relatively simple. However, beds of Unit 2 immediately to the east and overlying the boundary, are macroscopically folded.

(vii) In the northern half of the area, the eastern boundary between Units 1 and 2 is at present shown on the Truro (1 inch to 1 mile) Geological Sheet (Thomson and Coats, 1959) approximately parallel to, and situated between north-south grid lines 100 and 110. The zone trends from near 100376 to near 110435. Although outcrop in this area is mainly limited to sporadic creek exposures, evidence was not found to indicate that the boundary should be placed in this position. Significant differences in lithology were not detected in numerous traverses across the reported position of this boundary. In fact, the general rock types can be traced from west of the 'boundary' for an appreciable distance east. The most easterly outcrop of similar lithology observed in the area is probably just to the east of the quartzite near the eastern margin of the area where induration with iron oxides has taken place (locality 120387). The approximate trend of the boundary through the southern half of the area is shown in Fig.2.

(b) Discussion

Two interpretations can be based on (v) above. The bedding attitudes and apparent thicknesses may require that the anticlinal axial plane is dipping to the east at a moderate angle. However, evidence presented in Section C suggests that the axial surfaces in the area have dips that are close to vertical. It would seem then that the following alternative interpretation is required to explain the field evidence: part of the western limb of the anticline has been covered by the boundary zone. This would require either folding before Unit 1 was unconformably overlain by Unit 2, or faulting at some time along the boundary. Thomson and Coates (1959) interpret the boundary between Units 1 and 2 as an unconformity between Proterozoic and Lower Cambrian units. The fact that, in certain places ((iv)above), the trend of the boundary is discordant with beds of Unit 1 below is in agreement with this interpretation. However, beds of Unit 2, which are younger than the boundary,are discordant with it. This must certainly indicate that the boundary is not a stratigraphic one.

If the boundary is not stratigraphic, one must assume that it has arisen by major faulting of some kind. The general lack of outcrop, the crushed and brecciated nature of many boundary zone rocks, and the localisation of mineralization in the zone ((i),(ii) and (iii) above) serve to support this interpretation.

The simple nature of the boundary in the south-east ((vi) above) may also contribute to the interpretation of the boundary. Even if one allows for a difference in competency between Units 1 and 2, one should expect the boundary to be folded somewhat in accordance with the macroscopic folds present in the younger Unit 2. However, in Unit 2, a crush zone has been mapped, trending approximately magnetic north between north-south grid lines 100 and 110 (Figs. 1 and 2). This separates the boundary from the macroscopically folded province of Unit 2 by a smaller area of Unit 2 in which macroscopic folding is not apparent. The interpretation in this case is, then, that possibly the crush zone represents a fault; if this is not the case the evidence requires a fault along the boundary. Both possibilities could apply.

One concludes that the boundary between Units 1 and 2 is not stratigraphic and that the only alternative explanation requires the boundary to represent the effect of a fault. The configuration of the boundary would seem to require either folding of the fault (a most unfortunate possibility), or the existence of more than one fault. The writer suggests that it is premature to guess at the exact nature of the fault. It seems necessary to search in adjacent areas for additional evidence concerning the nature of the boundary between Units 1 and 2. Ideally, the actual boundary should be observed in ~~actual~~ outcrop. The following discussion of the stratigraphic sequence has been presented with the above conclusions in mind.

2. Stratigraphic Sequence

Any stratigraphic sequence presented for the area studied must be extremely tentative. Causes contributing to the uncertainty include the general lack of outcrop which prevents the observation of continuous stratigraphic sections in surface outcrop. The poor outcrop also severely limits the tracing of individual beds, and this fact combined with lack of distinctive marker beds limits interpretation of their structural configuration. It is also noted at this stage that a large part of the difficulty in tracing individual marker beds could be caused by rapid facies changes along strike as an examination of distribution of rock units on Fig.1 suggests. For these reasons it seems futile to present thicknesses of various units in the stratigraphic succession. A general outline of the stratigraphic sequence is presented in Table 1 and also with Fig.1. The boundaries between subunits were not observed in outcrop.

TABLE 1

THE STRATIGRAPHIC SEQUENCE - ANGASTON AREA

Western Side of Mapped Area	Eastern Side of Mapped Area
YOUNGEST	
ROCK UNIT 2	ROCK UNIT 2
Subunit 2B: Micaceous schists with interbeds of quartzite and lenses of marble	Subunit 2B: Micaceous schists with lenses of marble, impure marble and quartzites.
Subunit 2A: Marbles, impure marbles and lenses of quartzite and schist	

NATURE OF BOUNDARY CONJECTURAL

ROCK UNIT 1

Subunit 1C: Thick sequence of scapolite-spotted micaceous schists; cross-bedded and laminated; calcareous in part. Interbeds of quartzite and arkose. Quartzite near top (east side).

Subunit 1B: Dark grey, finely laminated and cross-bedded siltstones and silty micaceous schists; calcareous, pyritic or carbonaceous in part.

Subunit 1A: As for 1C

OLDEST

(a) Rock Unit 1

In general, the rocks of this unit are rich in lime, grey in colour and laminated. Various forms of cross-bedding are common and pyrite occurs as an accessory mineral in many beds, particularly in the beds of Subunit 1I

(i) Subunit 1A

The oldest rocks mapped can be found in the core of the anticline in the central part of the area. They occur as dark grey, laminated, sandy or silty schists, frequently having a white or light grey spotted appearance caused by ragged, oblong or roundish porphyroblasts of scapolite. The spots in some beds are so dense as to almost obscure the dark grey matrix.

Interbedded with the dark grey schists are massive white quartzites, more impure argillaceous quartzites and some hard, poorly-sorted beds which may be described as metagreywackes.

Although many exposures of this unit were not fresh, the Subunit is probably very similar to Subunit C stratigraphically above.

(ii) Subunit 1B

The rocks of this unit are characterised by their dark grey colour and absence of scapolite spots; they are generally sandy or silty micaceous schists or hard siltstones. Some beds are calcareous.

In fresh exposures, bedding is flaggy, and laminations common. The laminations can be extremely fine and planar (e.g. specimens A263-377, 291), or can outline small-scale cross-bedding (specimen A263-311). In some rocks the lamination is due to very fine-grained heavy minerals or graphite; in other rocks the lamination is due to irregular orange coloured surfaces of limonite, possibly after pyrite. Pyrite (or, in most cases, limonite after pyrite) can occur as scattered spots, or spots along bedding laminae (specimen A263-311). In some beds lamination is not apparent.

Many of the schists in this unit have a spotted appearance due to sugar-like aggregates of muscovite plates (specimen A263-337). In one of these beds a few quartzite pebbles up to ½ inch in diameter were observed scattered in a non-laminated carbonaceous mica schist (specimen A263-361).

(iii) Subunit 1C

This is a thick sequence of scapolite-spotted schists. The scapolite is commonly restricted to thin beds and the density of spots varies from bed to bed. Spots can be up to ½ inch in length. Bedding lamination is seen in many rocks, although it can be absent or obscured by scapolite spots. Current bedding is evident, varying in size from microcrossbedding to examples with foreset beds about one foot in length. (Plates 3 & 4.). Ripple bedding is present in some micaceous quartzites (specimen A263-24) and washout structures have been noted.

In this subunit, interbedded quartzites, argillaceous quartzites and arkoses are not uncommon but can rarely be traced for more than a few tens of yards. This may suggest that these beds are lenticular in nature. One exception is the quartzite near the top of Unit 1 which can be traced by discontinuous outcrops along most of the eastern margin of Unit 2.

(b) Rock Unit 2

From sedimentary facings in both rock units, it was deduced Unit 2 is stratigraphically above Unit 1. The nature of the boundary has been discussed above. It appears that the eastern and western sides of the mapped area show somewhat different parts of the succession represented by Rock Unit 2. These are discussed separately.

Western Part of the Area

Although the stratigraphic relations in this area are very obscure because of lack of outcrop, structural complexity, and, probably, facies changes along strike, a twofold subdivision of this unit has been attempted. It is stressed that this has been more for convenience at the present time than as a suggestion on which further stratigraphic work is to be based. Any difference in age between the two units is subject to doubt, particularly if the whole or part of one unit is considered to grade by facies change into whole or part of the other. However, it is assumed that Subunit 2A is possibly older than Subunit 2B, because the two appear to be part of a fold system which plunges moderately to steeply south (see Section C). It is therefore possible that the two subunits are separate units in corresponding parts of the eastern limb of a south-plunging syncline. This is suggested by the trends immediately south of 070360.

(i) Subunit 2A

The Subunit consists of medium to coarse-grained marbles with minor clastic beds. Some marbles are almost pure, but many are scapolitic and/or ampibolitic, probably representing originally more impure limestones. Silicification and other secondary effects including kunkar cappings prevent tracing of individual marble beds for more than a few tens of yards. This applies particularly to the more impure varieties. Thin interbeds of calcareous, sandy or silty schists rich in phlogopite, amphibole or scapolite are common in the marbles and probably represent beds of clastic origin. A few thicker clastic beds can be seen with the marbles. These are mainly micaceous schists - similar to those in Subunit 2B - and quartzites which are generally rather argillaceous or calcareous.

A sequence of thinly interbedded marbles and calc-silicates is seen in a short creek section in the north-western part of the area. Starting from 084014, the section west along the creek exposes calcareous siltstones and fine-grained sandstones, thinly interbedded with lenticular sandy and silty marbles. These grade into thinly interbedded calc- schists, calc-silicates and lighter coloured impure marbles (Plate 5).

(ii) Subunit 2B

This unit comprises a sequence of silty or sandy micaceous schists with occasional interbeds of quartzite and micaceous quartzite up to 30 ft. thick. Lenticular beds of marble similar to the marbles in Subunit 2A have been mapped and appear to intertongue with quartzites and the finer clastic beds.

Bedding is commonly thin to laminated and is usually shown by a change in proportion of quartz to mica; many rocks could be described as gneisses. Irregular heavy-mineral banding or lamination is characteristic of the ferruginous quartzites. Sedimentation structures are not uncommon; various forms of crossbedding occur, including ripple bedding (Plate 7). Washout structures have been noted (Plate 8), and sedimentary slumping was seen at one locality (Plate 9).

Rocks of this subunit are characterised by a metamorphic development of garnet, staurolite and andalusite.

Eastern Part of the Area

On the eastern side of the area the succession exposed overlying Unit 1 is similar to that exposed on the southwestern side. The extensive development of marbles seen in the north western corner has not been seen on the eastern side of the area. The succession has therefore been broadly equated with Rock Unit 2B of the western side. The lithologies differ only in the absence of ferruginous quartzites on the eastern side.

(3). Correlation

Except for the writer's modification of the position of its eastern boundary, Unit 1 of the present work is the unit assigned by Coats and Thomson (1959) to the Lower Glacial and Interglacial Sequences of the Sturtian Series. They report observation of a 'boulder bed' in the Lower Glacial unit (personal communication) as evidence suggesting glacial origin of beds in the unit. However, although the exact location of this reported occurrence has not yet been ascertained, the writer has not recognised a bed of this type despite detailed field investigation. It must be noted also that unsorted coarse clastic beds have been subject to many and varied genetic interpretations (e.g. Schemerhorn and Stanton, 1963).

The writer prefers not to make an attempt at regional correlation at the present time. Such an attempt is premature considering the uncertainty surrounding stratigraphic relationships in the area studied.

SECTION B : METAMORPHISM

Introduction

Amphibolite facies metamorphic rocks occupying the central portion of the Mt.Lofty Range metamorphic belt have been investigated in areas south of, and including the Tanunda Creek area. Granitised gneisses occupy the core of this belt of high grade metamorphism and include the Tanunda Creek gneiss (Hossfeld, 1925; Chinner, 1955). The centre of this gneiss lies about 4 miles south-west of the amphibolite facies metamorphic rocks area mapped in the present work. Chinner (1955) in the Tanunda Creek region, and Mills (1964) in the Springton area, 10 miles to the south-east of the gneiss, have carried out detailed investigations of the eastern Mt.Lofty Range amphibolite facies metamorphism.

The facies classification of Turner (Fyfe, Turner and Verhoogen, 1958; Turner and Verhoogen, 1960) is not sufficiently general enough to make allowance for the apparent combined effects of 'regional' and 'contact' metamorphism shown by the regional andalusite-staurolite type of metamorphism described from certain areas. Since this type has occurred in the Angaston area, it has been found difficult to use present facies concepts as an aid in describing the metamorphic mineral assemblages in the area. For this reason, and because of the preliminary nature of the work undertaken by the writer it was thus thought most convenient to map mineral isograds, based on the first appearance of index minerals. However, the areas of exposed rocks containing index minerals (in particular, staurolite and two aluminosilicate polymorphs, andalusite and sillimanite) were found to be rather limited - not only because of poor outcrop conditions, but also because of the relatively small size of the area studied in this work. It appears also that the rocks of Unit 1 probably have bulk compositions unsuitable for the development of index minerals. Thus it has only been possible to the present time to tentatively map the approximate position of one isograd in the area.

The isograd mapped is based on the first appearance of andalusite. Fig.4 shows the approximate position of the isograd together with the noted occurrence of staurolite, garnet, andalusite and sillimanite. From the limited data it is noted that staurolite probably appears before andalusite in the present area. The validity of this statement and the existence of the andalusite isograd is discussed later in the section. The tentative use of the isograd enables the metamorphic sequence to be subdivided for subsequent discussion into two zones:

(1) Staurolite Zone.

(2) Andalusite-staurolite zone.

- where the staurolite zone applies to rocks in which staurolite has appeared but not andalusite.

Rocks with ten to twenty percent mica minerals have been considered as sandy schists, those with 20 - 50% micas as semi-pelitic, and those with greater then 50% micas as pelitic. Since the rocks of Unit 2 show the index minerals which have been used as indicators of grade these are discussed first.

1. Metamorphism of Rock Unit 2

(a) Aluminous semipelitic and pelitic schists.

(i) Appearance and texture.

Pelitic schists constitute a relatively minor part of the rocks seen in surface outcrop, and are commonly only seen where interbedded with more resistant sandy layers. One assumes, however, that pelitic schists are much more abundant in the sequence than is seen in outcrop. Because of their paucity, and because of the similar mineral assemblages to the semi-pelitic schists, metamorphism of both the semi-pelitic and pelitic schists are considered together.

Rocks of the group rarely have a grain size exceeding 0.5 mm.. There appears to be some decrease in grain size, particularly of quartz, from southwest to northeast; the average grain size of quartz on the western side of the anti-cline is greater than 0.2mm., while that on the eastern side is about 0.1mm.. Original sedimentary grain outlines have not been observed in thin section, and the textures approach granoblastic in many cases.

Macrosedimentary structures involving beds of this type have been preserved, and bedding lamination is distinct in many cases (Plates 7,8 & 9.). The laminations are usually characterised by an abundance of mica. Micas in these laminations have a strong tendency to lie parallel to cross-cutting cleavage or schistosity, particularly where the second foliation is at a large angle to the bedding (e.g. specimen A263-246). In addition, the mica minerals are commonly elongate parallel to the cleavage/bedding intersection. Later deformations (Section C) have, in certain places, produced recrystallisation and dimensional reorientation of the micas, which lie parallel to the limbs of micro-crenulations; only in a few sections was reorientation observed to have produced complete transposition of bedding or cleavage to form a new crenulation cleavage. In more quartz rich layers crenulations are not developed, but in some cases micas can be found to be growing between those quartz/quartz grain boundaries approximately parallel to the limbs of crenulations formed in adjacent micaceous layers.

(ii) Petrography.

The pelitic and semipelitic schists maintaining an excess of alumina are characterised by the presence of staurolite and aluminosilicate polymorphs, andalusite and sillimanite.

The major minerals commonly observed in these rocks are: quartz, biotite, muscovite, chlorite, garnet,

FIG. 5

AKFM tetrahedra representing common mineral assemblages in aluminous semipelitic and pelitic schists of Subunit 2B.

Minerai compositions plotted are approximate only.

Abbreviations: And = andalusite; St = staurolite, Mu = muscovite; Ga = garnet; Bi = biotite.

Diagrams a - e represent assembalges (1) - (5) respectively, of the andalusite - staurolite zone. Some of these also correspond to staurolite zone assemblages. Note the apparent disequilibrium represented by diag. b.

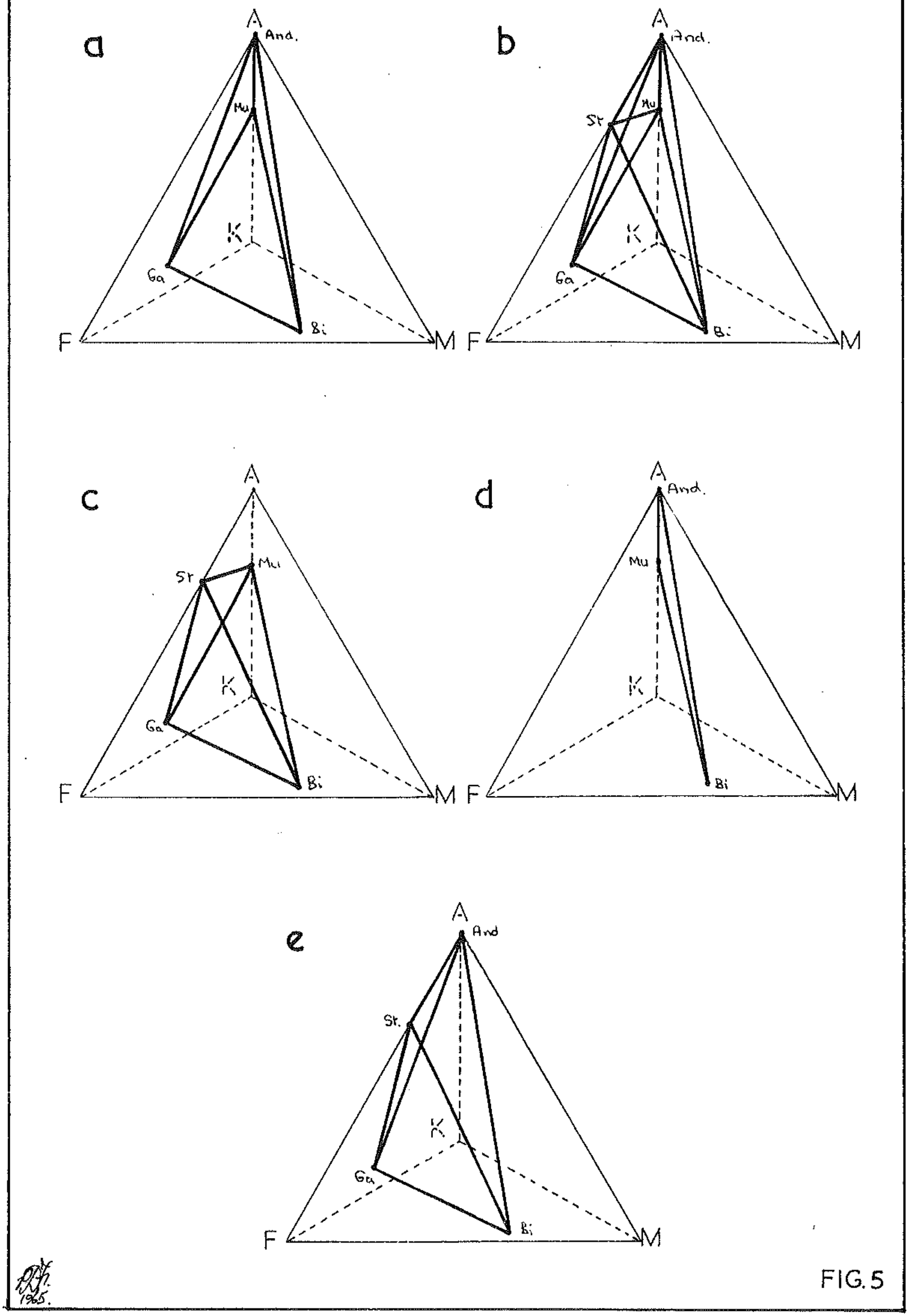

FIG. 5

FIG. 6

Explanation as for Fig. 5.

Diags. a - e represent assemblages (6) - (10) respectively of the andalusite - staurolite zone.

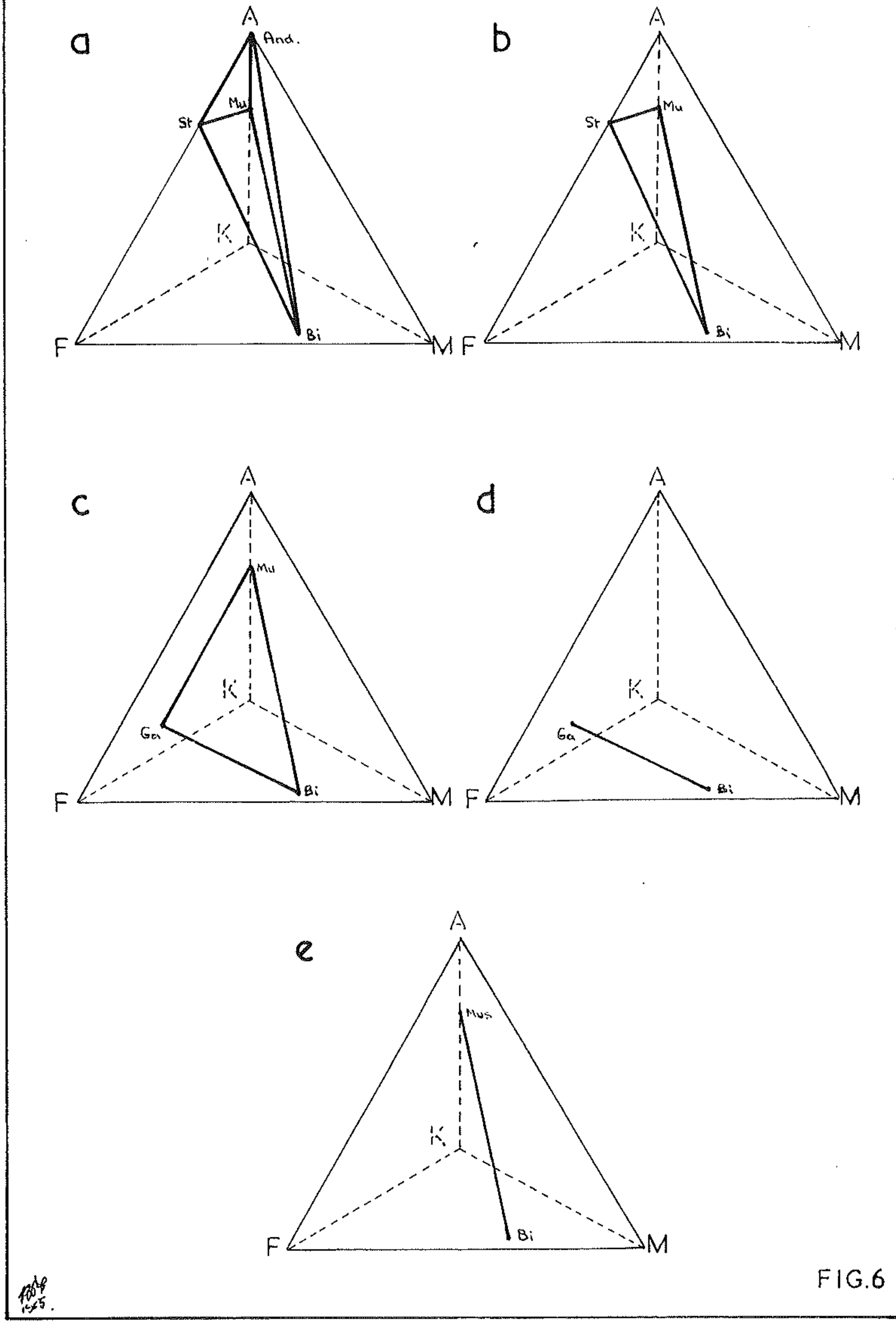

FIG.6

staurolite and andalusite; less common are plagioclase, rare potassium feldspar, and sillimanite (fibrolite variety). The following accessory minerals were observed: zircon, apatite, bluish-green tourmaline, and iron oxides. The mineral assemblages are listed below and summarised on the AKFM tetrahedra shown in Figs.5&6. All rocks examined contained quartz and biotite and these minerals are assumed to occur in all assemblages listed. Plagioclase is usually very minor when present.

Staurolite Zone

(1) Muscovite.

(2) (Plagioclase) - garnet.

(3) (Plagioclase) - muscovite - (muscovite porphyroblasts) - staurolite.

(4) (Plagioclase) - muscovite - (muscovite porphyroblasts) - (chlorite porphyroblasts) - staurolite - garnet.

Staurolite occurs in this zone as idioblastic to skeletal porphyroblasts up to 2 cm. in length, but more commonly less than a few mm.. Interpenetration twins can be seen in many thin sections (Plate 11). Most grains are poikiloblastic with inclusions of quartz and some iron oxides; a few grains show a thin rim almost free of inclusions. Staurolite is commonly surrounded by quartz of grain size slightly larger than the matrix quartz. Since these areas are deficient in micas, the indication is that staurolite has grown at the expense of biotite, leaving quartz/quartz grain boundaries free to enlarge as the quartz recrystallises to the larger grain size. Staurolite can be restricted to quite thin sedimentary layers (specimen A263-419; Plate 12); the occurrence of the mineral must therefore be intimately related to the bulk chemical composition of the rock.

Rocks containing staurolite are frequently seen in thin section to contain porphyroblasts of chlorite. These occur as disoriented sheaves or fan-shaped aggregates which may replace micas. The chlorite may have purplish or brownish pleochroic haloes surrounding minute inclusions of monazite or zircon. It has been suggested (Halferdahl,1961) that staurolite forms from chloritoid, but relic chloritoid has not been observed in the rocks of the area, and the supposed transition has seldom been identified elsewhere. Except for late stage coronas around staurolite, the chlorite porphyroblasts do not seem to be directly associated with the staurolite, although they do seem to occur in rocks with staurolite and/or aluminosilicates (in the staurolite - andalusite zone) and not in assemblages without these minerals.

In the more pelitic layers, biotite occurs interleaved with muscovite to form continuous mica trains. The pleochroic scheme is commonly Z = red-brown to X = pale brownish yellow. Some more greenish micas have been observed. Where the micas are less dominant, they tend to form as single flakes along the quartz/quartz grain boundaries, parallel to the latest imposed fabric - whether it be slaty cleavage or crenulation cleavage. In these rocks the quartz-rich matrix approaches a granoblastic texture: the texture is close to equigranular and grain boundaries are slightly curved or straight, with many triple-point junctions - the latter being taken to represent a close approach to textural equilibrium (Voll, 1960).

Muscovite can occur as porphyroblastic plates up to 1.5mm. in length . Occasionally these are seen to crosscut biotite trains (Plate 13), but in most cases they are aggregated in knots (e.g. specimens A263-125, 234), which whather in relief on exposed surfaces (Plate 14). The knots commonly have stumpy square prismatic forms (Plate 15), and in thin section are seen to contain, in addition to muscovite, quartz, relic biotite and specks of iron oxide. Similar prismatic knots have been reported by Mills (1964), and Hietanen (1963). Commonly the quartz is included in sieve-like muscovite. The occurrence of albite in the knots reported by Mills, has not been proved in the present area. Plagioclase is detected as odd grains in some sections, but is too small or sericitised for reliable optical determinations.

Andalusite - Staurolite Zone

The mineral assemblages common to this zone are listed below. (All assemblages include quartz and biotite as additional phases):

(1) (Plagioclase) - muscovite - (chlorite porphyroblasts) - andalusite - (sillimanite) - garnet.

(2) (Plagioclase) - muscovite - andalusite - (sillimanite) - staurolite - garnet.

(3) (Plagioclase) - muscovite - (muscovite porphyroblasts) - (chlorite porphyroblasts) - staurolite - garnet.

(4) (Plagioclase) - muscovite - (muscovite porphyroblasts) - (chlorite porphyroblasts) - andalusite - (sillimanite).

(5) Andalusite - staurolite - garnet.

(6) Muscovite - andalusite - staurolite.

(7) (Plagioclase) - muscovite - (muscovite porphyroblasts) - (chlorite porphyroblasts) - staurolite.

(8) (Plagioclase) - muscovite - (muscovite porphyroblasts) - (chlorite porphyroblasts) - garnet.

(9) (Plagioclase) - garnet.

(10) Muscovite.

In this zone, andalusite appears rather than the prismatic muscovite knots mentioned above. The transitional stage with skeletal andalusite forming in the knots was observed in thin section (A263 - 133; Plate 16). When andalusite is a stable phase in the area it forms large prisms up to 1.5 cm. in length; these weather in relief on exposed surfaces (Plate 17). The bedded nature of andalusite as well as staurolite is obvious in many outcrops (Plates 18).

In thin section the idioblasts of andalusite show poor grain boundaries and are sieved with matrix inclusions. In some cases the inclusions increase in size towards the rim, indicating andalusite crystallisation concomitant with increasing grain size of the recrystallising matrix. Andalusite has been seen enclosing staurolite, indicating the earlier crystallisation of the latter (Plate 19). The staurolite is fairly idioblastic, showing little tendency to undergo reaction with andalusite. Late stage alteration of andalusite produces coronas of, or complete replacement by shimmer aggregates of sericite; the occurrence of muscovite knots with chlorite cores probably also represents a late stage alteration of andalusite, relics of which are occasionally present (Plate 20). Many andalusite idioblasts show augen or caries-shaped boundary modifications of quartz and micas, mostly sericite (A263 - 94 , 166, 673 ; Plate 21 &22). The micas are parallel to the poor cleavage directions or square outlines of the andalusite in some cases, and appear to parallel the limbs of crenulations in the schistosity in others. It is not apparent whether these augen, which resemble similar augen seen confined to the matrix elsewhere (Plate 40), represent late stage alteration of andalusite or, an earlier feature inherited from the matrix by the crystallising andalusite.

Staurolite in this zone has a similar occurrence to that in the staurolite zone. The mineral can be readily found coexisting with andalusite. As in the lower zone, the staurolite appears to grow at the expense of some biotite. Pink idioblastic garnets are not uncommon and also appear to grow in some cases at the expense of biotite. Interleaved muscovite and pleochroic red-brown (Z) to pale yellow (X) biotite are commonly well oriented in the matrix; however, a less regular orientation is frequently seen in the vicinity of porphyroblastic grains. Odd grains of plagioclase occur, but sericitisation or small grain size prevented optical determinations.

Sillimanite has been detected in thin sections from four localities in the more southern areas of this zone. Sillimanite occurs as odd bundles of fibrolite closely associated with andalusite. These areas of early nucleation of sillimanite are usually observed in mica trains close, but not necessarily adjacent to andalusite grains (specimens A263 - 94b, 95, 673 ; Plate 23); growth of fibrolite along andalusite grain boundaries has been observed, however (Plate 24) . Biotite does not appear to be involved in any reaction responsible for the formation of fibrolite; its role may be nothing more than a favourable site for nucleation (Chinner, 1961; Mills, 1964.).

(b) Sandy Schists.

(i) Appearance and Texture.

The sandy schists are quite abundant in the exposed succession of Rock Unit 2,occurring as numerous interbeds with the more pelitic rocks of the group. Micas frequently define good bedding lamination, but when cleavage cuts the lamination at a high angle, are well oriented parallel to it. Large and small scale sedimentary structures are well preserved. As in the more pelitic rocks grain size rarely exceeds 0.5 mm..

(ii) Petrography.

As expected, the ubiquitous occurrence of staurolite and/or aluminosillicates seen in the more pelitic rocks is not observed in these rocks. Andalusite is absent but odd small (0.1 mm.) poikiloblasts of staurolite are present in some rocks (e.g. specimen A263 - 136.). Idioblastic pink garnet is common - occasionally up to 1 mm. in diameter. Some show radial quartz inclusions described earlier (Plate 23). As in the more pelitic schists , garnet can b seen growing at the expense of some biotite. A few thin sandy beds are rich in poikiloblastic garnet - occasionally up to 30%. Quartz has noticeably increased in grain size in these beds, presumably due to the disappearance of some biotite originally obstructing the growth of grain boundaries (Plate 26).

Biotite is of the pleochroic red-brown (Z) to pale yellow (X) variety, and tends to occur as discrete flakes between those quartz/quartz grain boundaries parallel to the foliation. Muscovite is noticeably scarce in the sandy schists, and is rarely interleaved with biotite. It usually occurs as somewhat skeletal, disoriented plates.

Quartz is seen to have a strong tendency to form granoblastic texture with gently curved or straight grained boundaries meeting in numerous triple-point junctions.

(c) Marbles.

Marbles are quite common in the Angaston area, generally cropping out as low pavements. Particularly along the western margin of the area, the more extensive masses form rounded hills. The purer marbles outcrop as such, but the more impure varieties are almost obscured by kunkar or silicification in many places; these secondary products are quite extensive along the western margin of the area.

The proportion of silicate minerals in the marbles varies from less than 1% to 50%. The marbles containing a large proportion of silicate minerals are usually seen as odd intercalations in fairly pure marbles, or as alternating thin interbeds with calcsilicates.

All the marbles are at least medium grained, and many are coarse grained. As indicated earlier they can show compositional inhomogenieties in the form of impure marble or calcsilicate bands; these are commonly highly folded (Plates 27-29). It is probable that these interbeds represent more silty or argillaceous layers in the original limestone. A new metamorphic layering has not been observed in these rocks, but a new foliation has been formed, shown by the flattening of calcite grains. Although this foliation is difficult to measure it is thought that it represents axial plain cleavage of the primary deformation. Micas are generally parallel to this foliation also. Scapolite prisms, and occasional amphibole prisms lie in the foliation to produce a pronounced lineation (Plate 30).

Mineralogy and Petrology.

The major minerals observed in the marbles are quartz, calcite, plagioclase, potassium feldspar, scapolite, biotite-phlogopite, muscovite and actinolite - tremolite, with accessory sphene, apatite, zircon, graphite, pyrite and magnetite.

Mineral assemblages are extremely varied, however some of the more common assemblages are listed below:

(1) Calcite - quartz.

(2) Calcite - quartz - phlogopite.

(3) Calcite - tremolite/actinolite - phlogopite.

(4) Calcite - scapolite - actinolite.

(5) Calcite - scapolite - actinolite - phlogopite.

(6) Calcite - quartz - phlogopite/biotite - plagioclase (An_{33}) .

(7) Calcite - quartz - scapolite - phlogophite - plagioclase (An_{37}).

(8) Calcite - quartz - actinolite - biotite - potassium feldspar - plagioclase (An_{12}).

(9) Calcite - quartz - scapolite - phlogopite.

The texture of calcite in the marbles is variable . It can be granoblastic with straight or gently curved grain boundaries - most commonly seen in the very pure marbles (e.g. specimen A263 - 81a); all transitions to inequigranular texture with sutured grain boundaries can be found. In marbles which have the appearance of having been partially mylonitised, various degrees of polygonisation are seen - mostly in the form of trains of granular calcite separating highly deformed larger grains (A263 - 812, 753; Plate 31). Deformation twin lanellae are very common and in many sections calcite is slightly biaxial.

Quartz can occur in granoblastic aggregates, in narrow trains presumably representing original silty or fine sandy laminae, or as odd scattered inclusions in calcite. Grain size is less than 1mm.- commonly about 0.2mm. In a few sections (e.g. A263 - 100) quartz forms irregular patches containing phlogopite and calcite grains.

The most common mica observed in the marbles has a pleochroism from pale orange-brown (Z) to colourless (X) and is probably close to the phlogopite member of the group. In the more impure marbles, the pleochroic scheme can be darker, from orange-brown (Z) to pale yellow (X), and is probably closer to the biotite end-member. Muscovite is seen very rarely in the rocks except as an alteration product of scapolite, where it can occur as small flakes forming parallel to scapolite cleavages. A few marbles show odd muscovite laths with no apparent preferred orientation.

Many of the marbles contain tetrahedral prisms of scapolite up to 2cm. in length, appearing on weathered surfaces as blue-grey needles. In thin section scapolite has relatively high birefringence (upper second order colours are shown), suggesting that the mineral is rich in the meionite (Ca) molecule as might be expected. In many instances the mineral is seen to be zoned, with concentric shells marked by difference in birefringence and also in some cases by concentric lines of minute apatite inclusions (Plate 32). The birefringence is usually lower away from the centre indicating a decrease in meionite content towards the margin. Calcite inclusions are seen in many grains, either as xenoblastic patches or blades parallel to cleavage directions; a number of grains have small calcite cores (Plate 32). In some sections tremolite and phlogopite can be seen to have replaced scapolite. In others a rim of sodic plagioclase has formed around the grain possibly representing a reaction similar to

$$(\underset{\text{marialite}}{3NaAlSi_3O_8.NaCl} + H_2O \rightleftharpoons \underset{\text{albite}}{3NaAlSi_3O_8} + NaCl + H_2O)$$

Mills suggests that a reaction of this type is responsible for late stage zoning in plagioclase in the marble, due to the formation of albite as a rim on the feldspar. However, feldspars were not observed in the sections where the suggested reaction appears to have taken place.

A few grains to a few percent of amphibole are present in some marbles. In thin section the amphibole is idioblastic, colourless to slightly pleochroic pale green. Optical tests suggest the amphibole is tremolite, ranging to actinolite in the coloured varieties. The mineral appears to be parallel to lineated scapolite if present. Inclusions of quartz and relic biotite or phlogopite are frequently observed.

Feldspars are detected in some sections. Plagioclase where determined had a composition ranging from An_{33} – An_{37}. Potassium feldspar is rare and has a moderately low $2V = 65^{\circ}$.

Some rocks contain a few percent of fine dust-like graphite occurring as disseminated inclusions and trails. Host minerals, particularly quartz and to a lesser extent calcite, show a marked tendency to clear the inclusions to grain boundaries.

The paragenesis of the observed minerals and mineral assemblages in marbles is not clear in many cases. The number of possible components in the more impure marbles makes the problem complex. Because of the scope of the present work only a brief discussion of some aspects of the metamorphism of marbles is presented at the end of the section.

Silicification of Marbles

Many marbles in the area appear to have been affected by surface alteration including silicification. As indicated, the products of this alteration are only found at or near the surface, although not limited to hilltops. Unaltered marble or impure marble can be found under the alteration products, or as remnants within them. Most of the silicified outcrops are hard masses of fine grained chalcedonic or opaline silica and/or secondary quartz. The silica can be spherulitic, botryoidal or colloform, and contain a few or numerous vughs or cavities; in other places the silica is massive and without form.

In a number of outcrops acicular or asbestiform masses of white to bluish-green amphibole are evident. The amphibole occurs as discrete prisms or clumps of prisms in an opaline or chalcedonic matrix, or can make up most of the rock with minor interstitial opal or chalcedony. Muscovite and/or talc are also present in some silicified rocks. Thin sections A263 - 35a,-40b, -96,-541,-542,and-868 illustrate most of the above features.

2. Metamorphism of Rock Unit 1

(a) Scapolite Schists

(i) Appearance and texture.

These schists crop out poorly over most of the area covered by Rock Unit 1. Grain size rarely exceeds 0.5 mm. and is commonly about 0.05 mm.. No significant change in grain size could be detected from one part of the area to another.

The rocks characteristically have good bedding lamination where not obscured by porphyroblastic growth of scapolite. Crosscutting foliation (cleavage orschistosity) is not as well developed as in the schists of Unit 2. Where recognised, some micas show a tendency to be oriented parallel to the bedding foliation. Elongation of biotite parallel to the intersections of the cleavage and bedding has been detected in some places. Sedimentation structures are well preserved.

(ii) Petrography.

The major minerals commonly observed in these rocks are quartz, biotite, muscovite, plagioclase and scapolite. More rarely chlorite and calcite occur. Accessory minerals include sphene≠, clino-zoisite, graphite, pyrite, zircon, apatite and ubiquitous bluish-green tourmaline.

All rocks contain quartz and biotite. In most sections the biotite was found to have the pleo-chroic scheme; Z = red-brown, Y = medium brown, X = pale yellow to colourless. Mineral assemblages on the whole are extremely similar. With few exceptions, the rocks contain in addition to these two minerals, scapolite, and from 5 - 15% plagioclas Calcite is an additional phase in a few rocks. Potassium feldspar was not observed in rocks containing scapolite.

The plagioclase commonly shows polysynthetic twinning, but in most sections sericitisation makes optical determination of composition difficult. However, generally the plagioclase is sodic with composition between An_5 and An_{10}. From the variation in maximum birefringence seen from section to section, scapolite appears to have variable composition from rock to rock as might be expected with a change of bulk chemical composition. The mineral can occur as ragged or rounded porphyroblasts, or as skeletal grains and relics associated with aggregates of muscovite plates and quartz. It is usually sieved with matrix inclusions. In some sections the scapolite is traversed by trails of sphene and even tends to grow along these trails for a short distance (e.g. A263 - 8). These sphene trails represent a fine bedding lamination.

Calcite, where present, is scattered through the matrix in single xenoblastic grains. Clinozoisite occurs in some sections, but is seen to be common around joints and is probably an alteration product due to a reaction similar to

$$(3\ (CaAl_2Si_2O_8)\ .\ CaCO_3 + H_2O \rightleftharpoons 2Ca_2Al_3Si_3O_{12}(OH)_2 + CO_2)$$

(b) Muscovite - knotted schists.

These rocks are mapped as Rock Unit 1b. In general, they are slightly more micaceous than the scapolite schists, averaging about 30% biotite; a better cleavage is thus more commonly seen.

A characteristic feature of the rocks is their 'sugary' weathered surface resulting from small knots of muscovite. In thin section the knots are seen to be composed of somewhat porphyroblastic, skeletal plates (0.4 mm.) of muscovite, occurring either singly, or as aggregates of several plates. (e.g. A263 - 312, 337, 361; Plate 33). The knots also contain matrix biotite, and quartz slightly coarser than the matrix. The muscovite does not appear to have a preferred orientation but in some cases (e.g. specimen A263 - 311) the knots appear to be dimensionally oriented parallel to the schistosity.

Calcite has been seen in some sections as scattered ragged grains. Plagioclase occurs in a few rocks, but reliable optical determination of composition was not possible. Accessory minerals include graphite, zircon and sphene in laminae or as scattered granules and dust. Pyrite, or limonite after pyrite, and bluish-green tourmaline also occur. The rocks are notable for the absence of scapolite, although a few relics were associated with the muscovite knots.

3. Intrusive Rocks - Metadolerites.

Apart from numerous quartz intrusions, the outcrop of intrusive rocks is restricted mainly to the south western corner of the area. The bodies usually outcrop in small patches of a few square yards where no contacts with the country rock can be observed. However, in the Lindsay Bridge Quarry (location: 067354) several small bodies are observed which have igneous contacts with the surrounding marble (Plate 34). Because of the likelihood, then, that these bodies are of intrusive origin the term 'meta-dolorite' has been used.

The rocks are generally hard, and dark green or green and white mottled on broken surfaces. The deep green colour is due to abundant (up to 65%) amphibole. White scapolite is found to constitute the lighter areas. The small plugs do not appear to have had any contact metamorphic effect on the marbles. The grain size of the latter does not show any change towards the contact. The only visible effect on the marbles is a pink colouration for some yards around the intrusive body.

In thin section (e.g. A263 - 73a, 73b and 102) the metadolorites are seen to be a complex intergrowth of coarse grained scapolite with common hornblende. The scapolite is often seen to completely surround hornblende grains in a manner which suggests a relic ophitic texture. Some scapolite grains are up to 7 mm. in diameter, but show a tendency to granulate to mosaics of smaller grains. Hornblende averages about 1 mm. in size and occasionally occupies relic euhedral outlines. The mineral has the pleochroic scheme: X = pale greenish-brown, Y = yellowish-green, and Z = dark bluish-green. A tendency to form granular mosaics is shown by this mineral also. Both minerals are poikiloblastic with inclusions of magnetite, sphene and calcite. Calcite occurs in xenoblastic grains or aggregates. Many sphene granules include cores of ilmenite, indicating the latter may have been responsible for its formation:

$(FeTiO_3 + CaO + SiO_2 = CaTiSiO_5 + FeO)$

This may explain the occurrence of magnetite.

Biotite may be present as dark orange-brown ragged flakes and appears to be forming from hornblende.

4. Discussion and Conclusions.

(a) Aluminous Schists of Rock Unit 2

(i) The tentative andalusite isograd merits some discussion. On the premise that the formation of andalusite probably depends not only on total pressure and temperature, but also the partial pressure of water vapour, one must assume that the partial pressure of water vapour varies regularly over the area.

The position of the isograd in the area is based partly on the interpretation of the prismatic muscovite knots. Both Hietanen (1963), and Mills (1964), who have also reported these structures suggest that they may indicate that the field of andalusite stability was just reached at a peak of metamorphism. After the peak had passed the andalusite would then be pseudomorphed by its reactants. If this were so, then in the present area, the position of the isograd, which has been placed between the first occurrence of stable andalusite and the occurrence of these knots, may have some meaning. The reaction by which andalusite first appears is open to question. Mills suggests that "the abundance of albite in association with the early andalusite crystals does suggest the break-down of paragonite in the presence of quartz is one possibility for the origin of andalusite." However, as mentioned earlier in the section, albite does not appear to be common in the knots of the present area. Perhaps a reaction similar to that expressed by Hietanen may be more important:

$$1 \text{ biotite} + 14 \text{andalusite} + 2 \text{quartz} \rightleftharpoons \text{almandite} + 1 \text{muscovite}$$

This reaction takes place without gain or loss of water and is thus invariant; it would not then be necessary to assume a regular variation of water pressure over the area. It must be pointed out, however, that the writer has observed no significant occurrence of garnet associated with the knots.

A second consideration involves the occurrence of staurolite. From the very limited data shown on Fig.4, it appears that staurolite becomes stable before andalusite and again disappears before andalusite. It is unfortunate that suitable rocks do not outcrop very far north on the western side of the area. However, some evidence is seen in thin section to support the idea that in the present area staurolite is stable before andalusite - idioblastic staurolite is seen in a few sections to be completely enclosed by later (presumably) andalusite (Plate 19). The earlier stability of staurolite relative to andalusite has been noted in a few areas (e.g. Hietanen, 1956; Zwart, 1963), but has not yet been recognised as the rule. As discussed recently by Albee (1965), the first appearance of andalusite and staurolite in the metamorphic sequence involves, not so much entering into the stability fields of the minerals, but primarily a progressive dehydration during progressive metamorphism. Hietanen's suggested reaction above would then appear to be slightly misleading.

(ii) The mineral assemblages summarised in the text and on Figs.5&6 suggests that there is disequilibrium in at least the rocks showing assemblage (2). Here there appear to be five phases present (andalusite, muscovite, biotite, staurolite, garnet), while the number of components (four) indicate from the mineralogical phase rule that only four should be present. No textural evidence was detected in thin section to suggest which of the phases were not in equilibrium. The difficulty which has thus arisen certainly indicates the desirability of chemical analyses, which the writer hopes to make the next phase of work on this problem. A chemical analysis on the mineral components would serve to plot their positions on the AKFM diagram more accurately; of more importance, total rock analyses of the rocks involved would enable one to suggest which mineral or minerals do not 'belong' in the assemblage by plotting this composition on the AKFM diagram. This would then give some object to a more searching petrographic and petrologic investigation.

(iii) Despite these anomalous mineral assemblages it is probable that most andalusite - staurolite assemblages in the area are stable. In addition it appears that in certain parts of the area, perhaps corresponding only to certain bulk compositions, the stability field of sillimanite has just been reached - indicated by the occurrence of fibrolite in some rocks. Thus it is most probable that the present area represents another where the classical Dalradian sequence of progressive metamorphism, chlorite - biotite - garnet - staurolite - kyanite - sillimanite, should not be considered the only 'normal' sequence of progressive regional metamorphism. Miyashiro (1961) has emphasised the importance of considering andalusite - staurolite - sillimanite metamorphism as a distinct metamorphic facies series of regional metamorphism - his low - pressure intermediate group.

(b) Marbles

(i) Muscovite is rare in the marbles, however it can be found with calcite and quartz as an alteration product pseudomorphing scapolite. It may be that possibly the formation of scapolite and the rarity of muscovite are complementary. Mills proposes that quartz, calcite and muscovite could react to form orthoclase and anorthite . It might be possible that in the presence of volatiles - either from muscovite or pore solutions - scapolite could then form from plagioclase.

(ii) The absence of diopside is interesting. It is probable that the grade of metamorphism has not quite reached that necessary for the formation of this mineral in these marbles. The association of phlogopite, calcite and quartz in some patches suggests diopside should have been formed if the reaction suggested by Ramberg (1952) is possible:

$$\underset{\text{phlogopite}}{KMg_3AlSi_3O_{10}(OH)_2} + \underset{\text{calcite}}{3CaCO_3} + 6SiO_2 \rightleftharpoons \underset{\text{K.feldspar}}{KAlSi_3O_8} + \underset{\text{diopside}}{3CaMgSi_2O_6} + 3CO_2 + H_2O$$

The phlogopite - quartz - calcite association could suggest the reaction has proceeded in the reverse direction after a peak of metamorphism, but one might expect the products to pseudomorph the diopside if this had taken place. This is not observed.

(iii) The alteration which has produced the 'silicified marbles' is probably not the result of metasomatism such as occurs sometimes in the late stages of metamorphism. Field evidence seems to preclude this possibility: the products of the alteration appear to be limited to surface or near-surface occurrences. Explanations as to the occurrence of tremolite and actinolite in the alteration zones are certainly lacking and this problem may warrant more extensive investigation. Similar silicified marbles with clumps of amphibole have been noted 10 miles to the north, in the Dutton area, by J.Worden(personal communication).

(c) Rock Unit 1

The origin of scapolite in most of these rocks is possibly similar to that in the scapolite marbles. The lack of muscovite except for late cross-cutting plates may support this idea, as the reaction mentioned proceeds at the expense of muscovite. It is possible that the sediments themselves were the source of volatiles. This seems likely because of the frequently observed bedded nature of scapolite in the field. In addition, accessory minerals rich in volatiles such as tourmaline and sphene are ubiquitous in the rocks and sphene can even be found in bedding laminae (e.g. specimen A263 - 8). It has been noted that scapolite even tends to grow along these laminae.

Disoriented muscovite porphyroblasts are particularly common in Rock Unit 1. Similar porphyroblasts were also noted in some schists of Rock Unit 2(Plate 13). These porphyroblasts are probably a late stage feature as they grow across all foliations. In the field, some beds (e.g. Subunit 1b), particularly the more pelitic, show the feature more prominently than others. This is probably due to the influence of initial composition. Billings (1938) in Western New Hampshire, and Mills (1964) in the Springton area have described similar features, and attribute the origin of the porphyroblasts to late stage regional metasomatism.

However, evidence (e.g. for the addition of K_2O) necessary to support this idea in the present area has not been sought.

Because of the lack of index minerals in this unit, care should be taken in assuming that because the overlying rocks (Unit 2) represent rocks of amphibolite facies grade, the Unit 1 rocks are of the same grade. It is to be noted that the average grain size of the lower unit is significantly smaller than in the upper unit. Thus the possibility that the rocks of Unit 1 are of lower grade should not be discarded in any later interpretation of the regional geology in the area - particularly when the uncertainty surrounding the nature of the boundary between the two units is considered.

(d) Metadolerites

It is probable that the abundant scapolite in these rocks is the result of the addition of volatiles to the original plagioclase. The fact that plagioclase was originally present is suggested by the occurrence of relic ophitic textures now occupied by scapolite and hornblende. The country rocks which were observed to be intruded by the metadolerites are marbles ~~are~~ containing scapolite. Thus it does not seem unreasonable to postulate these rocks as the source of at least some of the volatiles necessary for the scapolitization of the metadolerites.

Metadolerites with similar partial or complete scapolitization and/Or similar relic ophitic textures have been described from a number of places in the Mt. Lofty Ranges. These include the Woodside district (Alderman, 1931), the Tanunda Creek area 4 miles southwest of the present area, (Chinner, 1956), and the Cambrai area (Mills, 1964).

The paragenesis of hornblende in the rocks presents many complex problems which will not be discussed in detail. Various processes have been suggested, including the uralitization of original pyroxene, and subsequent re-crystallization of the uralite to a clear hornblende (e.g. Mills, 1964). These types of processes may have taken place - rare relic euhedral outlines are suggestive of pyroxene outlines rather than ~~amzibole~~ amphibole outlines. However, it should also be considered that the original magma may have crystallized hornblende if the partial pressure of water vapour had been high at the time of primary crystallization.

SECTION C : STRUCTURE

1. Folding

(a) Introduction

There appear to have been three major successive phases of deformation of the rocks in the Angaston area. These are recognised by the three different types of folded surfaces which have been produced. The axial surface of the first phase folds is marked by slaty cleavage which in many rocks has developed into a well defined schistosity. Crenulation cleavage represents the axial surface of folds which appear to be the result of ~~a~~ second and third phases of deformation. The occurrence of kink bands is considered to be the result of a later, ~~third~~ deformation. The bands are discussed in subsection 2.

The following terms have been used to represent structural elements, and are similar to those summarised by Turner and Weiss (1963):

Structural Surfaces	S_1	Bedding and transposed bedding.
	S_2	Slaty cleavage, as defined by planar orientation of flaky minerals.
	S_3	Crenulation cleavage.
	S_4	" "

Fold Axes

- $B_{S_1}^{S_2}$ or B_2 — Folds in bedded surfaces with slaty cleavage, S_2, parallel to the axial surface.
- $B_{S_2}^{S_3}$ or B_3, $B_{S_2}^{S_4}$ or B_4 — Folds produced in schistosity, with the development of crenulation cleavages, S_3 and S_4.

It should be noted that S_3 and S_4 cleavages cannot be distinguished in the field. Only in a few thin section could a crenulation cleavage (S_4) be seen to have over-printed an earlier one (S_3). Thus, except where the context leaves no doubt as to the meaning of S_3, S_3 has been used for convenience to represent either of the crenulation cleavages. This applies also to B_3 and B_4 folds. The nomenclature for lineations is similar to that of the particular set of folds with which the lineation is supposed to be genetically associated. Hence, B-lineations are those assumed to have been formed by the same deformation which produced the B_2 folds.

(b) Descriptive features of folding and fold style

(i) B_2 folds

These folds have been recognised on macroscopic and mesoscopic scales. Except in marbles, the number of mesoscopic folds recognised in the field was very limited. This is probably because of the absence of closures of macroscopic folds in the present area - in other areas the best development of smaller scale folds is commonly in the closures of macroscopic folds

The B_2 folding appears to control the shape of major tectonic features in the area and also the observed distribution of rock types.

The regional structure (Figs.1, 2 and 3)is dominated by a large anticline in the centre of the area. Although outcrop at either end of the structure is limited, the fold appears to close just outside both north and south margins. Certainly over most of the area folds appear to plunge steeply to moderately steep south, but the closing of the major fold to the north at the opposite end of the area is not quite expected from consideration of smaller scale structures in that area. (See later in this section) Smaller macroscopic fold closures are recognised in the area and these are also indicated on Figs.1, 2 and 3. Figure 7a shows the statistical fold axis (β) determined from data collected over most of the area: Fig.8a is a synopsis of all B_2 fold axes measured. The latter diagram also indicates the regional attitude of axial surfaces of the folds as generally dipping at steep angles to the east-northeast.

Mesoscopic folds have been measured in both the schists and marbles of Unit 2. They were not observed in Unit 1. The few folds measured in the schists have plunges varying from moderate angles to the south, through vertical, to steep angles north. The style of these folds is approximately concentric; this is probably because, although micaceous beds are numerous in these folds, the interbedded more competent, sandy layers tend to fold concentrically and control the over-all style. In some cases the folds are slightly appressed and show some characteristics of similar folding. Plate 35 and large thin sections A263-246 and -729 illustrate the fold styles. Folds in the marble commonly show strong transposition of S_1 surfaces into close parallelism with axial surface S_2 defined by flattening of calcite grains (Plates 27-29 & 36). Although the axial surfaces of the folds in the marbles appear to be planar the folds can be non-cylindrical in some areas. This is indicated by variation in plunge of the folds from outcrop to adjacent outcrop. The variation can even be observed in single outcrops. The regional plunge of these folds varies from shallow to moderately steep angles to the south.

(ii) B_3 and B_4 folds.

Macroscopic B_3 folds have not been recognised in this area. Two small folds in the western schists of Unit 2, are thought to be the only mesoscopic folds of this type recognised in the area. These folds have crenulations in the more micaceous laminae. Cremulation are parallel to the fold axis ; in addition, a poorly developed crenulation cleavage is parallel to the axial surface of the fold. The style of folding is open concentric (Plate 37).

The small scale mesoscopic to microscopic expression of B_3 folds is in the form of crenulations in earlier S surfaces(Plate 38). The crenulations can have a wave-length up to 3cm., although this is rare. They are only fully developed in pelitic layers, but micas in more sandy layers commonly show a marked parallelism to those in the crenulation of adjacent micaceous laminae.

The crenulations are mostly asymmetric: few show well developed crenulation cleavage. In some rocks though, crenulation cleavage becomes evident in thin sections at first as a slight displacement between the asymmetric limbs, and, in a number of rocks, as a complete trans-position of micas to form the new crenulation cleavage. In the field this cleavage can be recognised in some places by its less penetrative nature relative to earlier cleavages. Elsewhere, more penetrative cleavage similar to slaty cleavage is seen in thin section to be a crenulation cleavage. Crenulation or crenulation cleavage overprints some mesoscopic B_2 folds (e.g.speci-men A263-246), but does not appear to have changed the style significantly .

B_3 or B_4 structures have not been observed in the rocks of Unit 1.

The existence of two sets of crenulation cleavage (and hence two sets of crenulations) can only be recognised in thin section, although the spread in orientation of these elements is suggestive of there being more than one set. For example, in a few sections (Plate 39) porphyroblasts show helicitic structures which are not compatible with the present crenulation or crenulation cleavage seen in the section. This indicate that two crenulation cleavages can affect the same rock and probably one (S_4) was at least slightly later than the other (S_3).

(c) Lineations

(i) B_2-lineations.

Mineral elongations statistically parallel to B_2 folds are not uncommon in all types of rocks in the area. It is assumed (and can be observed in places) that these mineral elongations are parallel to the intersection of S_1 and S_2 surfaces. Minerals dimensionally oriented in this manner include biotite and muscovite in schists, and scapolite and amphibole in marbles.

(ii) B_3 and B_4-lineations.

The lineation formed by micro-crenulation of earlier S planes and/or intersection of crenulation cleavage of these planes has been discussed above.

A lineation approximately parallel to these lineations is defined by mineral augen. These augen can be perfectly circular in cross-section, and are slightly to extremely elongate parallel to the crenulation(Plates 40,41). The augen contain the same minerals as the matrix, but have a coarser grain size and are deficient in micas. The crenulation does not seem to have had a direct control in the growth of the augen, because they seem to be scattered randomly through the matrix. It is probable that since the B_2 and B_3 lineations are broadly co-axial (see below) that these lineations are in fact inherited B_2-lineations

(d) Structural Analysis

The available sources of structural data collected during the mapping program were subject to certain restrictions. Apart from the distribution of suitable rock types containing the various structural elements investigated, the variability of outcrop conditions in the area obviously prevented measurement of some elements in certain areas. Where possible, the source of data has been shown on the figures summarising them. A number of sub-areas, 1a, 1b, 2, 3, and 4 have been delineated in an effort to represent areas of structural homogeneity and/or for data locality reference. The location of these areas and also representative data concerning various structural elements are shown on Fig.3.

The data are summarised on Schmidt-Lambert equal area projections; contours were prepared by using a rotatable primitive overlay containing overlapping 1% ellipses whose shape was appropriate to their position on the net. This method gives more reproducible results than the Schmidt method using 1% circles. The method was suggested by Dr.A.W.Kleeman as a modification of the Strand (1944) method.

Following a present convention discussed by Turner and Weiss (1963), the statistically determined axis of folding obtained by plotting the pole to the circle of best fit drawn through poles of measured S segments is called β rather than π .

(i) Geometry of S_1 (Bedding).

The πS_1 analysis for the areas 1a, 2 and 3 is given in Fig.7a. A fairly well-defined girdle is shown whose statistical axis (β) plunges 55° in a direction 171°.

πS_1 analysis for subareas 1, 1a, 1b, 2 and 3 appear as Figs.7b - f. All these plots except 7d (area 1b) show concentrations corresponding to various parts of the collective diagram, but it is evident that most of the fold closures must be in area 3, unless folding in the other areas is isoclinal. It is most likely on consideration of Figs. 1 - 3, that area 1b represents only one limb of a fold and that the lack of points away from the maximum in the plot for area 2 is a bias caused by lack of outcrop in the area of fold closure. The diagram for subarea 1b is interesting, however . The limited data show a fairly well defined girdle whose statistical axis (β) plunges steeply in a direction 009°. This suggests that subarea 1b may be inhomogeneous with respect to the rest of the area. Proof of the inhomogeneity is given below.

(ii) Geometry of S_2 (Slaty cleavage).

The geometry of S_2 in areas 1a and 1b is shown in Fig.8c, and that for area 3 in Fig.8d. For areas 1a and 3 slaty cleavage or schistosity can be seen to strike north to just west of north, whil in 1b the orientation is markedly different - about east-southeast. It might be argued that the difference between subareas 1a and 1b is not statistically significant, particularly if more dat were available and had the effect of spreading both populations, causing them to merge into each other. However, the reader is referred to B_2 lineations plotted for these two areas, where further evidence is presented for inhomogeneity with respect to structural geometry associated with the first phase deformation.

(iii) Geometry of B_2 Folds.

The orientation of B_2 fold axes for the whole area is shown in Fig.8a together with poles of axial planes of these folds. Because of the lack of data few conclusions can be drawn. The most obvious feature is that the folds in the marbles appear to have axes plunging at shallower angles than those in the schists. The marbles from sub-area 4 have been plotted also on Fig.8b. Since mos of the marbles outcrop in the northern part of the area, one might deduce that therefore the regional B_2 plunge becomes progressively shallower towards the north, preparatory to plunging north (where, from geological boundary configuration, the macroscopic folding appears to plunge north). It is to be noted, however, that some of the most northern marbles show mesoscopic B_2 folds plunging moderately steep south (e.g. at locality 093431). It seems that in detail fold structure in this area is more complicated than macroscopic field relations suggest.

There are too few data to make a definite statement about the agreement between the β axes and the measured axes. But reference to Fig.7d shows that the two small folds are not significantly different from β for subarea 1b; this applies also to Fig.7f for subarea 3. A β axis could not be determined for subarea 1a, but the folds measured plunge more steeply to the south than the β axis shown in Fig.7a.

(iv) Geometry of B_2-lineations.

The B_2-lineations for areas 1a (dots) and 1b (crosses) are plotted in Fig.9b. The different populations resulting are further evidence of inhomogeneity between areas 1a and 1b. The lineations for area 1a show some spread, but are clustered about the β axis determined for areas 1, 2 and 3 (excluding 1b) from Fig.7a. The agreement between the β axis determined for area 1b (β_{1b}) from Fig.7d, and the lineation of that area is not quite so marked. However, the disagreement may not be significant without additional data.

The agreement between lineations, measured folds and statistical β for subarea 3 is excellent, as shown in Fig.9d.

B_2 lineations measured for subarea 2 are plotted on Fig. 9c. They show a tendency to spread from a shallow south-dipping maximum along a great circle striking 345° and dipping 70° west. The reasons for this are not clear: an attempt to divide area 2 into homogeneous subareas was not successful. It is to be noted that the great circle is of similar orientation to the spread obtained on the collective Fig.9a for the whole area. The spread could result from folding which is noncylindrical on a regional scale; however, using the present data no other evidence for this has been recognised.

(v) Geometry of B_3 and B_4 folds; geometry of S_3 and S_4 (crenulation cleavages)

Fig.10a summarises the geometry of micro-crenulations and mesoscopic B_3 folds. The spread of plots shown in this diagram is partially resolved in the separate plots for subareas 3, 1a and 1b (Figs.

10b – d). Asimilar spread is still apparent for areas 1a and 1b, but the plots for area 3 cluster around a maximum whose orientation is similar to that of B_2 lineations and folds for this area (compare Fig.9d). Thus in this subarea at least, it would appear that crenulation (B_3 folding) and B_2 folds are close to co-axial. For this subarea the measured data strongly suggest one set of crenulations. However, it is from this area that evidence of an early crenulation (e.g. thin section A263-652) is found. It is possible, then, that the present crenulation (B_4) is a result of overprinting of rocks with B_3 crenulation, to such an extent that obvious traces of the earlier crenulation have been destroyed. In the other two subareas it is also possible that the two crenulation-producing deformation have been active. This may explain the spread of plots mentioned. One would then have to assume that both deformations have been confined to certain restricted places in these areas, or that, if B_3 was wide-spread, the overprinting effect of B_4 has been more intense only in certain areas.

The geometry of crenulation cleavage is shown as a S_3 plot in Fig.11a. Although most poles represent cleavages with steep dips, their spread is remarkable. For this reason the diagrams 11b – d for subareas 3, 1a and 1b were constructed, in an effort to determine whether a particular well-defined population of crenulations (crosses) correspond to a certain population of planes (circles). Crenulation and corresponding cleavage poles are joined by arcs of small circles. Inspection of the figures does not reveal two obviously separate populations. The plot of subarea 3 is interesting, however, where the cleavage planes have been plotted also. These cleavages fan through a large angle about an axis approximately coincident with both the crenulation axis and B_2 fold axis.

(e) Discussion and Conclusions

The first deformation phase, which produced B_2 folds with slaty cleavage, appears to have been the most important phase in controlling the regional structural geometry. A similar control of macroscopic geometry by first phase deformation has been reported from the Springto area, 10 miles to the southeast of the present area (Mills, 1964). On the other hand, R.Offler presently working some 4 miles to the southwest of the Angaston area in the Pewsey Vale area reports (personal communication) that the last phase of folding - a crenulation cleavage movement - appears to have controlled the macroscopic geometry of Adelaide Supergroup rocks in that area.

The spread of crenulations has been partially resolved by considering subareas. A spread is to be expected in any case where the deformation producing crenulation has acted upon an already folded surface. It is significant that the area which is most homogeneous with respect to S2 (subarea

3 - Fig.8d) is most homogeneous with respect to the crenulations which are formed in this surface.

The inhomogeniety in crenulation cleavage, particularly in subarea 1, is not expected; the reason for this is not clear. Similarly the reason for fanning of crenulation cleavage about the crenulation axis and the B_2 fold axis is not known. The lack of data probably contributes to the difficulty in interpreting these features.

2. Faulting

In general, outcrop is too poor to allow recognition of faults in the area. The existence of a major fault or faults between the two major groups of rocks has been suggested and discussed in Section A.

In the more micaceous schists of Unit 2, kink bands were observed (e.g. Specimens A263-130c, 602; Plate 42). These structures consist of narrow ($\frac{1}{8}$ - $\frac{1}{4}$ in.) semiplanar bands, in which the strong schistosity has been kinked about two planes bounding the edge of the bands. The sense of movement in the kink bands was not determined. Fig.11e shows the orientation of a few measured kink planes (plotted as poles). The average orientation of the planes is close to horizontal. Recent interpretations of these structures attribute them to brittle deformation occurring at a late stage in the orogenic history of a region (e.g. Anderson, 1964: Dewey, 1965).

If the fault between Unit 1 and Unit 2 does exist, there may have been some renewed movement along it in late Tertiary times. This is suggested by field evidence between 109372 and 113367. The proposed major fault zone lies midway between these localities. On the top of a residual hill around 109372 the rocks of Unit 1 have been subject to deep weathering and are capped by a lateritic horizon - the erosion surface so formed probably representing part of the old Tertiary peneplain. A similar weathering of Unit 2 rocks around 113367 suggests that the Tertiary surface is also represented around this locality. The significant thing is that the two surfaces, on opposite sides of the intervening fault zone, are separated by a vertical distance of about 100 feet, suggesting movement along or near the fault zone in later Tertiary times.

SECTION D : GENERAL CONCLUSIONS

1. At the present time stratigraphic relationships in the area are obscure.

There are two major groups of rocks in the area. The older group constitutes a series of well-bedded and laminated scapolite schists. The younger group consists of pure and impure marbles underlying, or grading by horizontal facies changes into a sequence of aluminous schists with minor quartzites.

The boundary between the two major rock units is not a stratigraphic one. Evidence suggests the boundary is the result of faulting, the exact nature of which is not known.

Correlation of rock units with units in other areas seem inadvisable at the present time.

2. The rocks can be broadly stated as having reached the amphibolite facies grade of metamorphism.

Metamorphism has resulted in andalusite-staurolite assemblages in aluminous schists, characteristic of a distinct metamorphic facies series of regional metamorphism - Miyashiro's low pressure-intermediate group. Chemical analysis is required to interpret some of the disequilibrium assemblages observed in these rocks.

It can only be assumed that the rocks of Unit 1 have a similar metamorphic grade to those of Unit 2.

3. The area has undergone three main phases of deformation.

The macroscopic geometry has been largely controlled by the first phase of deformation which produced folds with slaty cleavage as axial plane.

Effects of second and third phases of deformation are apparent only in certain areas. Few second or third phase structures are recognised apart from microcrenulation and crenulation cleavage. Third phase structures are indistinguishable from second phase structures except where both are seen in thin section.

A late stage brittle deformation has given rise to kink bands in micaceous schists.

Faults in general have not been recognised because of poor outcrop. There may have been renewed movement in late Tertiary times along the postulated major fault zone between the two major rock units.

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FIG. 7

Structural Geometry

a. Subareas 1a, 2 and 3. 228 πS_1.

Contours: 1%, 2%, 4%, 8% of 1% area. Poles outside 1% contour plotted as dots.

b. Subarea 1. 113 πS_1 - dots.

4 B_2 - circled dots.

2 B_3 - squares.

c. Subarea 1a. 76 πS_1 - dots.

2 B_2 - circles.

d. Subarea 1b. 42 πS_1 - dots.

2 B_2 - circled dots.

2 B_3 - squares

e. Subarea 2 71 πS_1

f. Subarea 3 81 πS_1 - dots.

3 B_2 - circled dots.

FIG. 7

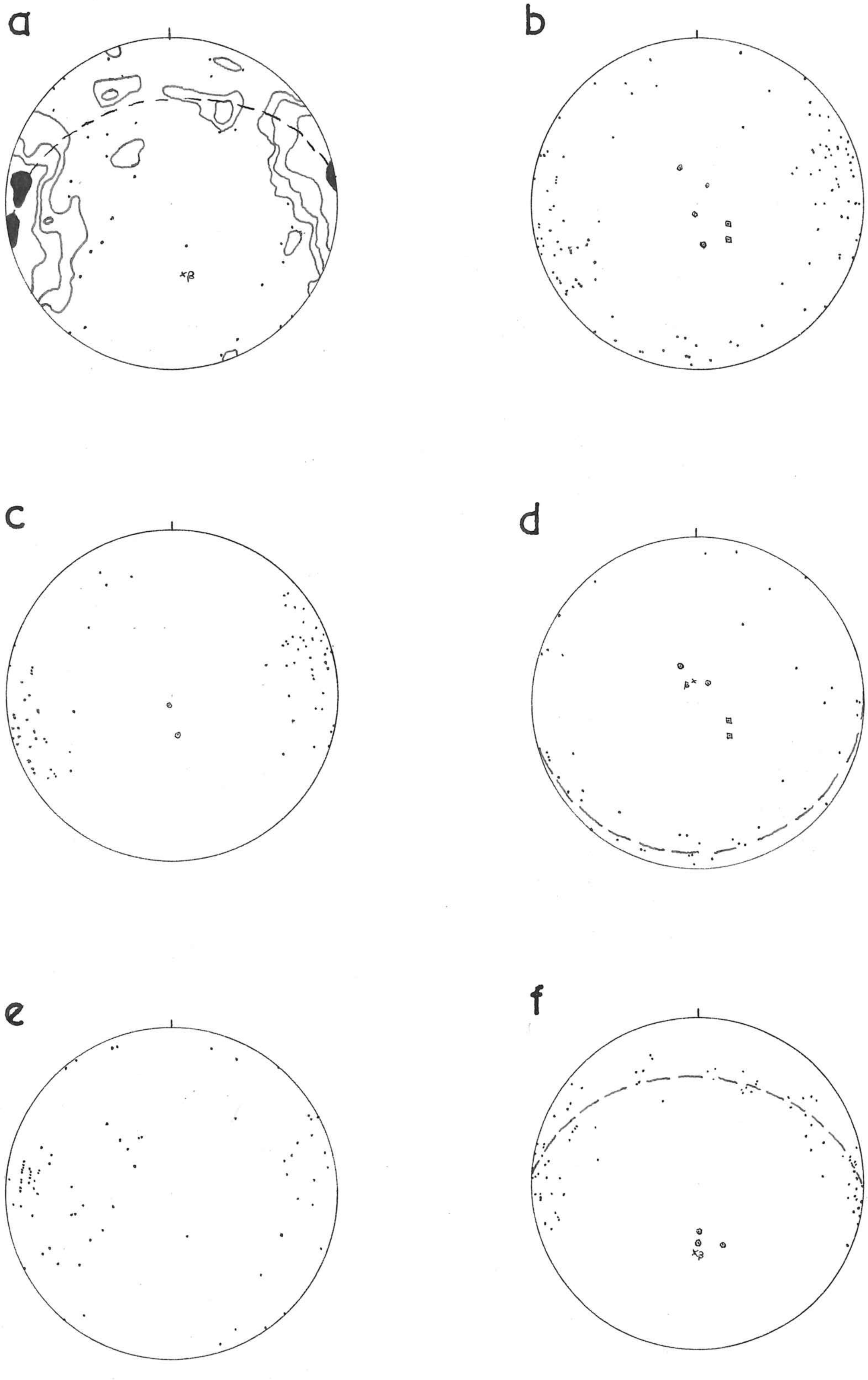


FIG. 8

Structural Geometry (cont.)

a. Whole area. 14 B_2 in schists - crosses.

8 B_2 in marbles - dots

8 axial planes of B_2, in schists - triangles

4 axial planes of B_2, in marbles - circles.

b. Subarea 4 10 B_2 - circled dots.

8 B_2 lineations - dots.

c. Subarea 1a 26 πS_2 - dots.

2 B_2 - circled dots.

Subarea 1b 9 πS_2 - crosses.

2 B_2 - circled crosses.

d. Subarea 3 29 πS_2 - dots.

3 B_2 - circled dots.

β -(from Fig. 7f.) - circled cross.

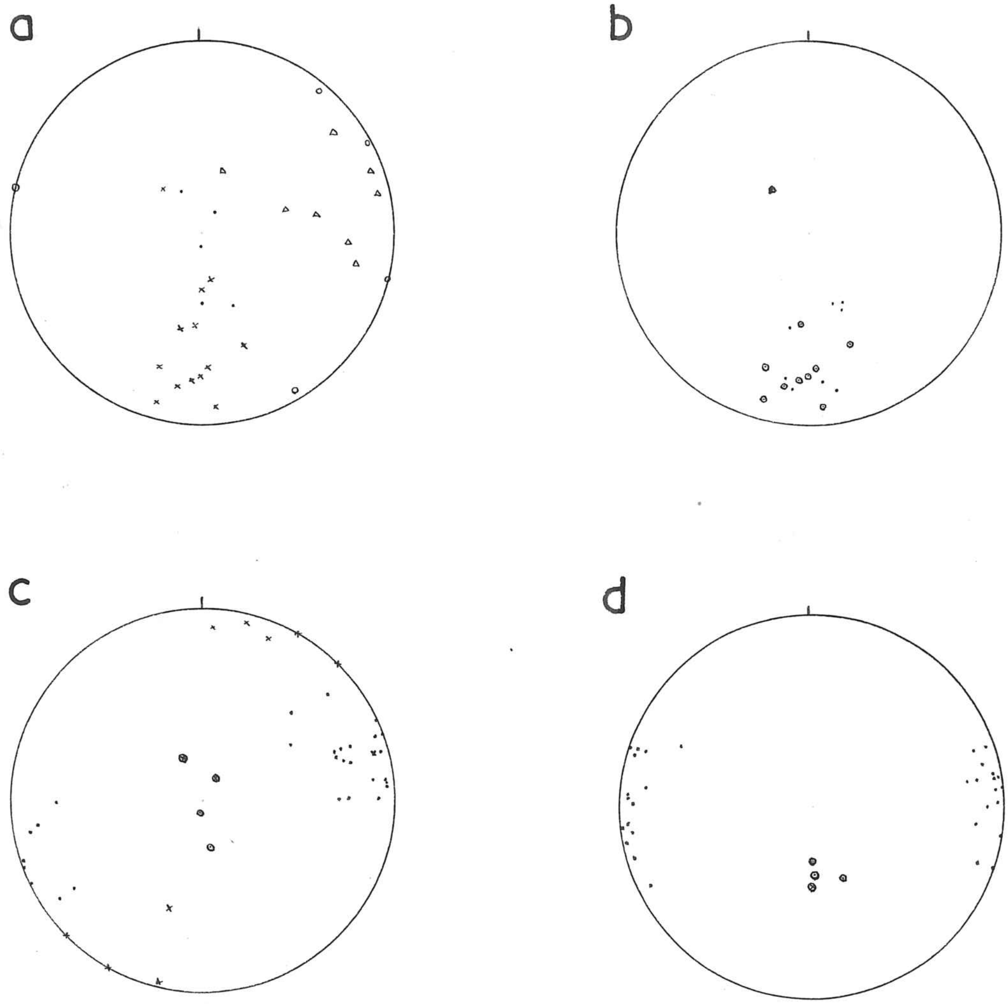


FIG. 8

FIG. 9

Structural Geometry (cont.)

a. Whole area 79 B_2 lineations.

b. Subarea 1a 19 B_2 lineations - dots

2 B_2 folds - circled dots

β (area 1a, 2,3) - Squared dot.

Subarea 1b 6 B_2 lineations - crosses

2 B_2 folds - circled crosses.

β - squared cross.

c. Subarea 2 30 B_2 lineations.

d. Subarea 3 14 B_2 lineations - dots.

3 B_2 folds - circled dots.

β (from Fig.7f) - squared dot.

FIG. 9

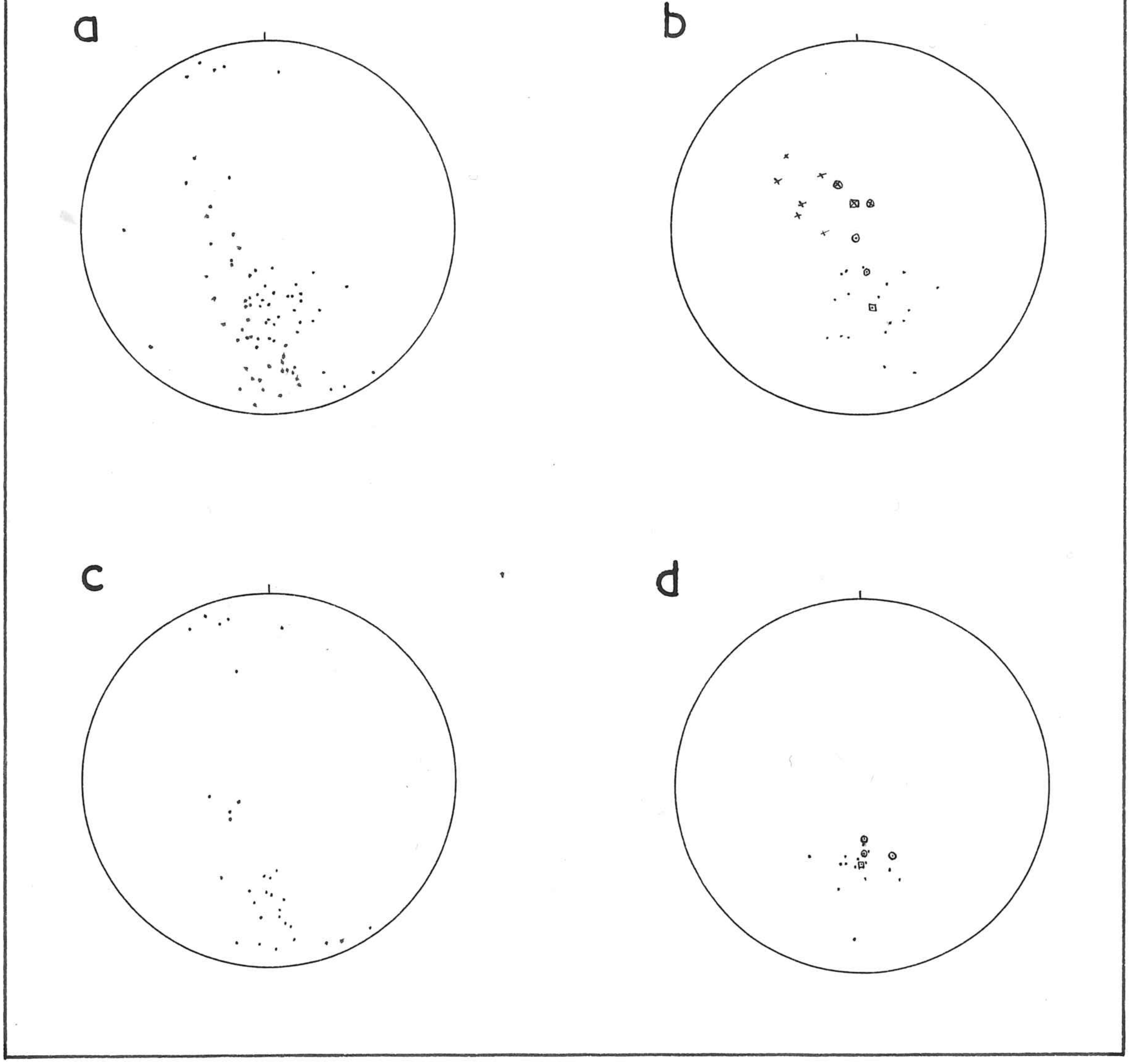


FIG. 10

Structural Geometry (cont.)

a. Whole area. 70 B_3 and/or B_4 lineations (microcrenulation) - dots

2 B_3 and/or B_4 folds - circled dots

b. Subarea 3 26 B_3 and/or B_4 lineations (microcrenulation)

c. Subarea 1a 24 B_3 and/or B_4 lineations (microcrenulation)

d. Subarea 1b 20 B_3 and/or B_4 lineations (microcrenulation)

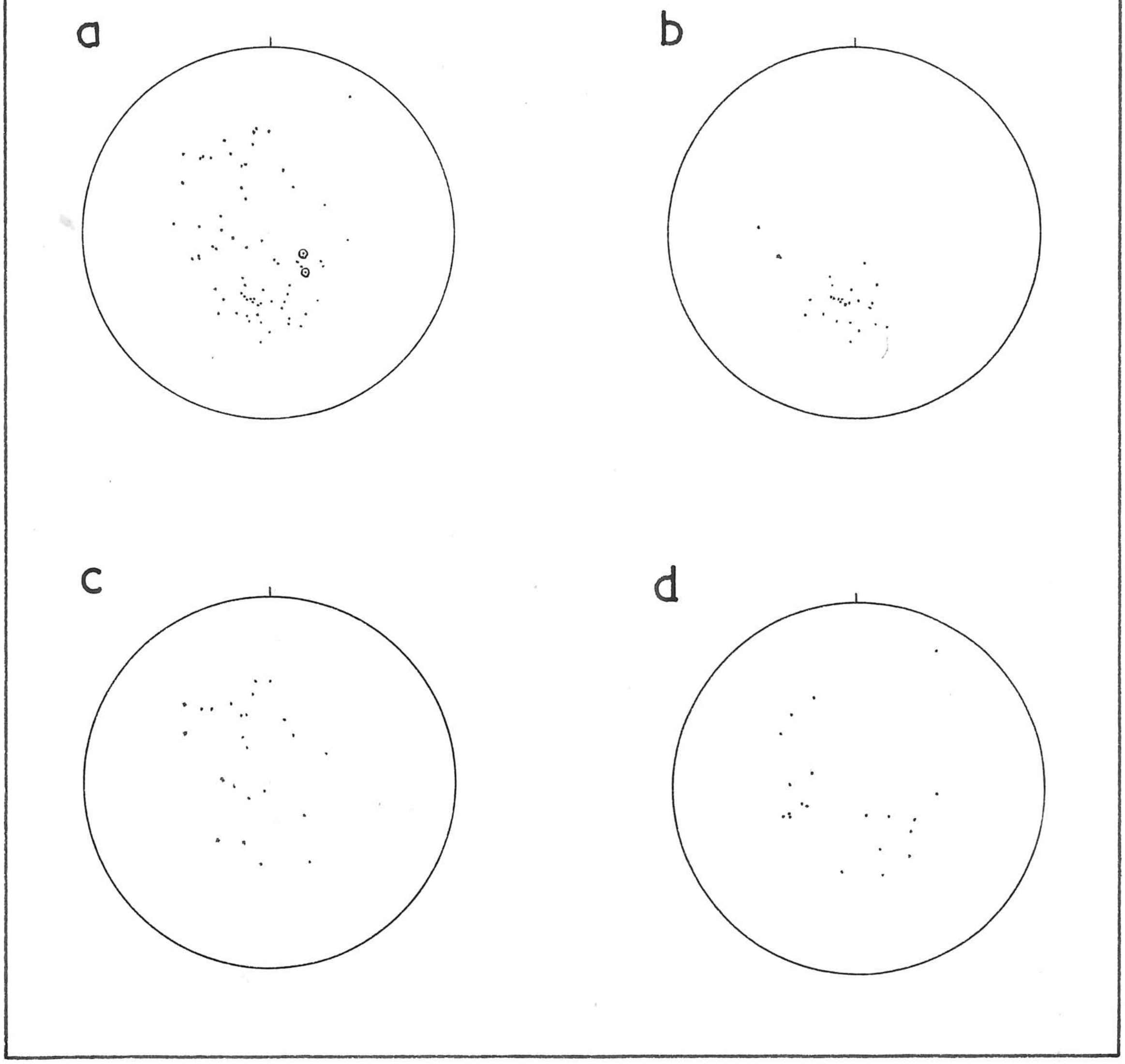


FIG. 10

FIG. 11

Structural Geometry (cont.)

a. Whole area 46 S_3 and S_4 (crenulation cleavage) - dots.

2 S_3 or S_4 (mesoscopic axial planes) - circled dots.

b. Subarea 3. 10 S_3 or S_4 - circles.

10 B_3 or B_4 lineations - crosses.

Arcs of small circles (solid) join corresponding lineations and (poles to) S_3 or S_4. S_3 and S_4 planes are dashed.

c. Subarea 1a 11 S_3 or S_4 - circles

11 B_3 or B_4 lineations - crosses

Lines as for b.

d. Subarea 1b. 10 S_3 or S_4 - circles.

10 B_3 or B_4 lineations - crosses.

Lines as for b.

e. Poles to kink planes.

FIG. 11

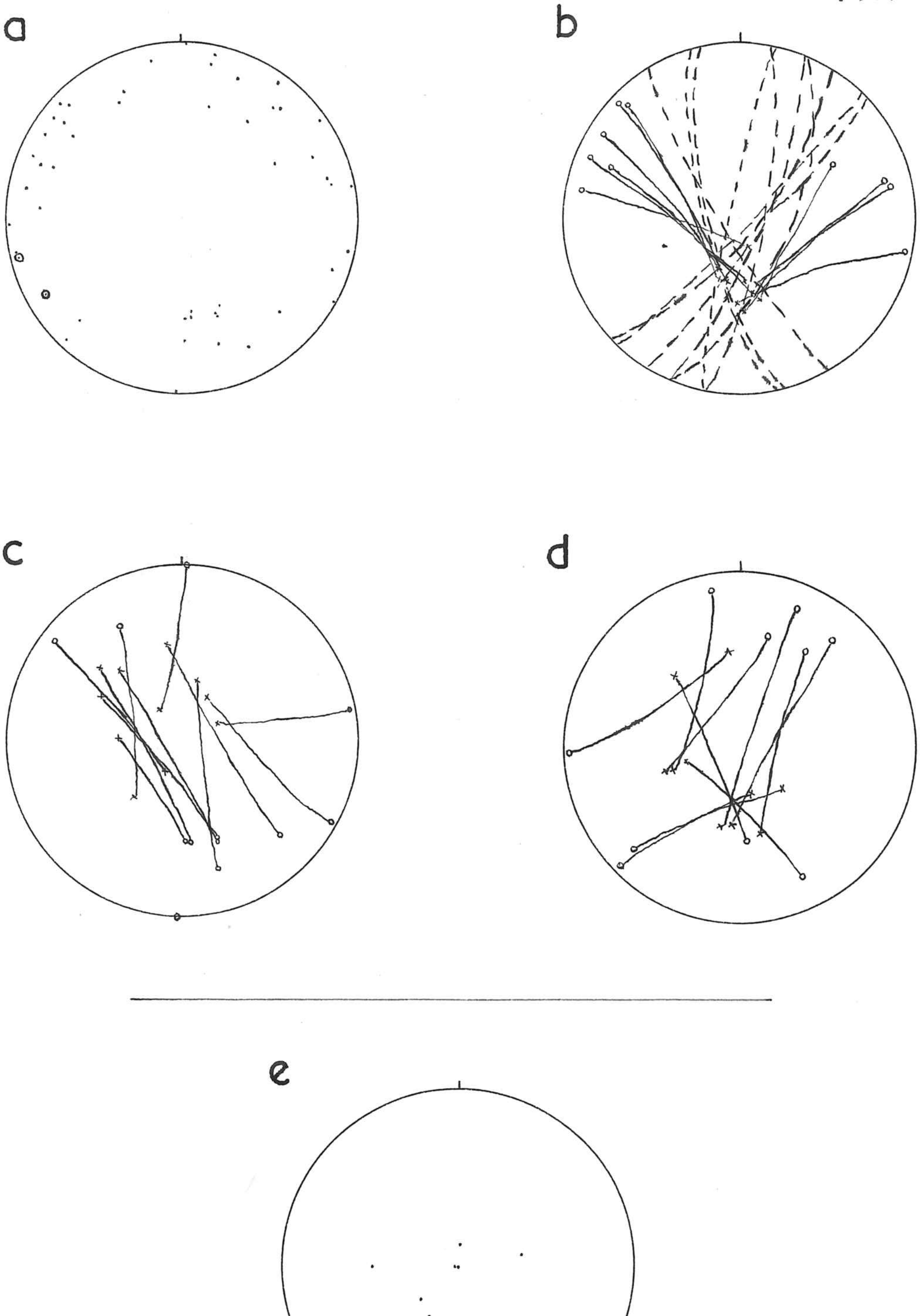


PLATE 1.

Physiography of portion of the mapped area.
Looking north from locality 079350.

PLATE 2

Poor outcrop of Unit 2 quartzite striking directly away from observer. Spotted schists of younger Unit 1 occupy, and strike approximately parallel to the first ridge (from A to B) in the photo). Looking south from locality 345076.


A
B

PLATE 3

Scapolite-spotted laminated silty schists of Unit 1. Note small scale current bedding marked by truncation of laminae near centre of photo. Locality : 108432.

PLATE 4

Scapolite-spotted siltstones of Unit 1. Note portion of large foreset bed on the left. Locality : 108432.

PLATE 5

Thinly interbedded calc-silicates (dark) and impure marbles (light) of Subunit 2A. Locality : 081414.

PLATE 6

Well bedded and laminated outcrop of aluminous semipelitic and pelitic schists of Rock Unit 2B, with boudinaged interbed of fine grained quartzite. Locality : 066356.

PLATE 7

Small-scale current bedding in Rock Unit 2B.
Locality : 069348.

PLATE 8

Washout structures in beds of Rock Unit 2B.
Semipelitic and pelitic beds have been cut and filled with lighter more sandy material.
The beds are overturned. The dark pelitic bands (A) are rich in andalusite. Locality : 069349.


A
A

PLATE 9

Sedimentary slumping in Rock Unit 2B.

Locality : 069348.

PLATE 10

Typical outcrop of Rock Unit 2B. Looking south from locality 073348.


12 in.

PLATE 11

Photomicrograph: porphyroblastic staurolite in quartz-mica matrix. Staurolite shows interpenetration twinning. Matrix shows crenulation cleavage Specimen A263 - 156a. Crossed nicols.

PLATE 12

Porphyroblastic staurolite developed in thin beds and laminations of deeply weathered schist of Subunit 2B. Locality : 112367.

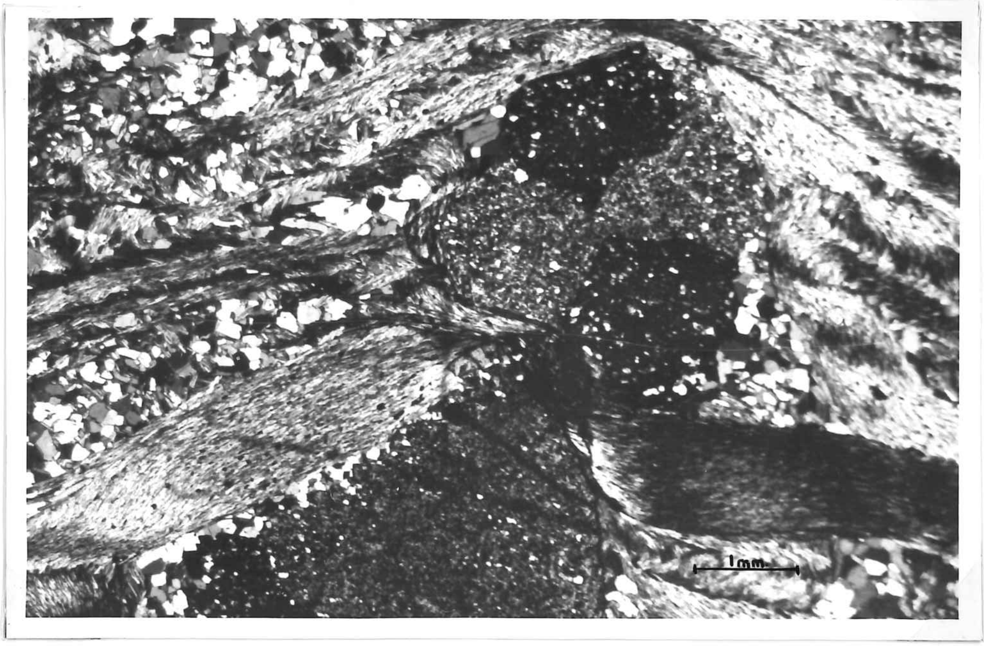

1mm

PLATE 13

Photomicrograph: post-tectonic muscovite porphyroblasts in andalusite staurolite biotite schist. Specimen A263 - 117, Ordinary light.

PLATE 14

Muscovite knots (arrows) in staurolite schist. Locality : 078363.

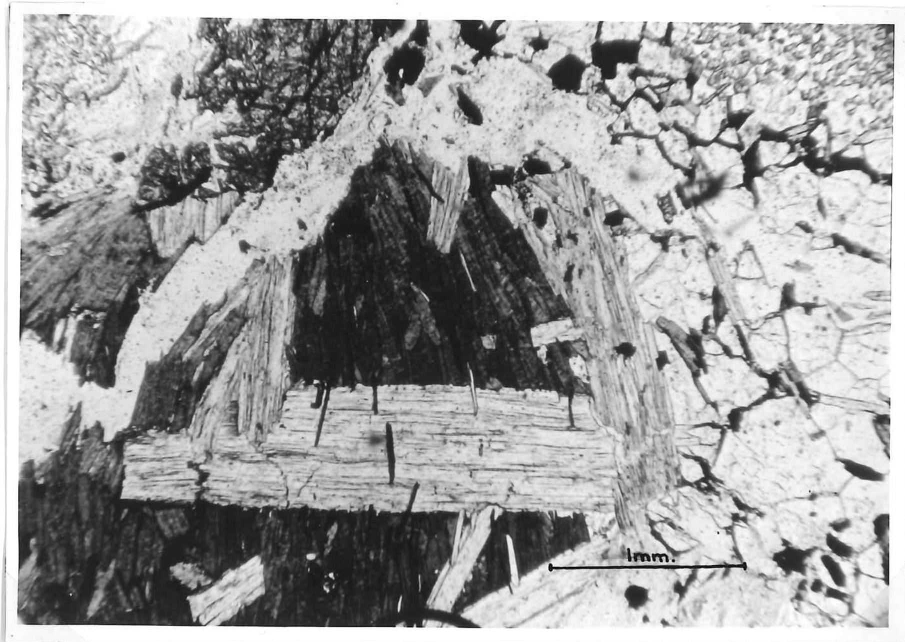
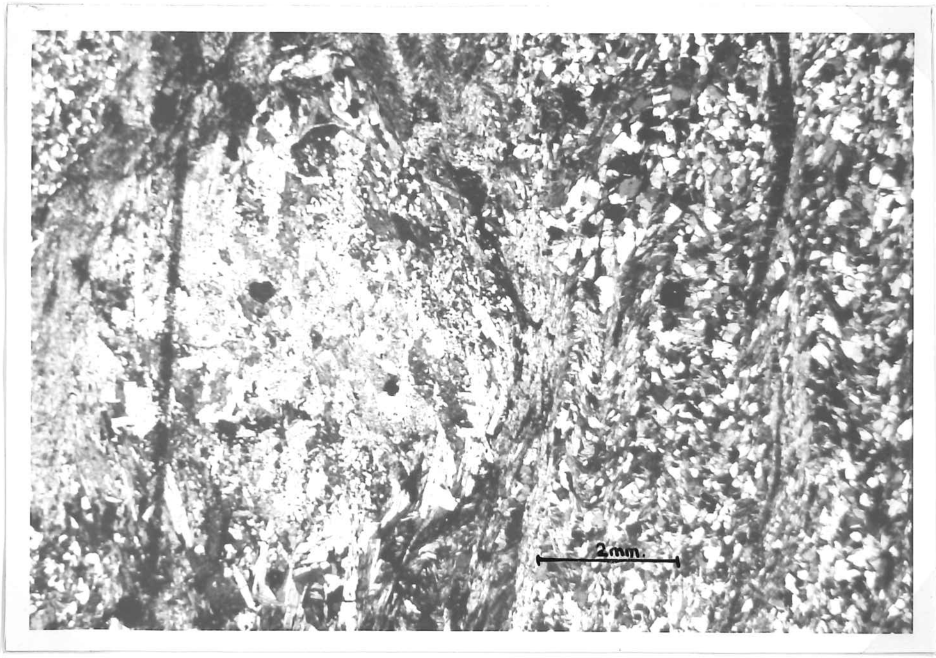

1mm.

PLATE 15

Photomicrograph : Squarish outline of muscovite aggregate after andalusite. Knot also contains quartz, relic biotite, and iron oxide. Specimen A263-234. Crossed nicols.

PLATE 16

Skeletal andalusite (A) forming from plates of muscovite (M). Specimen A263-133(3). Ordinary light.


2mm.

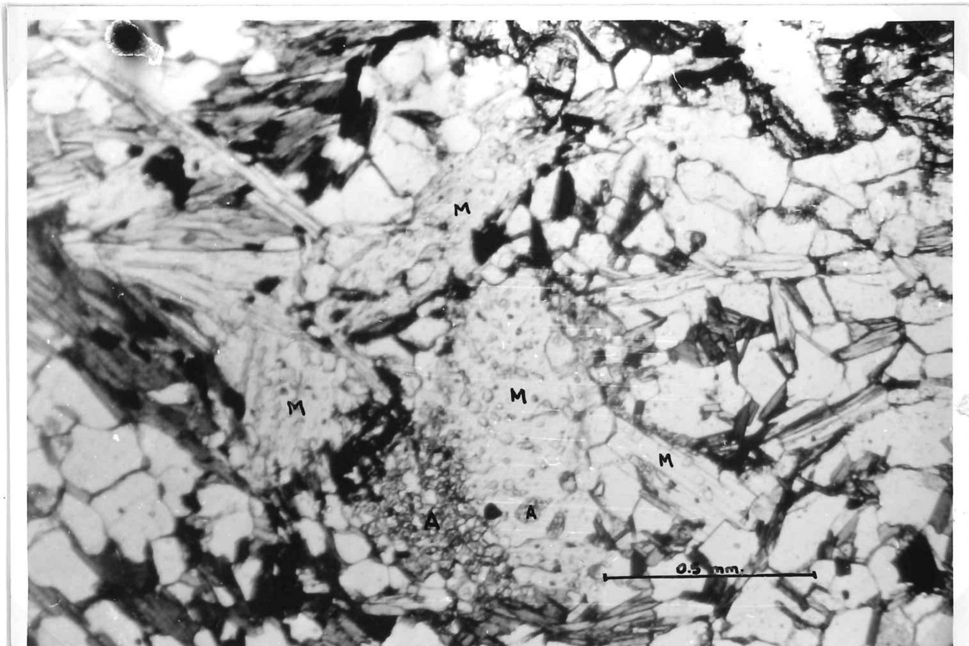

M
M
M
M
A
A
0.5 mm.

PLATE 17

Stumpy orthorhombic prisms of andalusite weathering from pelitic schist. A metamorphic banding is almost vertical. Diameter of coin is 2.8cm. Locality : 067357.

PLATE 18

Andalusite-rich bands (A) marking sedimentary bedding. Locality : 072347.

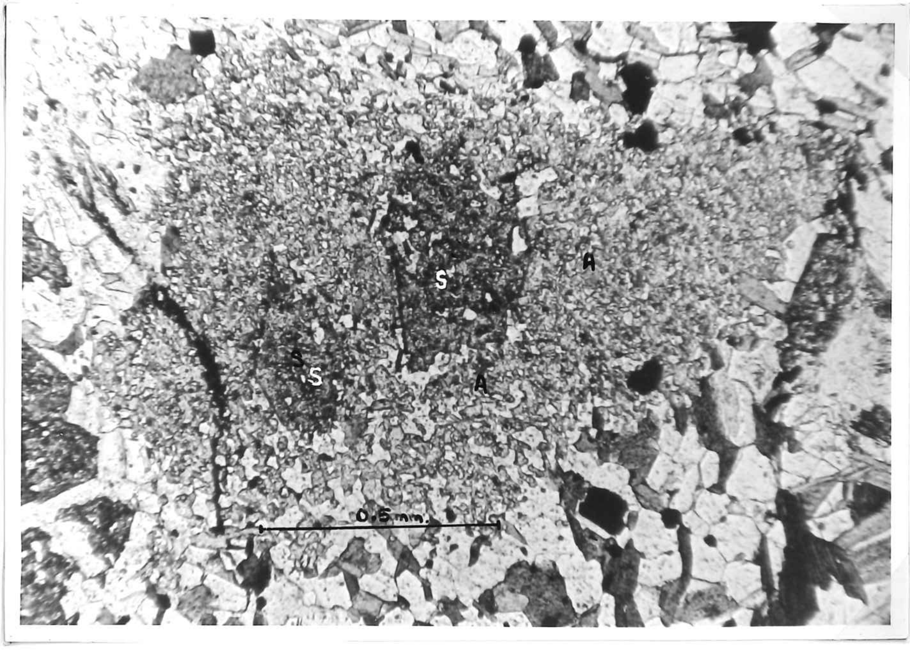

A
A
A
A

PLATE 19

Photomicrograph : staurolite (S) enclosed by poikiloblastic andalusite. Specimen A263-117. Ordinary light.

PLATE 20

Photomicrograph : late stage alteration of andalusite (A) to muscovite (M) and chlorite (C). Note crenulations in matrix. Specimen A263-109. Ordinary light.


S
S
S
A
A
0.5 mm.

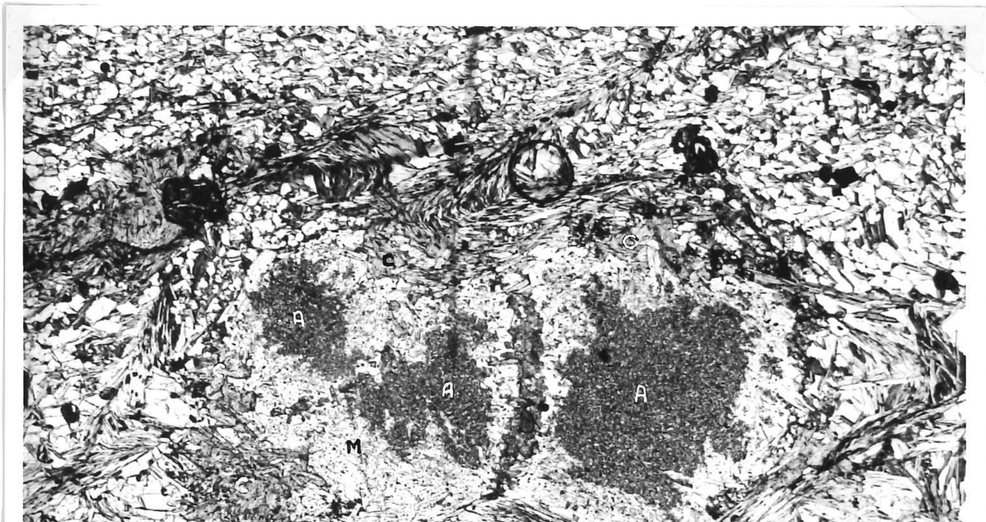
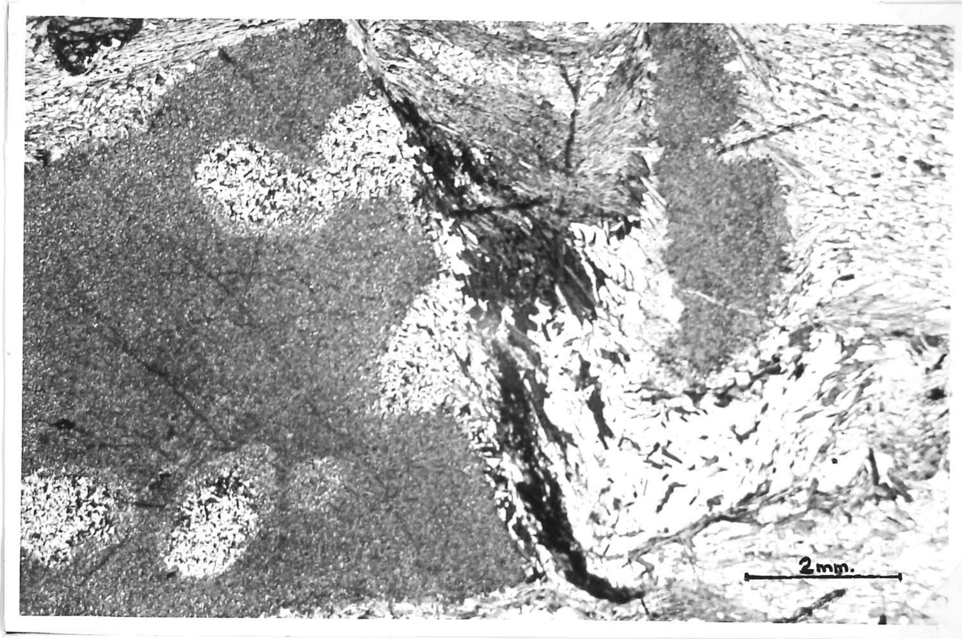

C
C
A
A
A
M
C
2 mm.

PLATE 21

Photomicrograph : quartz-biotite augen in andalusite porphyroblast. Note sillimanite (dark) forming as fibrolite in biotite near the andalusite boundary. Specimen A263-95. Ordinary light.

PLATE 22

Photomicrograph : One of the augen shown in Plate 21. Ordinary light.


2mm.

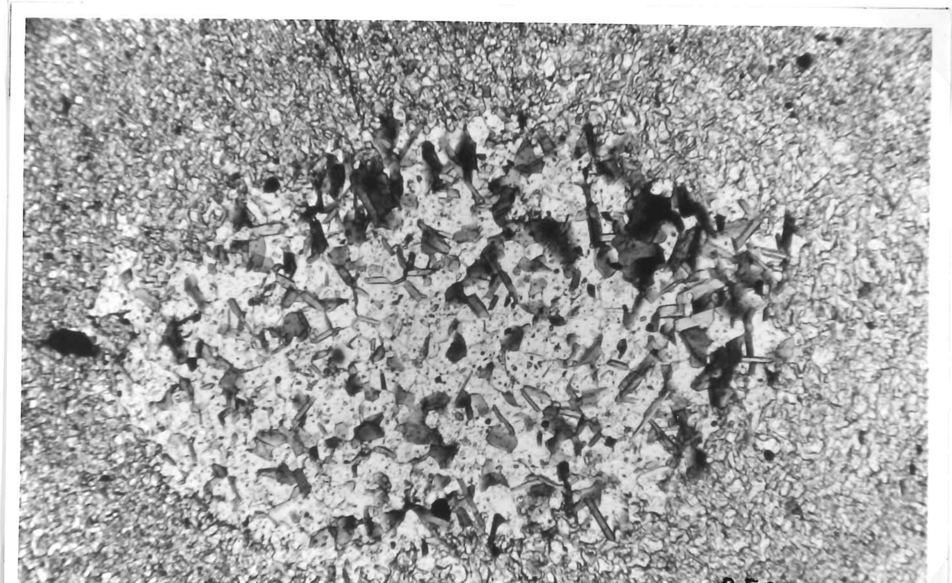
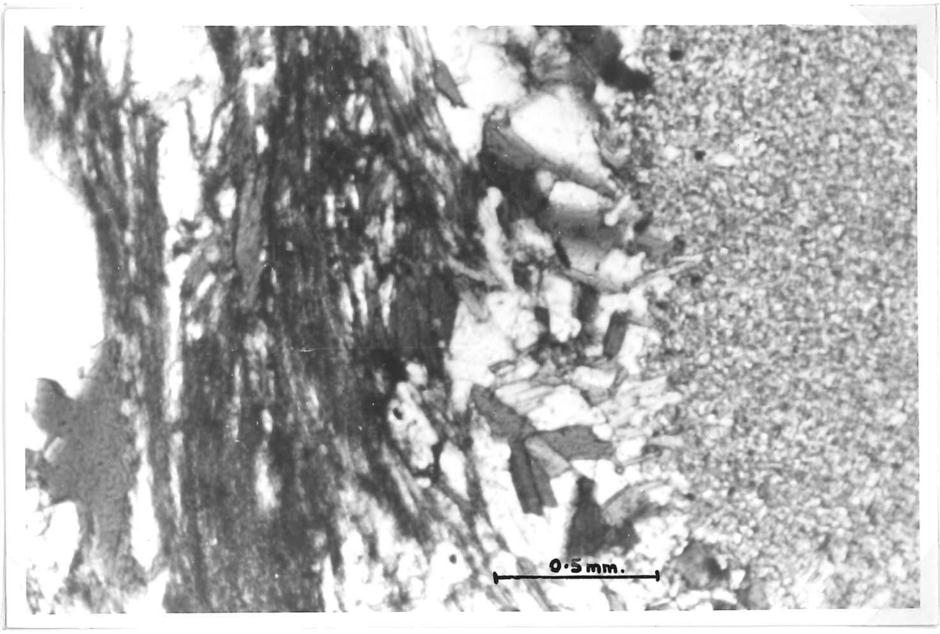

0.5mm.

PLATE 23

Photomicrograph : sillimanite (fibrolite) growing as dark masses in biotite. Note relation to andalusite grain boundary at right. Specimen A263-95 . Ordinary light.

PLATE 24

Photomicrograph : Fibrolite (dark masses) forming in and around skeletal andalusite. Specimen A263-631. Ordinary light.


0·5mm.

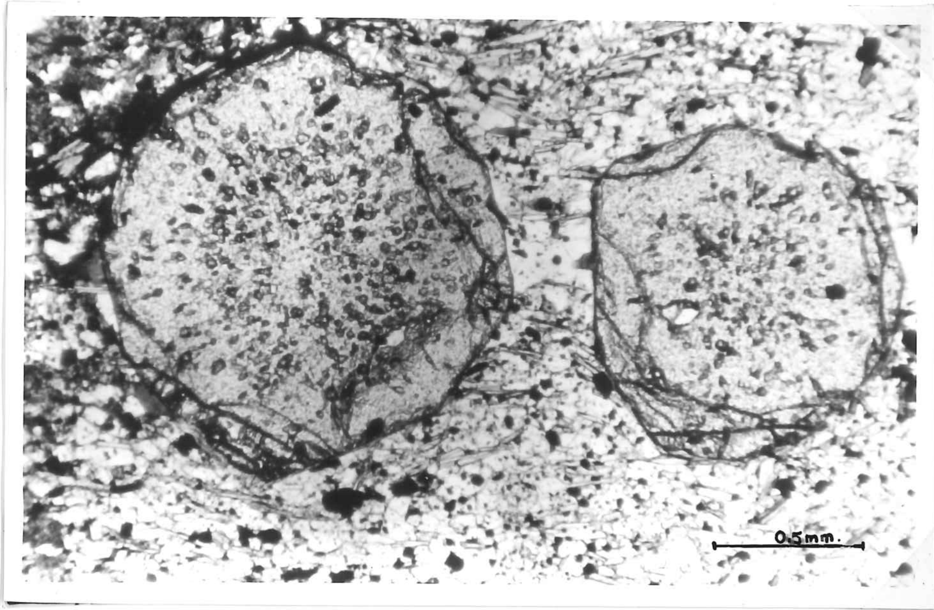

0·1mm.

PLATE 25

Photomicrograph : porphyroblastic garnets in sandy mica schist of Subunit 2B. Note radial quartz inclusions. Specimen A263-136. Ordinary light.

PLATE 26

Photomicrograph : garnet band in schist of Subunit 2B. Note coarsely recrystallized quartz and biotite deficient areas associated with the garnets. Specimen A263-226. Crossed nicols.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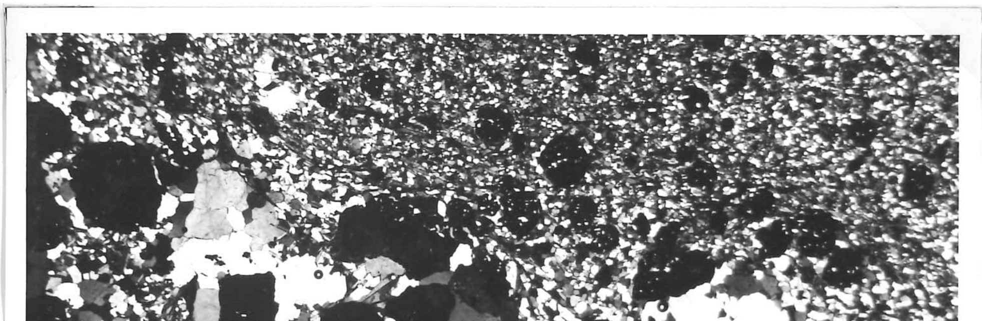

2mm.

PLATE 27

Intensely folded silty beds in marble.

Locality : 079352.

PLATE 28

Large thin section : folded, thin, phlogopite-rich beds in marble. Specimen A263-256b.

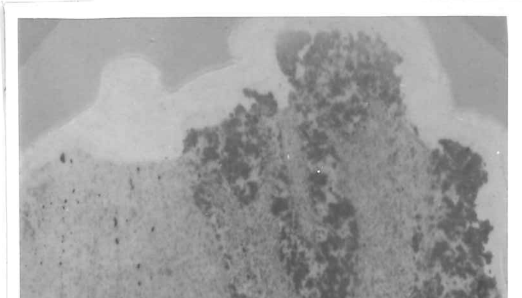

Natural
Size.

PLATE 29

Large thin section : strongly folded im-pure marble. Note calcite filled tension cracks normal to the limbs. Specimen A263-158b.

PLATE 30

Lineation (approximately parallel to pencil) in marble, defined by scapolite and occasional amphibole prisms. Locality 065352.


Natural
Size.

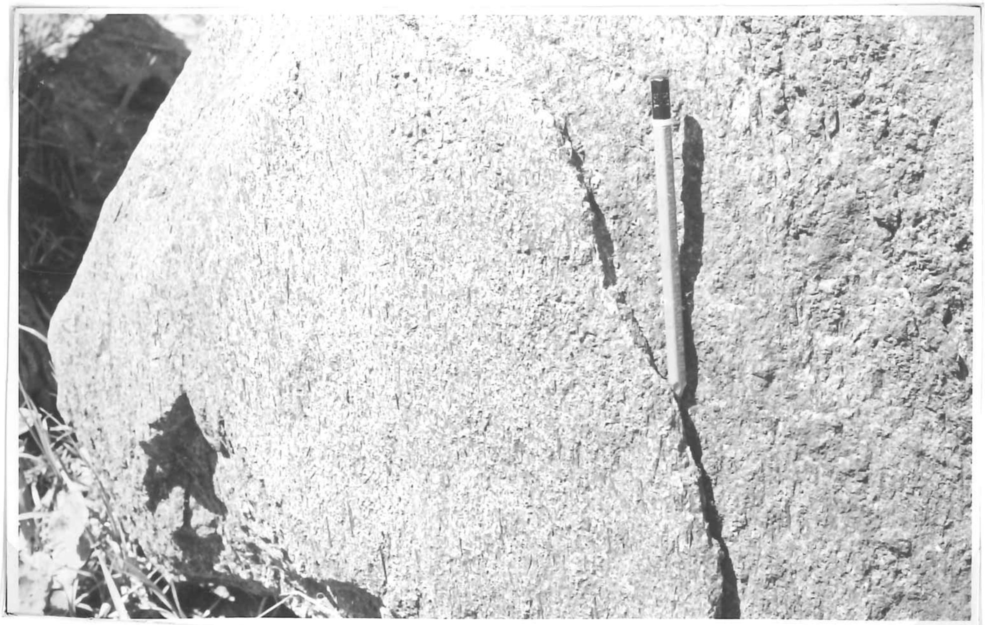
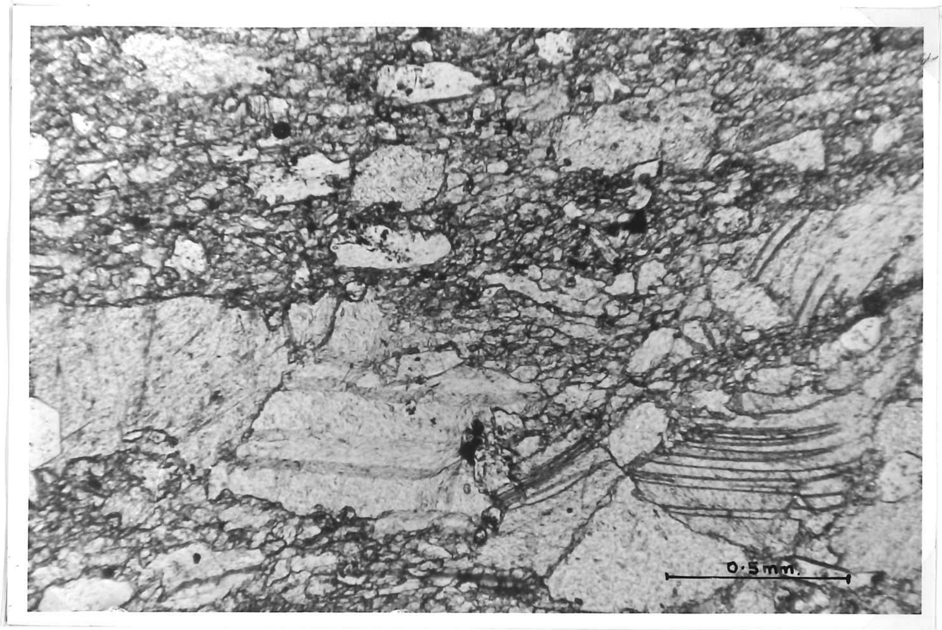


PLATE 31

Photomicrograph : strongly deformed marble showing trains of granular calcite separating larger deformed calcite grains with bent deformation twin lamellae. Specimen A263-812. Ordinary light.

PLATE 32

Photomicrograph : basal section of scapolite in marble. Note inclusions and core of calcite and zoning marked by dark lines of fine inclusions. Specimen A263-834. Crossed nicols.


0·5 mm.

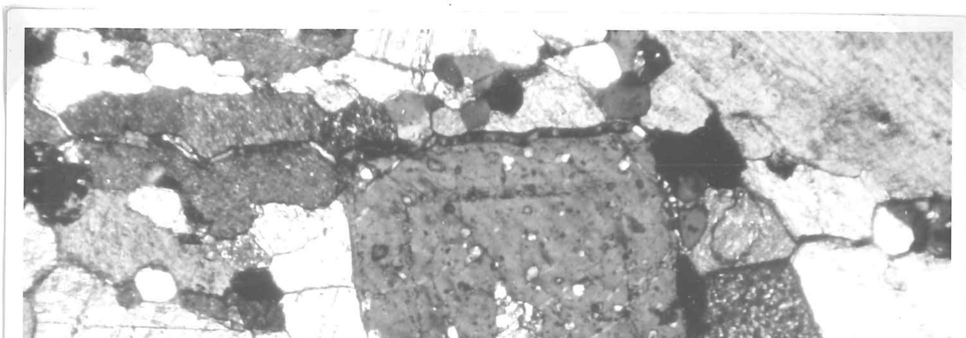

0.5 mm.

PLATE 33

Photomicrograph: Aggregates of muscovite (arrows) in schist of Subunit 1B. Plate also includes section of a rounded quartzite pebble. Specimen A263-361. Crossed nicols.

PLATE 34

Metadolerite (dotted outline) intruding marbles at Lindsay Bridge Quarry. Locality : 066354.

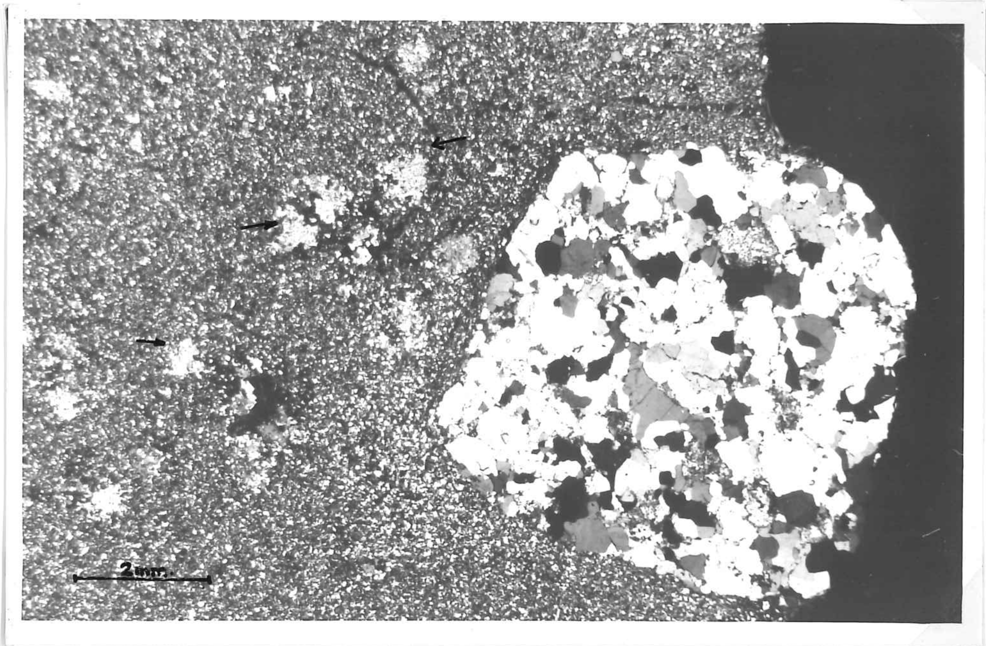

2mm

PLATE 35

B2 fold in laminated sandy schist of Subunit 2B.
Locality 077367.


Redheads

PLATE 36

Steeply plunging fold in thinly interbedded marble and silty marble. Locality : 122348.

PLATE 37

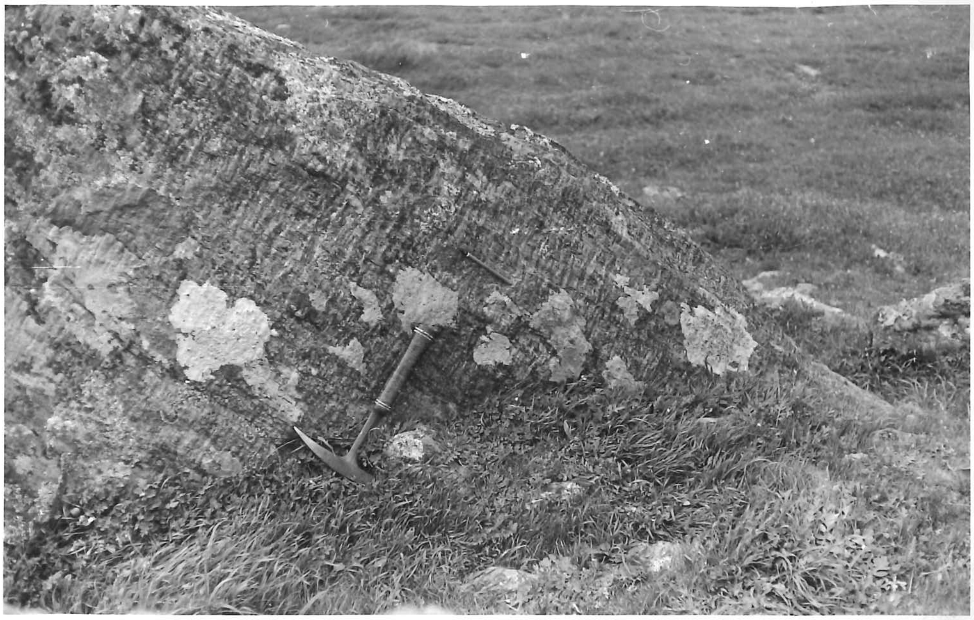
Open concentric B_3 folds in laminated sandy schists of Subunit 2B. Locality : 069358.

PLATE 38

Crenulations (parallel to hammer handle) in schistosity (S_2) of pelitic schist of Subunit 2B. B_2 (S_1/S_2) lineation plunges to right, parallel to pencil. Locality : 078338.

PLATE 39

Photomicrograph : staurolite, mica schist. Helicitic internal fabric (outlined in ink), Si_3, in idioblastic staurolite indicates present crenulation and crenulation cleavage, S_4, has over-printed an earlier one. Section cut normal to present crenulation. Specimen A263-652. Crossed nicols.



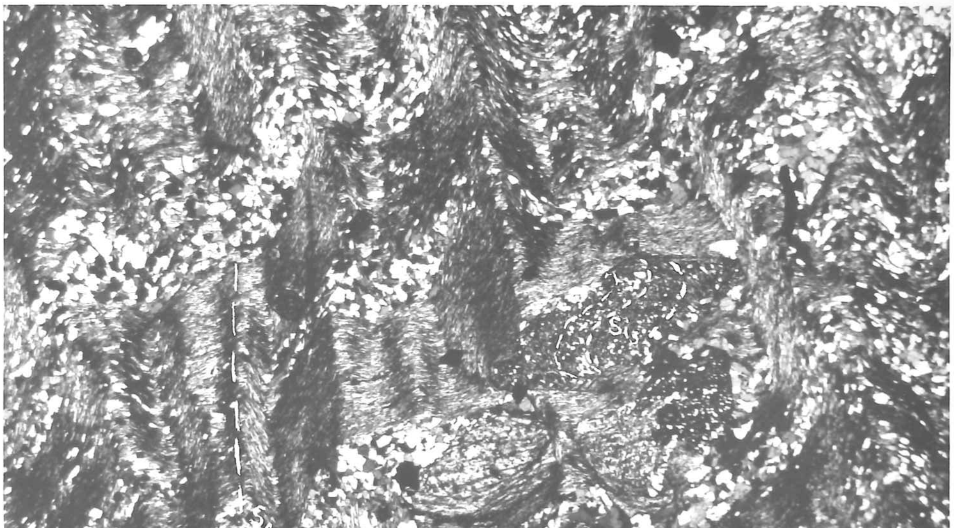
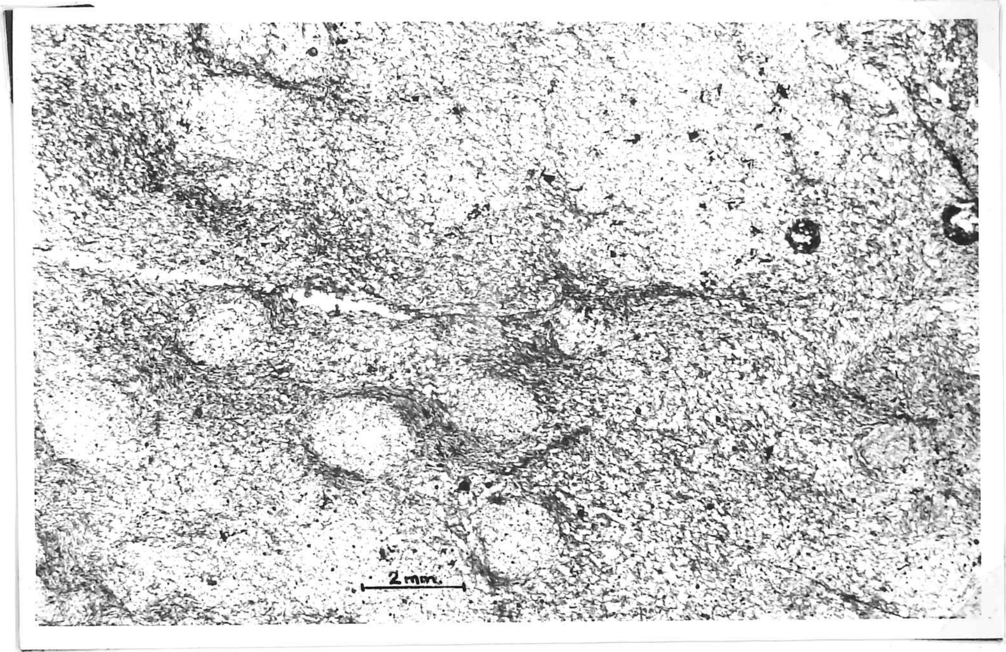

S
S4

PLATE 40

Photomicrograph : cross-sections quartz-rich augen in semipelitic schist of Subunit 2B. Section cut normal to crenulation. Specimen A263-673(1). Ordinary light.

PLATE 41

Photomicrograph : longtitudinal sections of quartz-rich augen showing pronounced elongation. Section cut parallel to crenulation. Specimen A263-673(2). Ordinary light.


2 mm.


2 mm.

PLATE 42

Kink bands (arrows) in schist of Subunit 2B. Fine B_2 lineation (mineral elongation and augen) approximately parallel to pencil.