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THE STRUCTURAL AND METAMORPHIC GEOLOGY OF THE ORMISTON AREA, CENTRAL AUSTRALIA

by

R. W. MARJORIBANKS

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SUMMARY

The effects of five deformational and metamorphic events are distinguished in an area spanning the margin of the Amadeus Basin and the crystalline basement rocks (Arunta Complex) to the north. Of these, the second (D_2), third (D_3), and fifth (D_5) are major orogenic events of probable regional significance; they correspond respectively to isotopic dates of about 1600 m.y., 1100 m.y., and 400 m.y. D_1 and D_4 are of local significance only.

During D_2, rocks within the Arunta Complex, some of them of sedimentary origin, were metamorphosed to granulite facies in the extreme northern part of the area and to amphibolite facies in the southern part; the metamorphic grade was controlled by a probable greater depth of burial of the rocks to the north. A major deformed zone (Redbank Zone) separates the two metamorphic regimes, and began forming during D_2. The Redbank Zone is a major thrust-fault zone with upthrow to the north, and can be traced within the Arunta Complex for at least 350 km along strike. D_2 deformation is most intense in the Redbank Zone, where it produces a north-dipping mylonitic foliation and north-plunging reolined intrafolial folds with strong axial mineral-orientation lineation; north and south of the Zone the intensity of D_2 deformation becomes progressively less. Correlation of D_2 structures south of the Redbank Zone is made difficult by the development of a D_3 migmatite complex which is the result of a rise in geothermal gradient in the area, coupled with, and perhaps caused by, metasomatism and granite intrusion.

D_2 and D_3 took place before the deposition, in the Adelaidean and the Palaeozoic, of the sediments of the Amadeus Basin. D_5, the Alice Springs Orogeny, affected both basement and cover. During D_5, uplift to the north took place along reactivated, steep

north-dipping faults within the Redbank Zone. These thrust faults penetrated the Heavitree Quartzite - the basal unit of the Basin sequence - and drove a wedge of basement with an attached veneer of Heavitree Quartzite (Razorback Nappe) for at least 20 km southward into the overlying shale and dolomite of the Bitter Springs Formation. Sediments above the Bitter Springs Formation were tilted into a vertical attitude, but were not overridden by the Nappe. Subsequently D_5 stresses within the Arunta Complex were relieved by lesser movements which resulted in the formation of a fold-thrust complex underlying the Razorback Nappe. A marked linear break in outcrop within the Arunta Complex and an intense gravity gradient, which are the major present-day features of the Redbank Zone, probably result largely from Alice Springs Orogeny movements.

INTRODUCTION

Location of area

The Ormiston area is on the northern margin of the Amadeus Basin about 120 km west of Alice Springs, and is contained approximately between latitudes 23°15' and 23°45'S and longitudes 132°20' and 133°00'E in the Hermannsburg 1:250 000 Sheet area (Figs. 1 and 2). Within the southern part of this area, the oldest formations of the Amadeus Basin crop out; over the remainder of the area, crystalline basement rocks underlying the Basin sediments are extensively developed.

The co-ordinates of localities mentioned in the text are given in the Appendix.

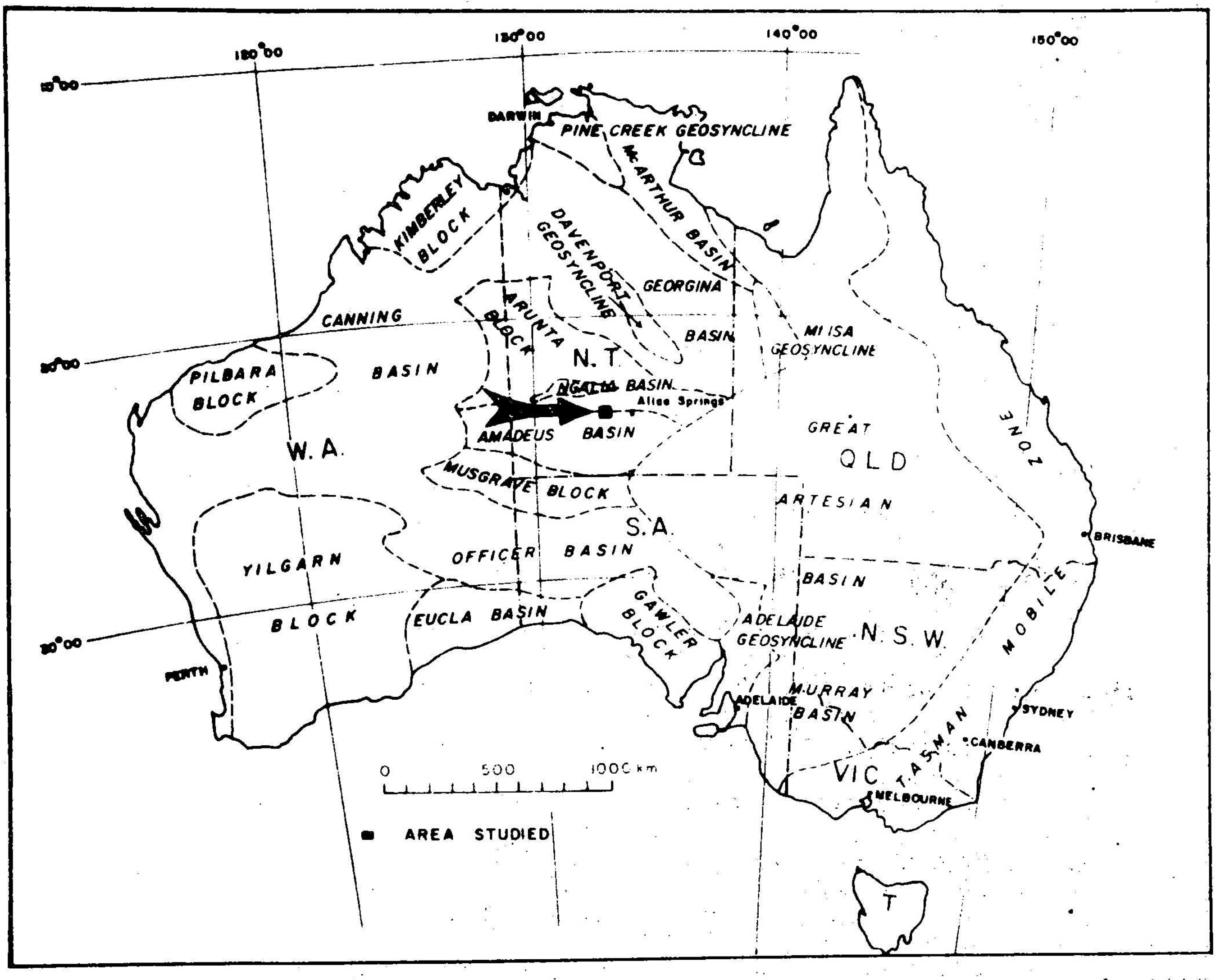

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Figure 1 LOCATION OF AREA

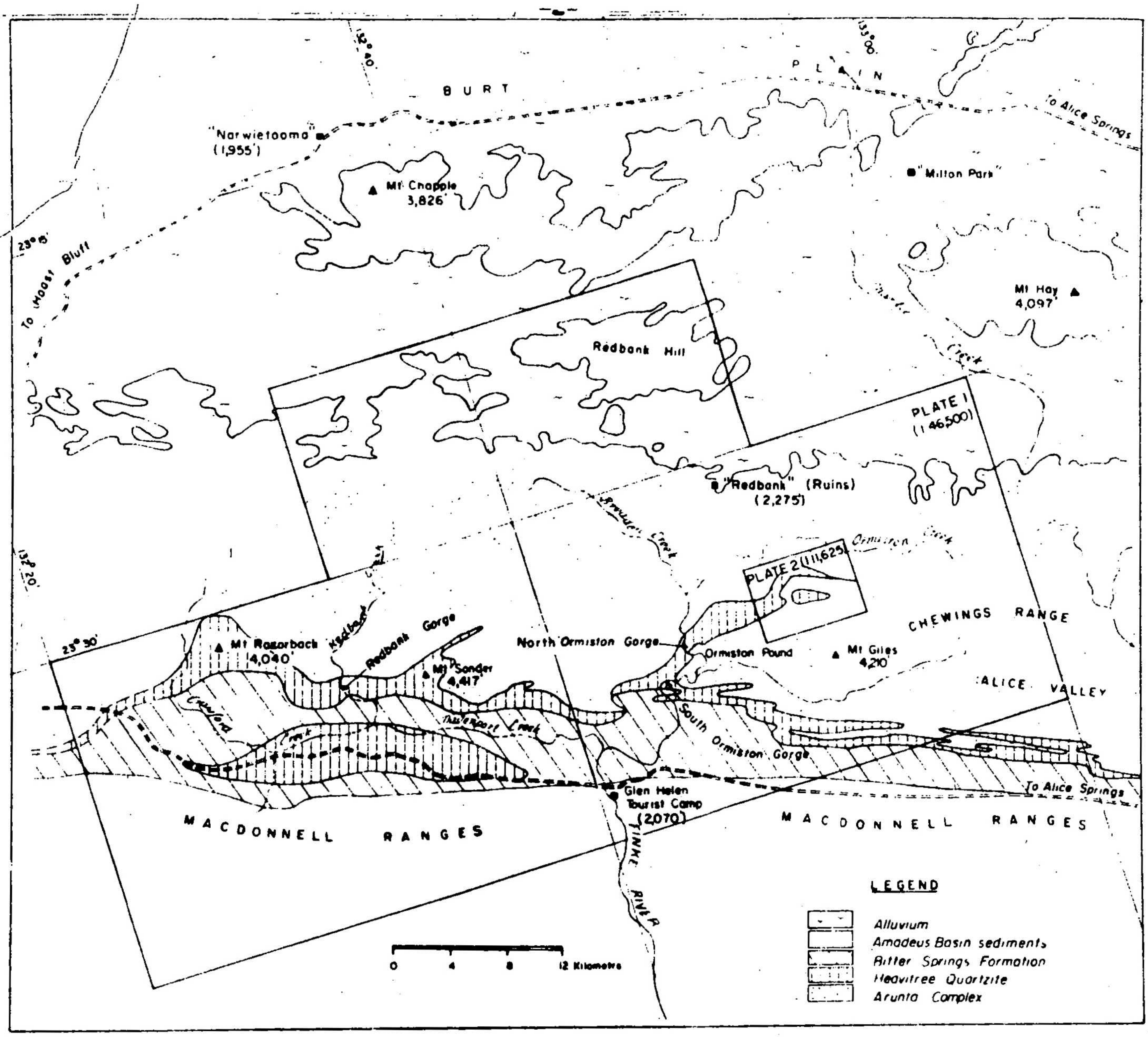

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Figure 2 LOCATION OF PLATES 1 & 2

Access

The area can be reached from Alice Springs by good graded roads which pass it to the north and south, but access is generally poor within the region. The westward-trending cliffs and precipitous slopes of the Chewings Range and the Heavitree Quartzite scarp can be crossed only with difficulty on foot, and the outcropping basement rocks are in general impassable to vehicles. Within the area of basement rocks two disused tracks provide limited access for four-wheel-drive vehicles. One track extends from the old Redbank homestead to North Ormiston Gorge; the other crosses the Heavitree Quartzite scarp at Boggy Hole Bore east of the area, and follows the Alice Valley as far as the southeastern entrance to Ormiston Pound. Elsewhere access is only by foot.

Physiography

Three physiographic regions extend westward across the area. The northernmost region constitutes part of Burt Plain, which beyond the study area is very extensive to the north. The plain has a low relief, and lies about 600 m above sea level; it is composed of alluvial outwash and some windblown sand. Mount Hay and Mount Chapple form steep-sided isolated ridges which rise out of the plain to a height of up to 1230 m (Mount Hay).

Burt Plain is bounded on the south by a sharp, west-northwest-trending linear scarp which marks the northern edge of the main outcrop of basement rocks and the boundary of a new physiographic region which extends south as far as the Amadeus Basin. This region is hilly (average height 760 - 900 m) and contains small alluvial pockets of limited extent. A quartzite unit within the basement forms a steep west-northwest-trending ridge, the Chewings Range, which rises in Mount Giles to a height of 1280 m.

The Heavitree Quartzite forms a major scarp across the whole area, and marks the northern limit of the third and southernmost physiographic division. This division is characterized by low but sharp ridges separated by long narrow valleys and is developed upon the basal, predominantly arenaceous units of the Amadeus Basin sedimentary sequence. The height of the region is 670 to 760 m.

The highest ground in the whole area is developed on the resistant Heavitree Quartzite, which rises to 1212 m in Mount Razorback and 1327 m in Mount Sonder.

The main drainage in the area is southwards into the Finke River via its two major tributaries, Ormiston and Davenport Creeks. Ormiston Creek cuts through the Heavitree Quartzite scarp in two deep gorges called the North and South Ormiston Gorges. Similar, though smaller, gorges allow Crawford, Redbank, and Rockybar Creeks -

tributaries of Davenport Creek - to pass through the Heavitree Quartzite ridge.

Climate and development

The climate in the area is arid, with an annual rainfall averaging 250 mm a year. Permanent surface water exists only in isolated waterholes in deep gorges where the major creeks cut through the scarp of the Heavitree Quartzite, and in a few small springs along the foot of the Chewings Range.

In the north of the study area the southern part of Burt Plain has been developed for cattle grazing on Narwietooma, Milton Park, and Hamilton Downs stations. In the south of the area, the spectacular gorges in the Macdonnell Ranges are exploited as a tourist attraction, and a small lodge at Glen Helen caters for visitors.

Ormiston Pound is gazetted by the Northern Territory Administration as a Wildlife Reserve, under the care of a Ranger based at South Ormiston Gorge.

Previous investigations

Comprehensive reviews of early exploration and geological study in Central Australia have been given by Forman, Milligan, & McCarthy (1967) and Wells, Forman, Ranford, & Cook (1970). In this section only the most important early regional work will be mentioned.

Reconnaissance of the Macdonnell Ranges was made after the opening up of the region with the construction of the Overland Telegraph Line in 1887, and the discovery in 1887 and 1888 of commercial gold and mica deposits around Arltunga and the Harts Range, east of Alice Springs. Notable among the early published accounts were those of Chewings (1891, 1894, 1914), the first geologist to enter the area, and Tate & Watt (1896), geologists with the 1894 Horn Expedition. These workers recognised that the west-trending Macdonnell Ranges were developed on the basal units of a large sedimentary basin, which rested unconformably upon a crystalline basement outcropping extensively to the north of the Ranges. Within the basement rocks, Chewings identified the quartzite of the Chewings Range, and thought that it represented an infolded deformed equivalent of the basal quartzite member of the basin sequence.

The first accounts of more comprehensive studies on the geology of the region were those of Chewings (1928, 1935), and Mawson & Madigan (1930; the latter authors named the crystalline basement rocks as the Arunta Complex. The Harts Range area of the Arunta Complex was studied in detail by Joklik (1955), who also defined and named the two lowest units of the overlying basin sediments as the Heavitree Quartzite and the Bitter Springs Limestone (subsequently renamed the Bitter Springs Formation by Wells, Ranford, Stewart, Cook, & Shaw, 1967). The basin itself was called the Amadeus Geosyncline by Hossfeld (1954), but following Condon, Fisher, & Terpstra (1958) it has been known as the Amadeus Basin.

The first geological mapping and comprehensive description of the area covered by this report was that of Prichard & Quinlan (1962), although these authors were primarily concerned with the Amadeus Basin, and their interpretation of the Arunta Complex was based almost entirely upon air-photo examination. Prichard & Quinlan commented on the structure of Ormiston Pound where the west-trending Chewings Range turns sharply northward and coalesces with a northeasterly spur of the Macdonnell Ranges to almost completely enclose with steep cliffs an area of 63 km^2. They considered that the Chewings Range Quartzite is equivalent to the Heavitree Quartzite, but recorded the view (M.A. Condon, pers. comm. _in_ Prichard & Quinlan, 1962) that there might be a strong structural discordance between the two Quartzites to the north of Mount Giles.

In 1964 the Bureau of Mineral Resources (BMR) compiled the

Hermannsburg 1:250 000 geological map Sheet, and the geology of the Sheet area, which includes the Ormiston region, was described by Forman et al. (1967) and Quinlan & Forman (1968). Within the Arunta Complex these authors made only widely scattered field observations, and interpretation was based largely on air-photo study. They determined that the Chewings Range Quartzite was older than the Heavitree Quartzite, and noted an unconformity between them at Ormiston Pound. Between Mount Razorback and Mount Giles, Forman et al. (1967) interpreted the basement and cover as being folded in two large basement-cored southwards-directed nappes, together comprising the Ormiston Nappe Complex; the upper nappe was named the Razorback Nappe, and the lower nappe the Ormiston Nappe. A similar, though more extensive nappe complex, the Arltunga Nappe Complex, was identified by Forman et al. (1967) east of Alice Springs, and Stewart (1967) described a smaller nappe, the Blatherskite Nappe, which involved both basement and cover rocks south of Alice Springs. These nappe structures along the northern margin of the Amadeus Basin were assumed by Forman (1966) and Forman et al. (1967) to be the result of a single event, the Alice Springs Orogeny. The Orogeny was thought to be coeval with syntectonic features, such as unconformities and thick molasse-type sediments, in the Upper Devonian to Upper Carboniferous Pertnjara Formation of the Amadeus Basin (Jones, 1970, 1972); this correlation is consistent with K-Ar dates of 358-322 m.y. on micas from deformed recrystallized Heavitree Quartzite and Arunta Complex rocks in the Arltunga Nappe Complex (Stewart, 1971).

A regional gravity traverse across the northern margin of the Amadeus Basin was made by Marshall & Narain (1954), and a regional gravity survey of the whole basin and surrounding area was subsequently made by BMR (Langron, 1962; Lonsdale & Flavelle, 1963). These surveys show a deep gravity trough (down to -145 mGal) over the northern margin of the Amadeus Basin, and a gravity high (up to +40 mGal) between the

Amadeus and Ngalia Basins to the north of the area. A steep gravity gradient with a maximum value in the Hermannsburg Sheet area of 6.5 mGal/km separates these anomalies. This gradient is a linear feature which can be traced westward for almost 500 km along strike parallel to the northern margin of the Amadeus Basin, although east of Alice Springs the gradient weakens and appears to be offset to the north. The gravity gradient is located within the Arunta Complex 20 to 40 km north of the northern margin of the Amadeus Basin. The commencement of the steep gradient corresponds approximately to the edge of the main outcrop of basement rocks, where they abut with a marked west-trending linear break in outcrop against the alluvial plains to the north. The regional gravity pattern was discussed by Wells et al. (1970), who concluded that the density contrasts between the Amadeus Basin sediments and the outcropping basement rocks are not sufficient to explain the observed gravity contrast between these areas; following Marshall & Narain (1954), they proposed a linear zone of crustal upwarp between the Amadeus and Ngalia Basins to explain the anomalies. In a review of the geology of central Australia, Forman & Shaw (1973) correlated the steep gravity gradient with a proposed west-trending belt of retrogressed (greenschist facies) rocks within the Arunta Complex. They suggested that this zone represents a north-dipping thrust-fault zone formed during the Alice Springs Orogeny, and that granulite-facies rocks which outcrop to the north of the zone in Mount Hay and Mount Chapple represent basal crustal material which has been brought to the surface by fault movement.

Forman et al. (1967) defined the Arunta Orogeny as that event which folded and metamorphosed the Arunta Complex before the deposition of the Heavitree Quartzite, and Forman subsequently redefined it (in Wells et al., 1970) as the main metamorphic event before the deposition of the Warramunga Group in the Georgina Basin region to the northeast of the Arunta Complex. However, Forman presented no evidence to demonstrate that one single widespread isochronic metamorphic event can be identified within the Arunta Complex, and in the absence of comprehensive regional knowledge of the Arunta Complex, the Arunta Orogeny remains somewhat obscure. In a recent description of the geology of the Arunta Complex, Shaw & Stewart (1973) did not use the term Arunta Orogeny, and divided the complex into three rock groups based on metamorphic facies; however, they emphasized that the ages and stratigraphic relations between and within these groups are largely unknown. Shaw & Stewart (1973) reviewed isotopic ages which have been published from the eastern and northern parts of the Arunta Complex, and showed that a widespread isotopic event occurred at about 1700 m.y. Many younger dates than this have been published from the Arunta Complex (Hurley, Fisher, Fairbairn, & Pinson, 1961; Riley, 1968; Stewart, 1971); many of these are interpreted by Shaw & Stewart (1973) as indicating widespread resetting during the Palaeozoic Alice Springs Orogeny.

Since 1966 detailed field examination and mapping have been undertaken by BMR on the basement geology and basement-cover relations in the Arltunga region to the east, and the Ormiston region to the west, of Alice Springs. The results in the eastern area (Forman, 1971; Shaw, Stewart, Khan, & Funk, 1971; Khan, 1972) provide much detail on the Arltunga Nappe Complex, but little additional information on the geology of the Arunta Complex. Preliminary results of the writer's work in the western area have already been reported (Marjoribanks, 1972).

Organization of the survey

Because of the lack of any previous detailed geological knowledge of the area, and the scale and inter-relations of the structures occurring within it, it was necessary to undertake the geological mapping of a fairly large area totalling about 2000 km^2. The greater part of the area lies within the Hermannsburg 1:100 000 Sheet area, but rocks lying to the north and west of the Sheet margins were also investigated and mapped.

Mapping was carried out using 2X enlarged black and white aerial photographs at a scale of 1:23 250, the geological information being transferred to corrected line-compilation overlays, and subsequently reduced photographically to a scale of 1:46 500. A geological map of the whole area at this scale is presented as Plate 1. In areas of great structural complexity around Ormiston Pound and the Chewings Range, more detailed mapping was done using 4X enlarged aerial photographs (1:11 625); a map of the northeastern corner of Ormiston Pound is presented at this scale as Plate 2.

It was not possible in the time available to map the rocks of Mount Hay and Mount Chapple in the north of the area, but for completeness in understanding the regional geology, they were briefly examined in the field and will be described in the text.

In recording structural information on the maps, no attempt was made to classify the various foliations or lineations according to a time sequence, and the symbols used are descriptive only. In addition, Plate 1 contains no interpretative structural symbols, such as fold axial-plane traces, for basement rocks. This information is given in structural maps within the text.

Acknowledgments

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In addition I have benefited from association with many colleagues at the University and in the Bureau of Mineral Resources, especially Messrs J.L. Funk, M. Yar Khan, R.D. Shaw and Dr A.J. Stewart, for discussions on the problems of central Australian geology. I express appreciation to the Bureau of Mineral Resources for providing a four-wheel-drive vehicle and a field assistant during the project.

BASEMENT ROCKS

The Arunta Complex is divided into four approximately west-northwest-trending zones (Fig. 3) which are distinguished from each other on the basis of their distinctive lithology, metamorphic history, and structure. Redbank Zone is composed of dynamically metamorphosed rocks; it separates dominantly granulite-facies rocks of Mount Hay/Mount Chapple Zone to the north, from amphibolite-facies gneiss, metasediments, migmatites, and granite in the Ormiston and Chewings Range Zones to the south. Rocks south of Redbank Zone have been affected by two distinct metamorphic events. Structures associated with the older event are dominant in the Chewings Range Zone, whereas the younger event which formed an extensive migmatite complex characterizes the rocks of the Ormiston Zone.

The boundaries between the zones are generally either gradational or not exposed, and hence are difficult to locate precisely. The contact of the Ormiston Zone with the adjacent Zones is the migmatite front. This contact is gradational, and its postulated position is somewhat uncertain. It is represented in Plate 1 as a line which separates areas in which the dominant rocks are typical of the Redbank or Chewings Range Zones, and areas in which the effects of granitization and associated structures predominate. It is a boundary which can be fairly readily located on aerial photographs as it marks approximately the limit of well developed foliation in these Zones.

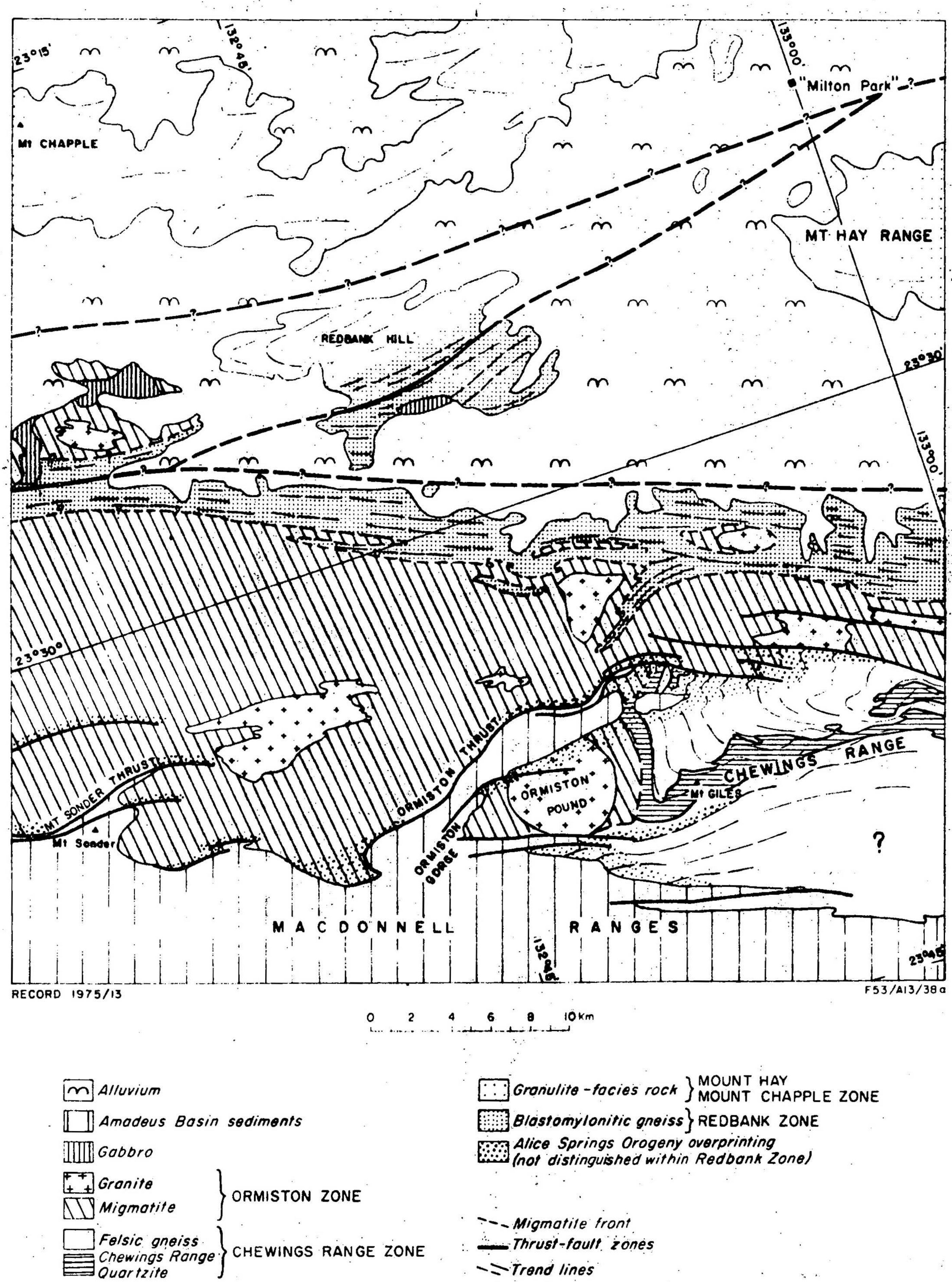

Fig. 3 Simplified map of the Ormiston area showing structural and metamorphic zones.

The following description will begin with the Chewings Range Zone, as in this Zone the most complete, easily interpreted structural and metamorphic record is preserved.

Chewings Range Zone: lithological units

Felsic gneiss

The oldest rock exposed in the Chewings Range Zone is felsic gneiss which underlies the metasediments and crops out to the north and south of the Chewings Range.

In the Eastern Pound the gneiss is leucocratic and coarse-grained, and contains about 10 percent mafic minerals. Towards the eastern part of the Zone the gneiss becomes finer-grained, and contains a greater proportion of dark minerals. In places the gneiss is compositionally layered, but generally the mafic minerals are scattered throughout the rocks in elongate plate-like aggregates up to 3 cm long. The aggregates are composed principally of biotite, and give a well marked foliation to the rock; their elongation defines a strong lineation. The rock generally is only slightly fissile, and weathers into massive tor-like outcrops.

In typical specimens the gneiss is composed of 60 to 90 percent quartz, oligoclase-andesine, and potash-feldspar in about equal proportions. The remainder of the rock consists of biotite, muscovite, and accessory opaque minerals and zircon. The quartz and feldspar have a generally granoblastic-polygonal texture, but show a slight elongation parallel to the foliation. Biotite and muscovite have a marked preferred orientation parallel to the foliation and lineation, and are generally interstitial to the other minerals. Rare large microcline grains in the rock have irregular contacts, partly enclose other minerals, and appear to be of later growth.

Pelitic and semi-pelitic schists

Within the felsic gneiss, and sharing its foliation and lineation, are numerous thin layers of quartzite, mica-schist, and, less commonly, amphibolite. The layers are up to 1 m thick, but cannot usually be traced very far along strike. However, the schists of the Chewings Range occur in a large synformal inlier upon the gneiss, and their outcrop is continuous and easily mapped. They are dominantly quartz-biotite schist, but contain numerous thin layers of biotite-schist or quartzite. In places (as at Locality A) the schists contain abundant euhedral almandine crystals to 3 mm across, and in other places (Localities B and C) contain euhedral staurolite or hematite crystals. In the semi-pelitic rocks the foliation is marked by alternating laminae up to 1 mm thick of quartz-rich and mica-rich layers. A prominent lineation on the foliation surfaces is caused by alternating streaks of biotite-rich and quartz-rich material. Both the dominant foliation and lineation in the semi-pelites and pelites are parallel to those in the underlying felsic gneiss.

The micro-texture of the pelites and semi-pelites is very similar to that of the adjacent felsic gneiss. Quartz and feldspar are slightly elongated parallel to the foliation, but have a generally granoblastic-polygonal texture. Biotite and muscovite have a strong preferred orientation parallel to the structures in the rock.

Chewings Range Quartzite

This unit rests with a sharp contact upon the underlying schists. It is very resistant, and its outcrop is marked by steep slopes and high ground to form the Chewings Range. Within the underlying semi-pelitic rocks, thin quartzite layers become more abundant, and the schists more quartz-rich, as the contact with the overlying main quartzite unit is approached. In addition, the lowermost few metres of the Chewings Range Quartzite contain abundant muscovite and biotite, commonly distributed in thin mica-schist layers which parallel the foliation of the underlying rocks.

The Chewings Range Quartzite is a massive coarse-grained very pure metaquartzite. Its texture is granoblastic with polygonal quartz grains enclosing dimensionally oriented laths of muscovite. Along its northern and southern margins the quartzite has a foliation defined by small aligned muscovite flakes and by a light-grey/dark-grey colour layering and slight quartz-grain flattening. A lineation on this surface is usually defined by elongation of quartz grains and muscovite laths, but is often difficult to see in the field. The foliation, except over small areas, is parallel to the foliation in the underlying schist and gneiss. The lineation is likewise parallel to the dominant lineation in the underlying rocks.

Away from its marginal zones, structures other than jointing within the Chewings Range Quartzite are difficult to identify. This is partly because the quartzite becomes very pure away from its lower margin and muscovite laths are not present to help define the foliation and lineation. In addition, the exposed quartzite surfaces across the crest of the Chewings Range have undergone extensive superficial mobilization and redeposition of silica; this weathering process has to a large extent obscured all underlying structures.

Pegmatite and dolerite dykes

Numerous irregular pegmatite sills and dykes associated with the Ormiston Pound granite cut all the rock units in the Zone, and are themselves cut by a suite of dolerite dykes. The pegmatites increase in abundance westward towards the margin of the granite, and die out towards the eastern part of the Chewings Range Zone. Their intrusion is generally controlled by the pre-existing foliation of the rocks.

A suite of dolerite dykes to 8 m wide cuts all the rocks of the Chewings Range Zone. The dykes trend northward in the eastern and southern parts of the Zone, and north-northeast in the northeastern part. They possess an igneous texture and, where exposed, have sharp chilled contacts against the country rock. The dolerite dykes are the youngest rocks seen in the Zone. On the southern margin of the Zone, they are truncated by the unconformity at the base of the Heavitree Quartzite. They thus antedate the deposition of the Quartzite and the Alice Springs Orogeny deformation. Because of this, the dykes are useful time markers, and help to distinguish between Alice Springs Orogeny folds and earlier fold phases within the Zone (see Page 63).

Original nature of the Chewings Range Zone rocks

The dominant structures and textures of all the major rock groups in the Zone result largely from a single widespread metamorphic event. The metamorphism has obliterated all pre-existing structures which might indicate the original nature of the rocks. The compositions of the pelitic, semi-pelitic, and quartzitic rocks of the Chewings Range indicate that they were derived from mudstone, sandstone, and orthoquartzite. The present regional contact between the major units must represent the original bedding contact, although it has now been largely transposed parallel to the axial plane of at least one phase of tight folding.

The composition of the felsic gneiss is compatible with its derivation from either an older granite or felsic gneiss, or from a thick bed of feldspathic sandstone. In the former model, the gneiss would represent a basement upon which the sedimentary rocks of the Chewings Range were laid unconformably. A sedimentary origin for at least part of the felsic gneiss is thought likely, because of the common occurrence of thin pelitic or quartzitic layers within it. In addition, it seems unlikely, if there was an unconformity, that the deposition of the Chewings Range sediments would commence over a large area with a thick sequence of shale rather than an arenaceous or conglomerate unit.

Chewings Range Zone: deformational and metamorphic history

The effects of at least three and probably four phases of deformation can be seen in the history of the Chewings Range Zone before the Alice Springs Orogeny.

In the following description, for brevity and convenience of reference, abbreviations are used to denote the phases of deformation (D), folding (F), s-planes (S), and lineations (L). Numerical subscripts indicate a time sequence:

Pre-Chewings Phase	....	D_1, F_1, S_1, L_1
Chewings Phase	....	D_2, F_2, S_2, L_2
Ormiston Phase	....	D_3, F_3. S_3, L_3
Mount Giles Phase	....	D_4, F_4, S_4, L_4
Alice Springs Phase	....	D_5, F_5, S_5, L_5

Of these events, D_2, D_3, and D_5 are widely developed outside the Chewings Range Zone, and are separated by considerable periods of time. D_1 and D_4 are only recognised within the Zone and may have no regional significance.

Pre-Chewings Phase

Evidence for this Phase is preserved only in rocks marginal to the Chewings Range Quartzite. In these areas abundant F_2 folds are defined by thicker quartzite layers and by the folding of a foliation in the main quartzite unit parallel to that layering. The surface defining these F_2 folds is labelled S_1. In the pelitic schists and felsic gneiss, S_1 has generally been destroyed by the pervasive F_2 axial foliation (S_2), but its former presence is indicated by a strong streaky mineral-orientation lineation upon S_2, which is parallel to adjacent F_2 fold axes. At one locality (T), an intrafolial fold (F_1) lying within S_1 has been refolded by an F_2 fold (Fig. 4). At two other Localities (F and G), a lineation upon S_1, defined by a fine mullion structure and mineral elongation, has been refolded by Chewings Phase folds (F_2). This lineation is probably L_1, although it is identical to the similarly defined L_2 structure. Where no refolding relations are available, it is impossible to assign these lineations with certainty. Chewings Phase folds are very commonly developed in the Zone and are almost invariably accompanied by a strong axial lineation (L_2). As two sets of such lineation are rare, it was assumed that the majority observed and measured belong to L_2.

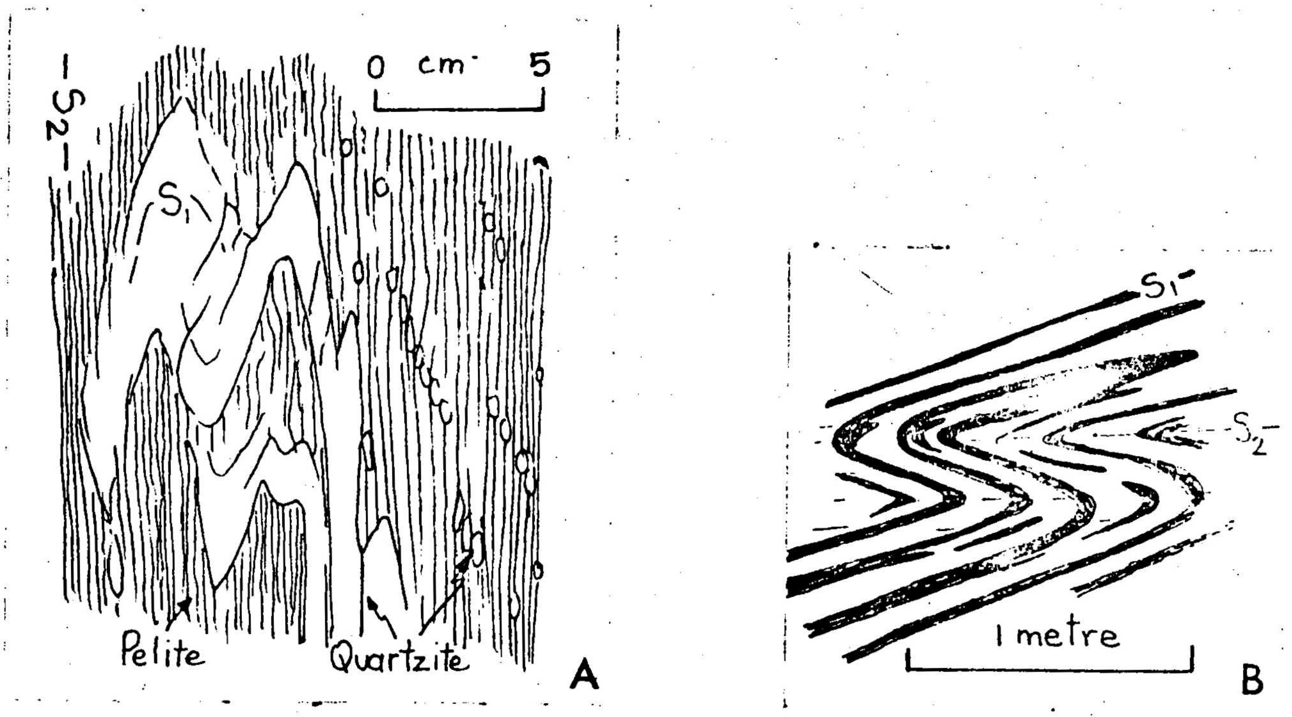

Fig. 4. F_2 and F_1 folds in the Chewings Range Zone.
A. F_2 intrafolial fold. S_1 marked in pelite by trains of quartzite mullions parallel to fold axis. Locality S
B. Tight F_1 fold refolded by F_2 fold in light-grey dark-grey finely banded basal Chewings Range Quartzite. Locality T.

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In the limbs of F_2 folds, S_1 has been generally transposed parallel to S_2, and the resulting surface is a composite S_1-S_2 structure.

Because of the obliterating effects of the Chewings Phase and its associated metamorphism, the metamorphic conditions during D_1 are difficult to deduce. The evidence suggests that during D_1 an earlier surface, possibly sedimentary layering, was transposed parallel to a strong foliation, S_1. The outcrop pattern of the rock units can be adequately explained in terms of D_2 to D_5 structures, and it is probable that the Pre-Chewings folds were never extensively developed in the Zone, and did not affect the major outcrop pattern.

Chewings Phase

Small F_2 folds, defined by S_1, are abundant in the margins of the Chewings Range Quartzite and in the adjacent schists. In the Quartzite, S_1 is the dominant surface and S_2 (the F_2 axial plane structure) marks a prominant intersection lineation (L_2) upon it (Fig. 5). In the pelitic and semi-pelitic schists, S_2 is the dominant surface and S_1 is preserved only within intrafolial fold noses or as trains of quartzite mullions (Fig. 4A). In the schists, L_2 is parallel to F_2 axes and is defined by a mineral streaking lineation upon S_2. In the felsic gneiss, S_1 is not preserved, and hence no F_2 folds were observed. In this rock type S_2 and L_2 are defined respectively by the gneissic foliation and by the mineral streaking lineation upon it.

The metasedimentary rocks of the Chewings Range lie within a major F_2-synclinorial structure. Because of secondary silicification, details of the major structure can be seen only where it affects the main quartzite-schist contact. The contact is so folded as to define large F_2 folds which can be clearly seen, for example, in Plate 1 or in Plate 3.2. The large F_2 folds on the northern and southern margins of the quartzite have opposite vergences and indicate that the major structure of the Chewings Range is synformal.

All the rock units of the Chewings Range Zone, except the pegmatite and dolerite dykes, were completely recrystallized by metamorphism which was at least partly coeval with the Chewings Phase of deformation. This metamorphism resulted in the growth of oligoclase-andesine and, at a few scattered localities where the composition was suitable, almandine, staurolite, and hornblende. These minerals characterize the almandine-amphibolite facies of regional metamorphism (Winkler, 1967; Turner, 1968).

During this metamorphism, minerals crystallized parallel to the axial structures of F_2. However, the generally granoblastic-polygonal texture of the quartz and feldspar indicates that crystallization of these minerals probably continued after the regional stress had waned (Spry, 1969; Soper & Brown, 1971), or that the rocks were affected by static metamorphism during a later event, perhaps at the time of widespread migmatization outside the Zone. General recrystallization at the time of the late migmatization does not seem likely, as a sample of the felsic gneiss yields a total-rock Rb-Sr age which shows no sign of any modification by the migmatite event (Marjoribanks & Black, 1974). However, a mineral age from the same sample of gneiss was reset during the migmatization, indicating that the temperature was raised within the Zone at this time.

Ormiston Phase

The westerly trend of the Chewings Range extends for at least 70 km east of the study area. Immediately west of Mount Giles the range swings sharply through 90° to strike northward. This swing in strike defines a large fold called the Eastern Pound Fold, which refolds D_2 structures. The gneiss to the south of the Range is not affected by this fold, and continues its westerly trend across the southern part of Ormiston Pound. The gap between the unfolded gneiss and the folded Chewings Range metasediments is occupied by the Ormiston Pound granite.

The axial-plane trace of the Eastern Pound Fold, defined by the folding of S_2, trends east-northeast, but has a sinuous outcrop due to the effect of D_4 deformation (Pl. 3.2). The Eastern Pound Fold becomes less intense towards the east, and cannot be distinguished 5 km east of Mount Giles. Axial-plane (S_3) and linear (L_3) structures associated with the Eastern Pound Fold are not widespread and are difficult to distinguish in the field from later structures. In the core of the large fold, small asymmetric F_3 folds facing north or northeast refold S_1 and S_2 surfaces. The F_3 fold profiles have a similar-style geometry, and, where affecting quartzite layers, characteristically have thin quartz-segregation veinlets parallel to their axial planes. They refold L_2 so as to distribute it on a planar surface (Fig. 5). In schistose rocks S_3 is defined by a crenulation cleavage. In the axial regions of F_3 folds, quartz, muscovite, and biotite have regrown parallel to the fold axes, and define a faint mineral-orientation lineation (L_3).

Along the southern margin of the Chewings Range Quartzite, to the south and southwest of Mount Giles, many distinctive small F_3 folds can be seen. Here, in the quartzite, S_1 is generally near-vertical and west-trending, and is cut at a very low angle by a strong penetrative S_2 cleavage so as to define an intersection lineation (L_2) on S_1. In many localities L_2 has been strongly folded by movements which do not, or only very slightly, fold S_1 (Figs. 5A and 5C). A faint mineral-orientation lineation parallel to the trace of S_3 on S_1 is also developed.

The Ormiston Phase is thought to be coeval with migmatization and granite intrusion widely developed outside the Zone. The arguments in support are as follow:

1. The simplest model for the formation of the Eastern Pound Fold is one which supposes that the Ormiston Pound granite was intruded into the area between the unfolded felsic gneiss and the folded Chewings

Range metasediments at the time of fold formation; forceful intrusion of the granite was responsible for the folding.

2. In folds associated with migmatization in the Ormiston Zone, small-scale local variation in the a-movement direction, and the internal deformation of pre-existing surfaces without folding of the surface are common features. Such a folding style is also developed during D_3 in the Chewings Range Zone.

It has already been shown that during the migmatization event the temperature in the Chewings Range Zone rose sufficiently to redistribute the Rb-Sr isotopes in the muscovite in a sample of felsic gneiss, and that the textures of the rocks of the Zone may have been modified. In addition, quartz, biotite, and muscovite began to recrystallize locally parallel to the axial structures of D_3 folds; the large irregular microcline crystals within the gneiss may also have formed at this time. However, the extensive flow-folding and granitization which completely modified the older gneisses outside the Chewings Range Zone are nowhere developed.

Mount Giles Phase

Folds belonging to the Mount Giles Phase are abundant, and occur on all scales within the west-trending outcrop of the Chewings Range metasediments. North of the Range, where S_2 has a northerly strike, D_4 rapidly dies out. D_4 structures were not observed within the felsic gneiss. South of the Range, D_4 structures can be traced across the schist zone into the adjacent gneiss, but the folds become much more open, and disappear with distance from the Range. Major F_4 folds can be identified by their effect on the westward-trending outcrop of the Chewings Range. Six such major F_4 axial traces are shown in Plate 3.2.

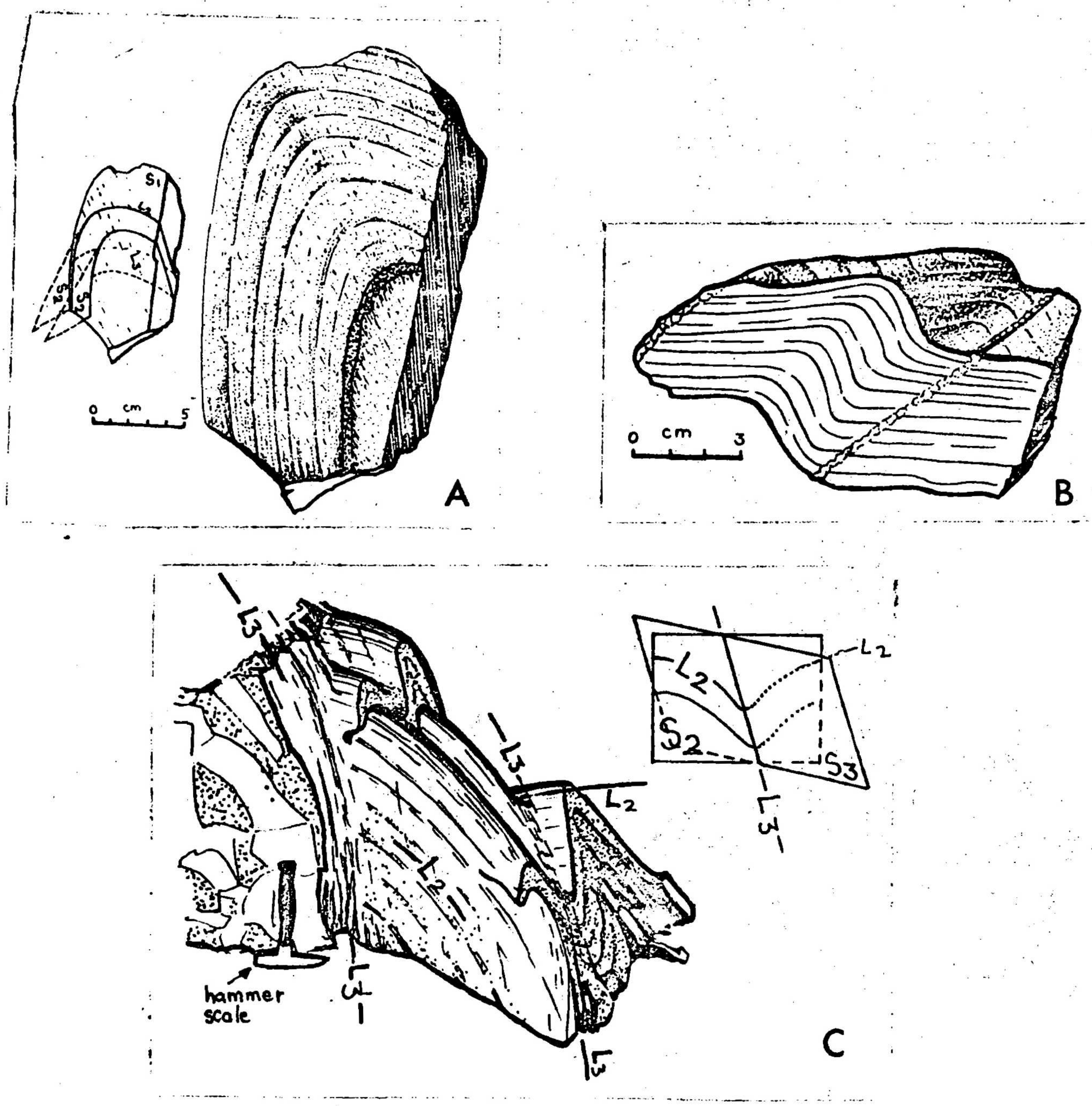

Fig. 5. F_3 folds, in the Chewings Range Zone.

A. Unfolded S_1 surface; internal deformation marked by distortion of intersection-lineation L_2. Basal Chewings Range Quartzite. Locality U.

B. Open similar fold in well foliated basal Chewings Range Quartzite. Lineation upon S_1 (L_2) distorted to lie on plane. Note quartz-segregation veinlet parallel to axial plane. Locality V.

C Tight F_2 folds refolded by F_3. The a-movement direction for F_3 lies within S_2 (compare with 5A). Quartzite layer adjacent to Chewings Range Quartzite. Locality W.

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F_4 is relatively open, and has an asymmetric profile with the steep limb facing south or southwest. It has a general parallel-style fold geometry, and in well foliated rocks shows long straight limbs and narrow hinge areas (Fig. 6A). No new mineral growth accompanied the Mount Giles deformational phase. S_4 is defined in pelitic and semi-pelitic rocks by a crenulation cleavage, and in the quartzite by rare fracture cleavage which may show slight divergent fanning around the fold hinge.

Along the northern margin of the Chewings Range, F_2 and F_4 are very nearly coaxial, although in detail L_2 is folded around F_4 hinges. On the southern margin of the Chewings Range there is a wider divergence between observed F_2 and F_4 axial directions, and L_2 is distributed to a greater extent by the later folding.

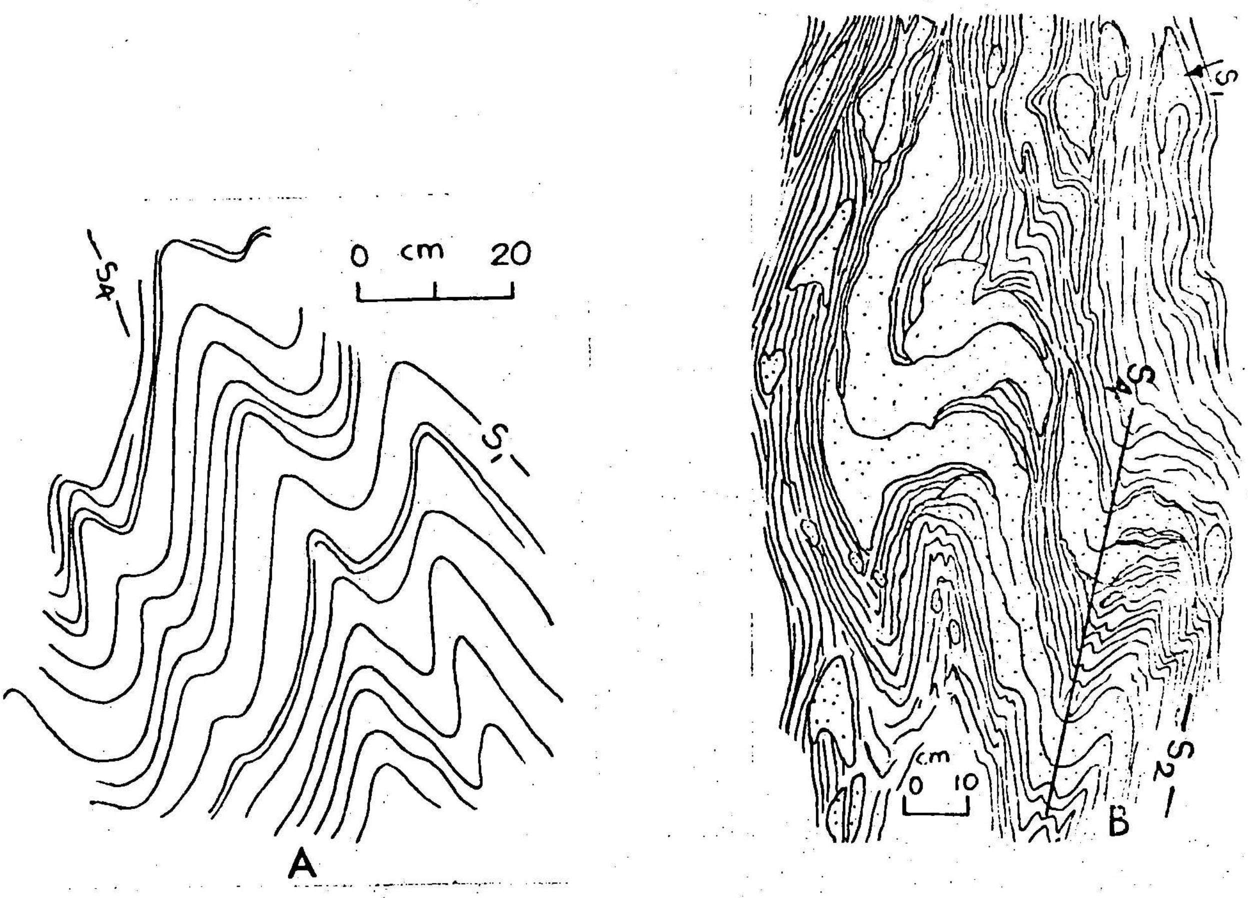

Fig. 6. F_4 folds in the Chewings Range Zone.
A. Well foliated basal Chewings Range Quartzite. Locality X.
B. S_2 surface in pelites containing abundant quartzite lenses, mullions, and isolated F_2 fold closures, refolded by F_4 folds. Locality Y. M(P1)166

Positively identified D_3 structures were not seen affected by D_4. However, the later age of D_4 is demonstrated by the changing angular relation between the trends of S_4 and S_2 from north to south across the area (Pl. 3.2). On the southern limb of the Eastern Pound Fold (F_3) where S_2 trends westward, S_4 cuts across S_2 at an acute angle. As the S_2 trend swings northward, S_4 becomes increasingly parallel to it. Thus the swing in strike of S_2 around the Eastern Pound Fold must have existed before superimposition of the D_4 structures.

The southward decrease in intensity of D_4 structures can be explained by supposing that during the Mount Giles Phase the thick synformal keel of quartzite of the Chewings Range acted as a competent layer in a less competent medium and reacted to stress by buckling, whereas the adjacent incompetent material, away from contact effects, deformed homogeneously (Ramberg, 1961; Ramsay, 1967). North of the Range, homogeneous deformation was aided by the fact that the pre-existing S_2 foliation lay parallel to the principal flattening plane (the S_4 surface) during the Mount Giles Phase.

It is possible that the gentle curve in S_4 across the Chewings Range (Pl. 3.2) was caused by the Alice Springs Orogeny (D_5), but the lack of any effect of such movements on the linear dyke swarm which was intruded between D_4 and D_5 is then difficult to explain. The curvature of S_4 probably resulted from either inhomogeneous strain during D_4 or from a further deformational episode between D_4 and the time of dyke emplacement. Inhomogeneous strain, caused by the different competencies of the quartzite and adjacent schist and gneiss during D_4, is thought to be the most likely explanation.

Chewings Range Zone: structural analysis

For the purpose of analysis the Zone is divided into eight Domains whose boundaries are shown in Plate 3.1. The axial-plane traces of the major fold axes are shown in Plate 3.2.

Domains A and H both lie on the north-trending or northeast-trending limbs of major F_3 folds, and outside the area affected by D_4. S_2 and L_2 in these Domains are deformed mainly by folds of Alice Springs Orogeny (D_5) age. Domains A and H are hence described later.

Domains B, C, D, E, and F are defined so that each Domain shows a constant attitude of D_4 axial lineation (L_4). The attitude of L_4 at any point is controlled by the orientation of S_4 and the orientation of the dominant foliation (S_1 or S_2) at that locality before the Mount Giles Phase. The Domains thus represent areas across which the attitude of S_1/S_2 to S_4 was approximately constant at the start of D_4. As S_2 was distributed by large F_3 folds (principally the Eastern Pound Fold) before D_4, the Domain boundaries are largely controlled by the position of the rocks on the limbs of the F_3 folds.

Orientation data for the structural elements of D_2, D_3, and D_4 Phases are presented in Plate 3. The Domains are described in sequence from north to south, using the nomenclature of Turner & Weiss (1963).

<u>Domain F</u>. Effects of post-D_2 deformation in this Domain are very slight. S_2 trends north, and dips at about 45° to the east (Pl. 3.3.f). Only two folds of possible D_4 age were observed; they are small open folds with near-horizontal axes. The fold axes lie close to a possible π-axis, which is weakly defined by a slight east-west scatter in the poles to S_2. L_2 is likewise close to horizontal in this Domain, and shows little sign of having been distributed by the D_4 event.

<u>Domain B</u>. This Domain lies on the northeast-trending east-dipping limb of the large Ormiston Phase fold (F_3) in the northeast of the Chewings Range Zone (Pl. 3.2). Poles to S_2 are distributed by F_4 folds to lie on a well marked great-circle girdle (Plate 3.3.b), with a π-axis plunging at 30° to 120°, and lying close to measured F_4 axes and axial lineations. L_2 lineations plot in the same approximate position on the stereonet at L_4, but show a greater distribution in orientation than L_4.

This agrees with the field observation that F_2 and F_4 are very close to coaxial in this Domain.

Axial planes to the Mount Giles Phase folds (S_4) have a fairly constant attitude in Domain B and dip about 65° to 040° (Pl. 3.5.a).

<u>Domain D</u>. Poles to S_2 in this Domain are distributed in a weak great-circle girdle defining a π-axis plunging at 34° to 144° (Pl. 3.3.d). The π-axis falls within the field of measured L_4 structures in the Domain, and hence the great-circle distribution of S_2 poles is believed to be caused by Mount Giles Phase folding. L_2 shows a wide scatter in this Domain, probably mainly as a result of small-scale F_3 folding. However, most L_2 lineations plunge to the southeast and lie at less than 40° to L_4.

Only two measurements on S_4 were made in this Domain. These planes have an average orientation of about 80° dip to 030° (Pl. 3.5.a).

<u>Domain C</u>. Domain C is very similar to Domain D. Poles to S_2 are distributed by F_4 folds to lie in a great-circle girdle (Pl. 3.3.c). The girdle π-axis plunges at 20° to 147°, and lies close to measured F_4 axes and L_4 lineation. L_2 lineation shows a fairly wide scatter, but most lineations have a gentle plunge towards the southeast, and lie at a small angle to L_4. In Domain C, as in Domain D, the F_2 and F_4 folds are close to coaxial, and distribution of L_2 during D_4 was thus minor.

S_4 surfaces have a fairly constant orientation, and dip at about 75° to 055° (Pl. 3.5.a).

<u>Domain E</u>. This large Domain covers most of the southern margin of the Chewings Range. S_2 planes have a relatively constant east-west strike, but their dips range from 40°N to 30°S. Poles to S_2 (Pl. 3.3.e) define a weak partial great-circle with a π-axis plunging at about 10° to 092°. This distribution of S_2 is thought to result from broad open F_4 folds, and measured axes and axial lineations of these folds

plot around the π -axis.

In contrast to S_2, L_2 shows a very wide scatter in this Domain, and defines no recognizable pattern on the stereonet. In attition, hardly anywhere in Domain E does F_4 appear to be coaxial with F_2. The wide scatter in measured L_2 lineation may be the result of different causes:

1. Confusion in the field between L_2 and possible L_1 lineations
2. Distribution of the lineation by Ormiston Phase (D_3) folds before D_4
3. A high angular discordance between the lineation and the axes of F_4

In Domain E, the axial planes of F_4 folds (S_4) dip at an average of 80° to the north or northeast (Pl. 3.5.a).

Domain G. Insufficient measurements of D_2 structures were made in this Domain to define adequately any distribution pattern.

Domains B, C, D, and F - L_2 lineation. A contoured synoptic plot of 86 L_2 lineations from these Domains is given in Plate 3.4.g. The plot shows that L_2 lies in a baoad partial great-circle girdle, although a fairly wide scatter of points does not lie on the girdle. The girdle distribution is not considered to be the result of D_4, because in each of the Domains F_2 and F_4 are close to coaxial. The distribution therefore must result largely from D_3, or from the swing in strike of the D_4 structures across the area. F_3 folds have a near-similar style, and in many exposures refold L_2 so that the lineation lies on a plane (Fig. 5). Small folds or axial structures were not observed associated with the broad warping of S_4 across the area, but it is expected that such a late open structure would be accomplished by a buckling mechanism, and would therefore tend to distribute early lineations into a small-circle rather than a great-circle girdle pattern (Ramsay, 1967). It is therefore believed that D_3 played the major role in the distortion of L_2 from Domain to Domain.

On the assumption that the distribution of L_2 principally is the result of the Ormiston deformational event (D_3), and that the mechanism of that fold phase was one of heterogeneous simple shear, then the regional D_3 a-movement direction can be obtained.

All measured poles to S_3 are shown in Plate 3.5.e. There is a scatter of values consistent with deformation by D_4, but an average value for this S-surface can be defined as striking at 080° with a vertical dip. Such a plane will define an approximate a-movement direction for D_3 folding of 25° to 080° (Pl. 3.4.g).

The Variation in Orientation of D_4. Figures 3.5.a and 3.5.c show the swing in orientation of S_4 across the area. As a consequence of this swing, both L_4 and the π-axes defined by the poles to S_2 ($\equiv L_4$) also show a systematic change from a near-northerly trend in the northern Domains to a near-easterly trend in the southern Domain E (Figures 3.5.b and 3.5.d).

The variable orientation of D_4 structures probably resulted from inhomogeneous strain during D_4 (see Page 22).

Synthesis. Structural relief diagrams for the southern part of the Chewings Range Zone are presented in Figure 7. The diagrams are drawn as if viewed from the northwest and from slightly above ground level. The two S_1 surfaces chosen as marker horizons represent the contact of the Chewings Range Quartzite with the underlying schist, and the schist/felsic gneiss contact. The outcrop of these horizons can be exactly defined (Pl. 1), and has been accurately transferred onto Figure 7. Although over 600 m of relief exists in the Chewings Range, the marker horizons intersect the ground surface in an approximately horizontal plane; this plane has been chosen to represent the upper surface of the block diagrams.

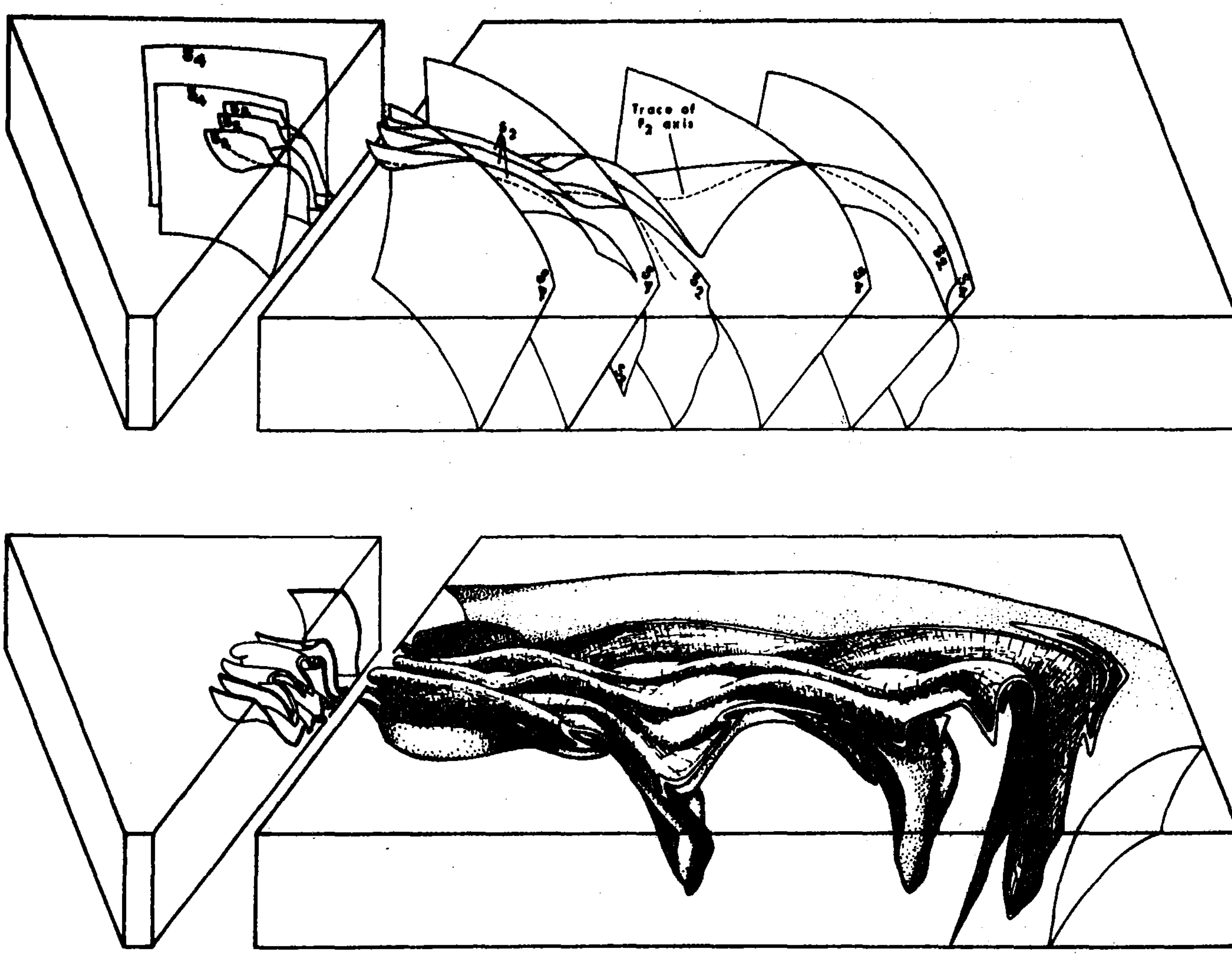

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Fig. 7. Structural relief diagram of the Chewings Range Zone.

Redbank Zone

Field Relations

The Redbank Zone is characterized by blastomylonitic rocks* which occupy a linear west-northwest-trending belt extending across the area and separating granulite-facies rocks of Mount Hay and Mount Chapple to the north from migmatitic rocks to the south. A large part of the Zone and most of its northern margin are not exposed. In the northern half of Redbank Hill (from which the Zone is named), a belt of synformally folded felsic gneiss (similar to the gneiss of the Chewings Range Zone) and amphibolite appears to grade southwards into Redbank Zone rocks. In the extreme west of the area, granite and migmatite similar to those of the Ormiston Zone occur north of a belt of Redbank Zone rocks. A belt of alluvial cover 2 to 6 km wide separates the two areas from the granulites of Mount Chapple. Blast-omylonitic textures slong the southern margin of Mount Chapple (Page 48) probably represent the northern margin of a linear zone of deformed rocks underlying the belt of non-exposure. Such a zone of deformed rocks would pass between Mount Chapple and Mount Hay, and probably coalesce with a strike extension of the blastomylonitic rocks of Redbank Hill. On this interpretation, the granulite-facies rocks of Mount Hay, and the area of felsic gneiss and amphibolite on the northern half of Redbank Hill represent slices lying within a wide complex zone of deformed rocks up to 25 km wide. Redbank Zone rocks

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* The terms 'mylonitic' and 'blastomylonitic' will be used in this Record in an unspecific way to refer to finely foliated rocks resulting from high strain. These terms are preferred to the term 'cataclastic rocks' (Higgins, 1971) which implies that rupture and rotation of mineral grains necessarily played a large part in producing the deformed fabric. The term 'mylonite' has a restricted definition (Lapworth, 1885; Christie, 1960; Higgins, 1971), and the rock is only definitely identifiable as such in thin section.

thus probably underlie much of the alluvial cover in the northern part of the area.

The rocks of the Zone have a well developed, fine north-dipping mylonitic foliation and a strong streaky north-plunging lineation. The foliation is generally marked by thin (1 - 3 mm) alternating laminae which are variously defined by a coarse to fine grainsize alternation or, in heterogeneous rocks, by mafic to felsic compositional variations. In thin section typical rocks from the Zone are composed predominantly of a mosaic of strain-free recrystallized quartz (0.3 mm average grainsize), which preserves mimetically a deformed texture of laminar foliation, ribbon grains, and augen within the foliation (Fig. 15).

The rock is typically studded with augen of quartz or feldspar, ranging upwards from 1 mm long. The larger augen consist of untwinned feldspar (determined in one specimen as orthoclase), and increase in both number and size northward across the Zone. At Redbank Hill, crystals 5 to 10 cm, and up to 30 cm, long may constitute over half the volume of the rock. The large augen are flattened and elongated parallel to the foliation and lineation (Fig. 12); the foliation partly swirls around the crystals and partly is interrupted by them, to be preserved as trails of inclusions. The augen are thus porphyroblasts; their abundance and large size suggest the action of potash metasomatism after the start of deformation in the zone, although deformation must also have either accompanied or postdated their formation.

Smaller, more ubiquitous augen, typically of quartz and alkali feldspar (orthoclase, microcline, albite, and oligoclase), are generally inclusion-free and show signs of high strain. They are probably relics of a pre-deformational quartzofeldspathic rock.

The composition of the Redbank Zone is dominantly quartzofeldspathic with rare layers to 1 m thick of quartzite, biotite-schist, quartz-biotite-almandine schist, or amphibolite. In their pre-deformational form the rocks of the Zone probably consisted of felsic gneiss with metasedimentary and amphibolitic layers. These rock types are similar to those now preserved in the Chewings Range Zone.

Small reolined intrafolial folds with axes parallel to the strong lineation are common, especially in the southern part of the Zone (Fig. 8).

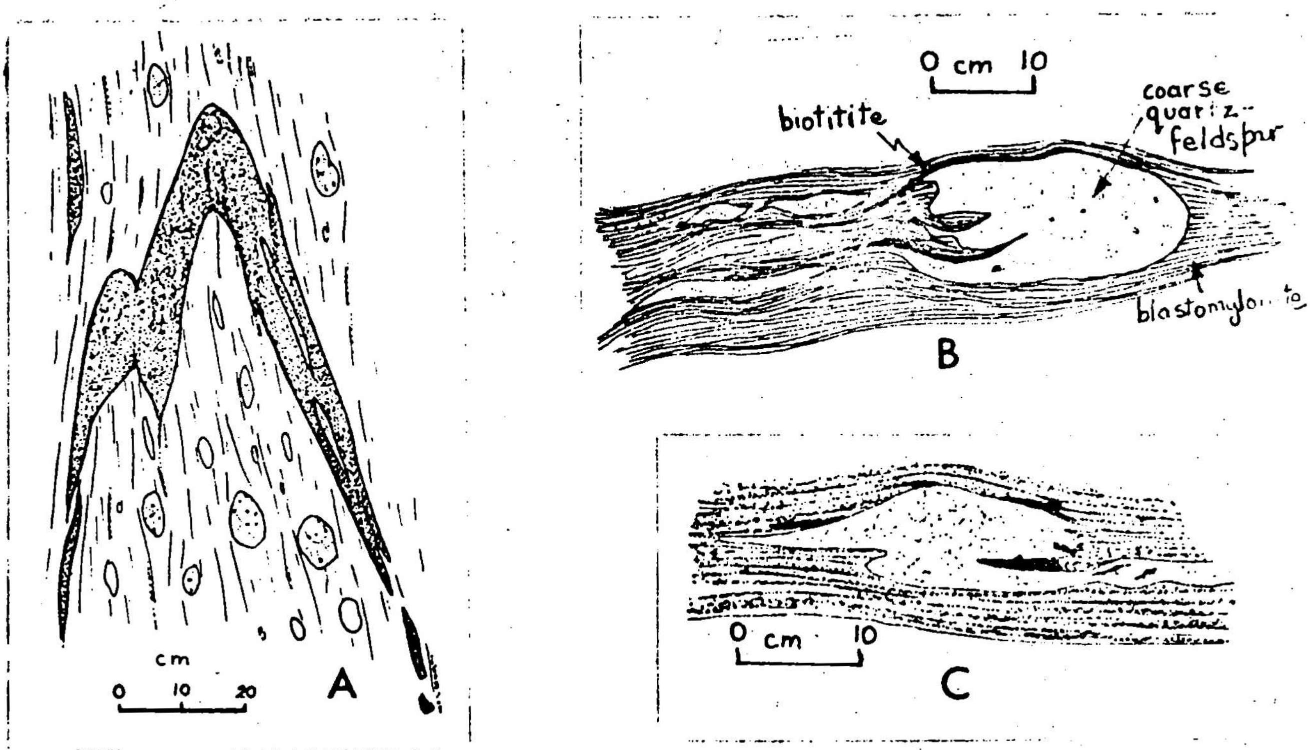

Fig. 8. Intrafolial fold profiles in the Redbank Zone.
A. Amphibolite layer in coarse blastomylonite. Note large inclusion-filled feldspar augen. Locality Z.
B. Finely foliated blastomylonite. Fold nose site of late-stage quartzofeldspathic segregation with dark biotite-rich selvedges. Locality AA.
C. As for B. Rock shows a more advanced stage of migmatization characteristic of the southern margin of the Redbank Zone. Locality BB.

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The folds are defined by quartzite, quartz-rich, or quartzofeldspathic layers; their limbs are completely transposed parallel to, and are obliterated by, the mylonitic foliation which is an axial-plane structure.

The mylonitic foliation and lineation are themselves folded by a second set of north-plunging reclined folds which range from open to tight; in some places they are associated with recrystallization of mica and quartz so as to form an axial foliation and mineral-orientation lineation, which may locally obscure the earlier mylonitic foliation (Figs. 9 and 10). The new mineral growth associated with the folds becomes more abundant towards the south, and is increasingly associated with the development of a granitic mobilizate within the rock, commonly as layers or vaguely defined zones parallel to the fold axial planes. The widespread development of the granitic phase marks the beginning of the development of the Ormiston Zone. Folds affecting the foliation continue into the Ormiston Zone, where they are coeval with general mobilization and granitization. All the folds in the Redbank Zone which affect the mylonitic foliation, even where not associated with the production of a granitic mibilizate, are probably of the same age as the deformation and migmatization of the Ormiston Zone, and hence

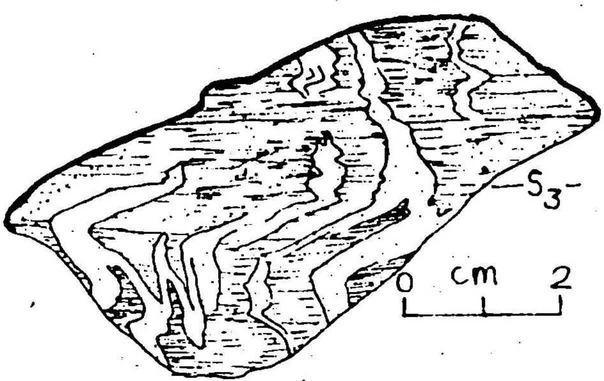

Fig. 9. Intrafolial folds refolded by F_3 folds in the Redbank Zone.
A. Semi-pelitic layers in pelitic rock. Note obliteration of mylonitic foliation by strongly developed S_3. Locality CC.
B. Finely foliated semi-pelite. Locality DD.

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probably equivalent to the D_3 (Ormiston Phase) structures of the Chewings Range Zone. The folds will hence be referred to as F_3, and their axial structures as S_3 and L_3.

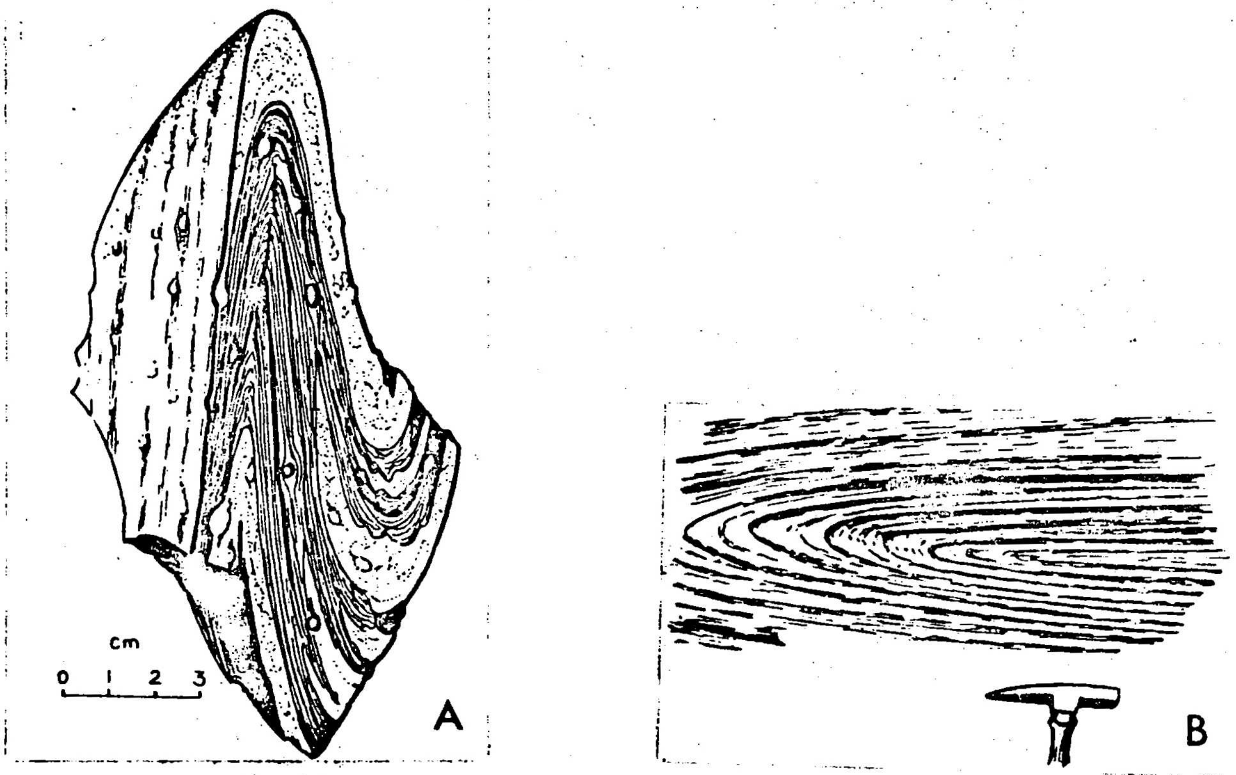

Fig. 10. F_3 folds in the Redbank Zone.
A. Quartzite and semi-pelite with feldspar augen and strong lineation refolded by F_3. Note curved fold axis. Locality E.
B. Finely foliated semi-pelite. Locality DD.
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Large bodies of hypersthene-gabbro have been intruded on the southern flank of Redbank Hill and in the extreme west and east of the Redbank Zone (Fig. 3 and Pl. 1). The gabbro intrudes mylonitic rocks at Redbank Hill and in the east of the area, and migmatitic rocks in the western part of the area. The gabbro at Redbank Hill is north-dipping, sill-like, and has a quartz-dioritic northern marginal phase crowded with xenoliths of partly assimilated country rock. The sill-like form probably reflects a control on intrusion by the north-dipping foliation of the Zone.

Within the southern Redbank Zone and northern Ormiston Zone, a swarm of west-trending dolerite dykes with sharp chilled margins cuts granitic, migmatitic, and mylonitic rocks. The dykes range up to 10 m thick, and cut the foliation at a low angle.

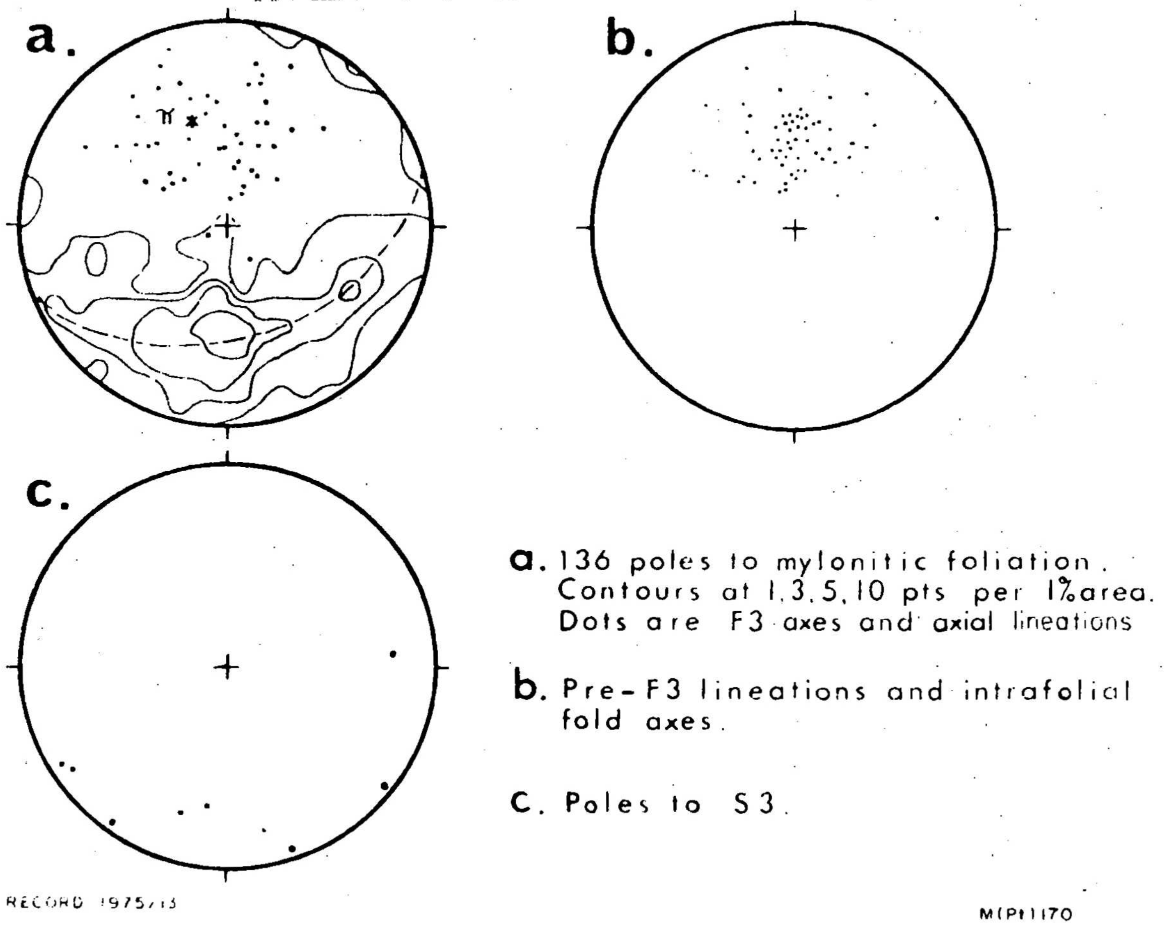

Fig. 11. Orientation data in the REDBANK ZONE.

In the orientation diagram (Fig. 11) the intrafolial folds have a fairly constant plunge to the north, and the early lineation has an approximate mean value of 45° to 350°. The F_3 axial directions have a slightly greater scatter but define a mean value not greatly different from that of the intrafolial folds. Because the two sets of folds are very nearly coaxial, the early lineation has not been distributed by the later folds to any great extent. The contoured plot of the poles to the mylonitic foliation shows the effect of F_3 folding in its broad great-circle girdle distribution; the girdle defines a π-axis plunging at 45° to 342°. However, the poles to mylonitic foliation show

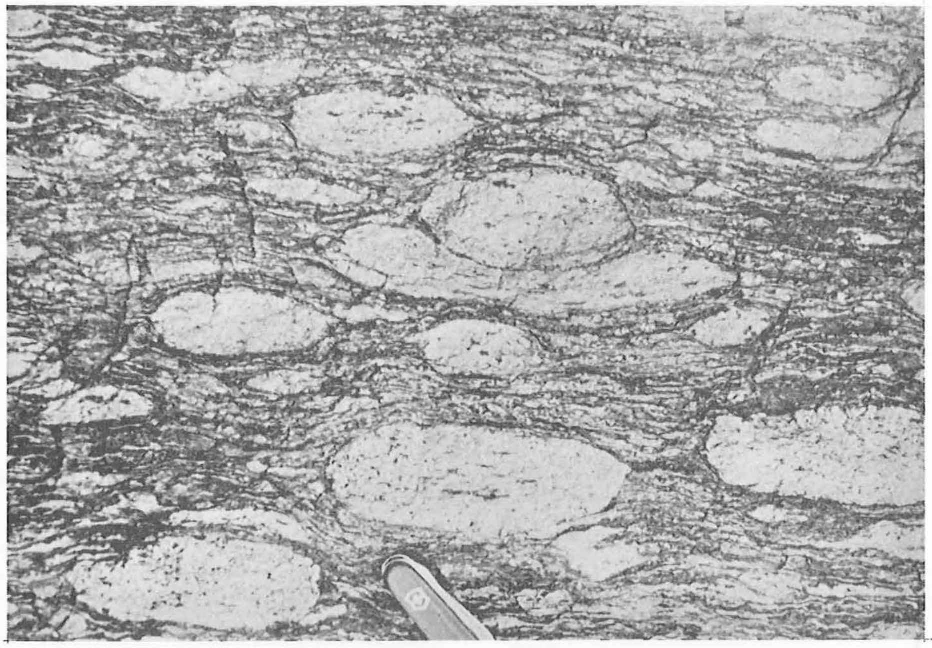

Fig. 12. Large inclusion-filled feldspar porphyroblasts in the Redbank Zone. The larger porphyroblasts are about 15 cm long. Note the fine-grained dark mylonitic foliation, and the elongate inclusions within the porphyroblasts parallel to the foliation. Locality EE.

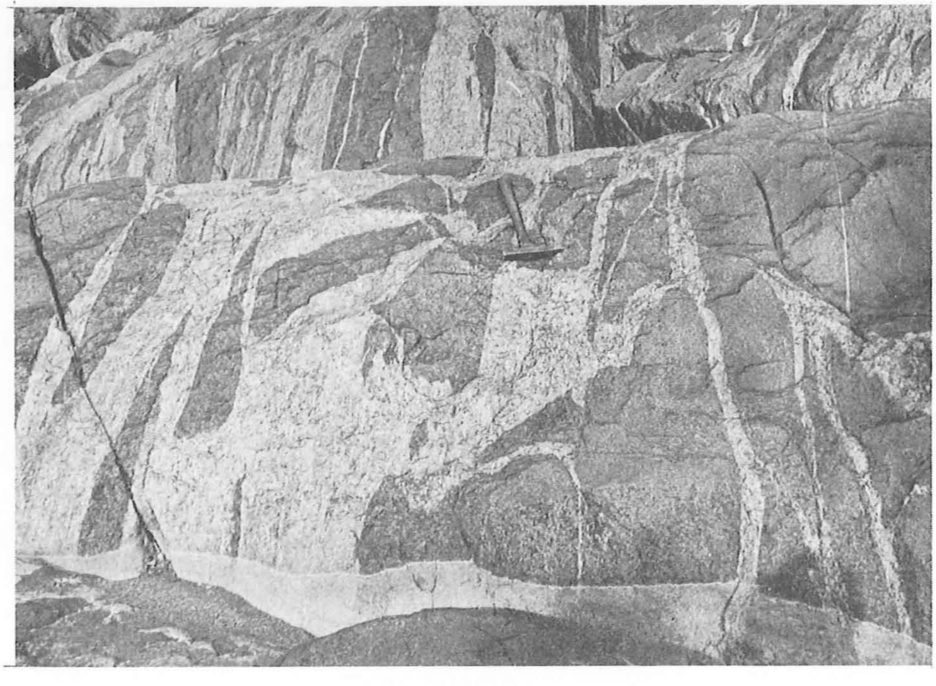

Fig. 13. Agmatite from the southern margin of Redbank Hill in the Redbank Zone. Granitic magma has been injected into, and has disrupted an amphibolitic layer within the Redbank Zone deformed rocks. The formation of the agmatite was probably coeval with migmatization in the Ormiston Zone to the south. Locality FF.

a marked preferred orientation at about strike 090°, dip 45°N, and the girdle distribution of the poles is not strong. This confirms field observation and mapping, which show that the regional effects of F_3 folds in the Redbank Zone are not marked.

Only a few S_3 planes were measured. Figure 11c shows that the attitude of the planes is not constant but indicates that S_3 is generally steep and north-dipping.

Origin of the Redbank Zone

Intrafolial folds and the dominant mylonitic foliation are coeval in the Zone, and their relations suggest that they formed as the result of high strain probably caused by a north-south principal stress direction oriented normal to the foliation. The reclined fold axes are best explained as resulting from rotation parallel to the principal extension direction of the strain ellipsoid, in the manner described by Flinn (1962). High stress within the Zone probably resulted from fault movement within it. Evidence for major upthrow to the north is provided by the juxtaposition of granulite-facies rocks to the north of the Zone against amphibolite-facies rocks within and to the south of the Zone, and by the steep gravity gradient across it. Major fault movement probably took place on at least two occasions. The dominant deformation of the Zone occurred before the migmatization (dated at about 1100 m.y.), and there is evidence of renewed fault movements within narrow portions of the Zone at the time of the Alice Springs Orogeny.

Granoblastic textures within the Zone probably result from both syntectonic crystallization and from post-deformational metamorphism, the effects of which are impossible to distinguish in thin section. Amphibolitic rocks within the Zone share its dominant foliation and lineation, and indicate that the major deformation took place at elevated temperatures within the amphibolite-facies range. During the subsequent migmatization, potash metasomatism was probably widespread, and was responsible for the formation of the large feldspar porphyroblasts at Redbank Hill. New mineral growth and quartzofeldspathic segregation accompanied and helped to define the D_3 structures, but over wide areas the initial effect of the migmatization was to emphasize the pre-existing foliation and the intrafolial fold noses.

From the time of its inception the Redbank Zone must have represented a major zone of weakness within the Earth's crust, and it has exerted strong controls on the subsequent geological history of the area.

Ormiston Zone

Field Relations

The Ormiston Zone is the most extensive Zone defined in the Arunta Complex. Within it, felsic gneiss, mica schist, quartzite, amphibolite, and mylonitic rocks are variously affected by granitization so as to form a migmatite complex with associated large bodies of granite. It was not possible to map the older rocks within the migmatite complex or to trace the outcrop of a particular unit for any distance, but the older rocks are sufficiently preserved to show that in the south and southeast of the Zone the migmatites developed from felsic gneiss containing minor metasedimentary bands similar to the gneiss of the Chewings Range Zone, whereas in the northern part of the complex the migmatization affects mylonitic rocks similar to those of the Redbank Zone. The relations between the Chewings Range and Redbank Zones are obscured by the intervening migmatite complex.

The stages by which the older gneiss and schist were converted into migmatite and ultimately to granite can be seen along the boundaries of the Ormiston Zone with adjacent Zones, and also throughout the complex where individual rock units may preserve their original composition and structures over small areas. On a large scale the boundaries of the

Fig. 14. Mylonitic foliation in the Redbank Zone affected by an F_3 fold. The coarse pegmatite on the right is parallel to the F_3 axial plane. Locality GG.

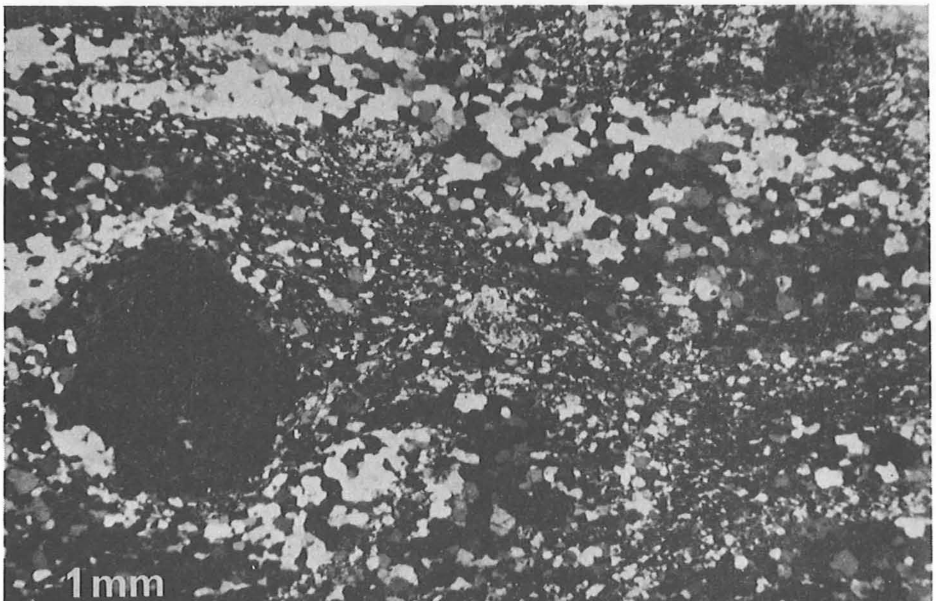

Fig. 15. Photomicrograph of typical coarse-grained blastomylonite from the Redbank Zone. Most of the rock is quartz; the large porphyroclast is oligoclase. Locality E. Crossed nicols.

migmatite complex are generally conformable with the foliation of the adjacent Zones. On the eastern side of Ormiston Pound the migmatite complex terminates sharply against the Chewings Range Quartzite. Along the northern margin of the Chewings Range Zone, the boundary is marked by thrust faults of Alice Springs Orogeny age, but between the thrusts a transition (or migmatite front) between the migmatite complex and the felsic gneiss of the Chewings Range Zone can be seen. The width of the transition zone is only 0.5 km, and begins with the appearance of generally conformable veins and sills of aplite and pegmatite within the gneiss. As the gneiss is traced across the strike towards the Ormiston Zone, the pegmatite veins become larger and more numerous until they constitute almost half the rock. At this stage, irregular patches, streaks, or general impregnations of quartzofeldspathic material (referred to as the 'mobilizate', Dietrich & Mehnert, 1960) begin to appear within the gneiss; commonly these segregations have associated biotite-rich selvedges. Along with the abundant new granitic material, the original planar (S_2) and linear (L_2) structure of the gneiss is distorted by abundant small irregular folds which have quartzofeldspathic material parallel to their axial planes. Finally the rock has a completely granitic appearance, with the original banding present only as swirling disordered streaks or knots of biotite-rich material.

Over much of the southern margin of the Redbank Zone, the first metamorphic effect which can be associated with the migmatization is the formation of an axial-plane cleavage and axial lineation to Ormiston Phase folds (F_3). Quartzofeldspathic material tended to segregate into favourable sites within the rock, such as parallel to the axial planes of F_3 folds (Fig. 14) or within the noses of the small early intrafolial folds (Figs. 8 and 22). At a later stage, augen or lenses of quartzofeldspathic material (leucosomes) developed within the layering; they generally have a biotite-rich dark selvedge (melanosome).

With increasing migmatization the leucosomes and melanosomes become continuous alternating bands, generally parallel to the original mylonitic foliation. The original strong north-dipping lineation is generally destroyed by this stage. The strong differentiated banding is finally disrupted and obscured in the highest stages of migmatization by the development of numerous small shears, disordered flow-folds, and associated patches, streaks, or general impregnations of granitic material. As with migmatization of the felsic gneiss, the ultimate stage is the production of a structureless granite.

The first effect of migmatization upon the Redbank Zone mylonitic rocks is thus to emphasize the initial layering. By contrast, in the initially more homogeneous gneiss of the Chewings Range Zone, migmatization rapidly obscures the initial planar structures, and well layered migmatites are only rarely developed. This contrast can be explained by the mimetic control on the movement and crystallization of mobilizate material exerted in the Redbank Zone by the fine pre-existing mylonitic foliation. The effect of this initial strong anisotropy persists until the whole rock has been almost completely granitized.

Within the Ormiston Zone, factors such as initial rock type and amount of mobilizate present led to a wide variety of migmatitic structures. Quartz-rich (quartzite and quartz-rich schist) and mafic-rich (amphibolite, biotitite, and biotite-schist) layers resist migmatization and may act as restites (Dietrich & Mehnert, 1960), preserving their original composition and structures, whereas adjacent quartzofeldspathic layers are completely granitized (Fig. 16). Small areas of such restites ranging from thick ribs of quartzite to thin wisps of biotitite often provide the only clue to the original nature of extensive areas of otherwise structureless granite.

The migmatite complex can be subdivided on the amount of the new granitic phase (the mobilizate) which has developed within it. At an estimated mobilizate content of around 80 percent, homogenization of the rock has generally proceeded to the point where the initial planar structures cease to exercise a control on its outcrop pattern. The value of 80 percent mobilizate content was thus a convenient one to use in mapping the complex. Relict structures within the highly migmatized (greater than 80% mobilizate) areas suggest that they are

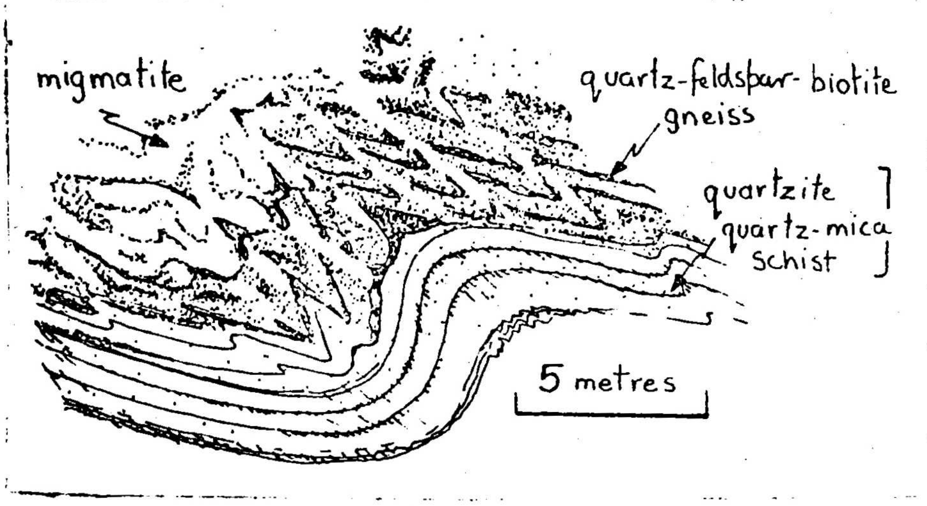

Fig. 16. Sketch showing relations between F_3 fold-style, migmatization, and lithology. Locality HH.

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largely formed from original felsic gneiss similar to that of the Chewings Range. This is consistent with the strong control which the original composition of the rock has on the susceptibility to granitization.

In Plate 1, it can be seen that the major granite bodies in the Ormiston Zone occur within or are intimately associated with areas of highly migmatized (greater than 80% mobilizate) rocks. The granite at Ormiston Pound grades imperceptibly into highly migmatized rocks on the western side, but has a sharp cross-cutting contact with granitized quartz-feldspar-biotite gneiss along the eastern margin. Similar contact relations can be found in most of the large granite bodies mapped within the Zone. From these relations it is evident that in the formation of the granites both the action of a mobile intrusive granitic liquid, and of granitization in situ of original gneissic material must be invoked.

Considerable deformation of the original banding and lineation accompanied granitization in the Zone. The syn-migmatization folds of the Ormiston Zone can be correlated with the Ormiston Phase deformation (D_3) in the Chewings Range Zone, and with folds in the Redbank Zone; they will thus be referred to as F_3 folds. F_3 folds range from tight to open, and have similar-style profiles, and characteristically have variably-plunging axes within the axial plane. A strong local axial foliation caused by the parallel alignment of platy minerals may be developed (Fig. 22), and quartzofeldspathic segregation veins parallel to the axial plane are common. A mineral-orientation lineation defined principally by parallel alignment of elongate biotite laths may be developed, and is typically parallel to the fold axis.

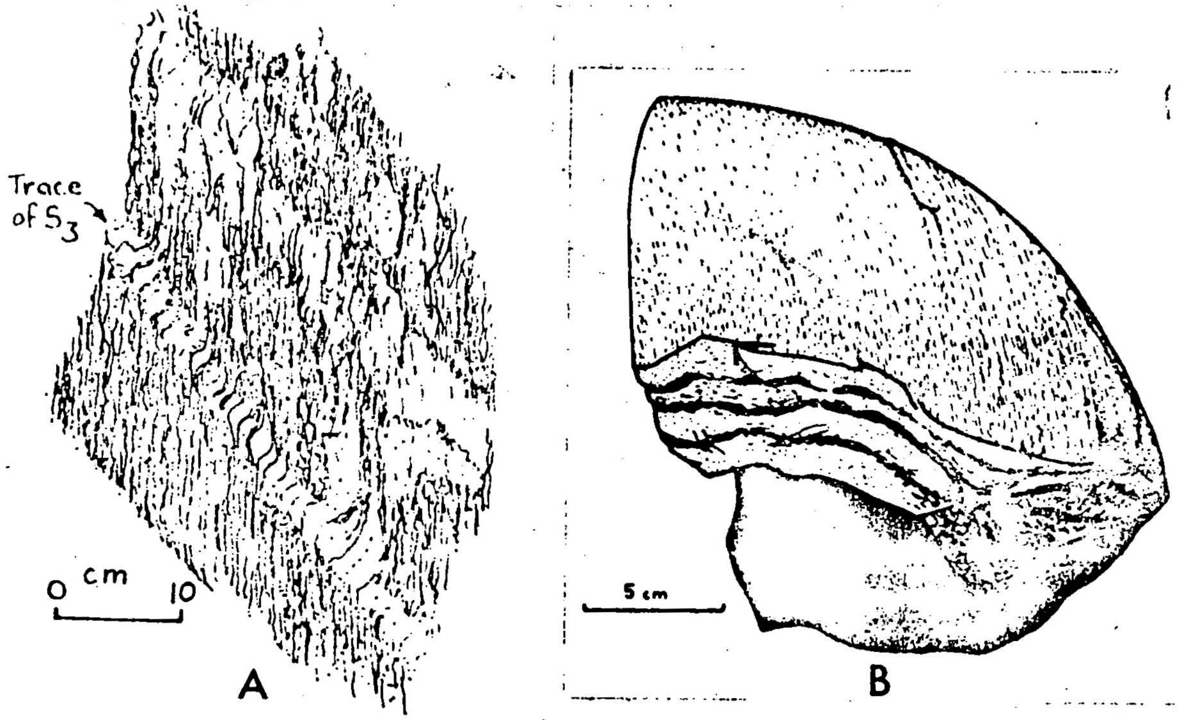

Fig. 17. F_3 folds in the Ormiston Zone.

A. Finely banded quartz-feldspar-biotite gneiss. Quartzofeldspathic segregations and parallel to small F_3 shears. Locality II

B. Quartz-feldspar-biotite gneiss with mineral-orientation lineation parallel to axis of early intrafolial fold. The F_3 fold axis is curved. Locality J J.

Increasing granitization leads to structures indicating increased mobility within the rock. The axial directions of the folds become variable, indicative of flow-folding (Wynne-Edwards, 1963); flow within the axial planes commonly detaches small fold noses. Amphibolitic layers are commonly boudinaged, and some separated amphibolitic blocks show signs of rotation (Fig. 18), indicating flow within the leucosome which contains them.

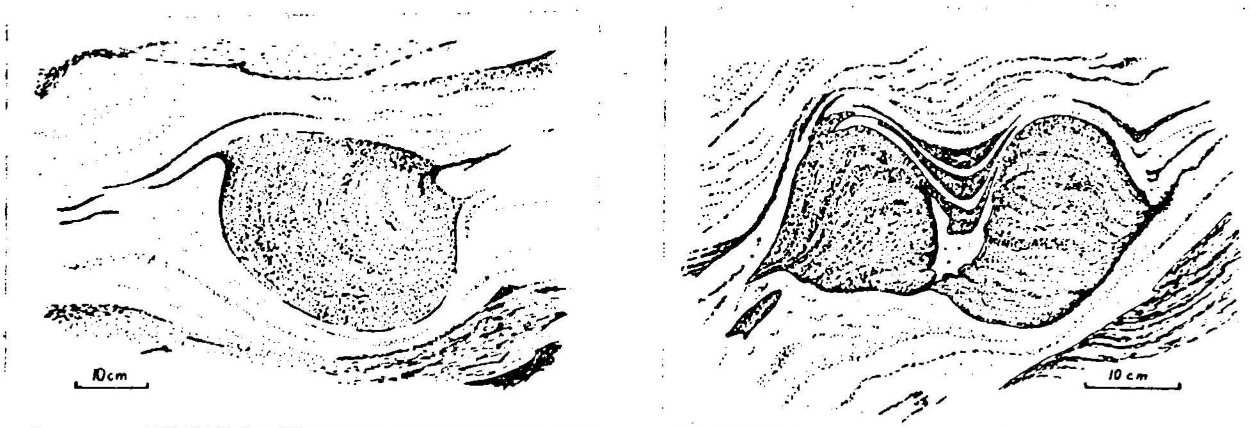

Fig. 18. Boudinaged amphibolite layers in nebulitic gneiss. Locality KK.
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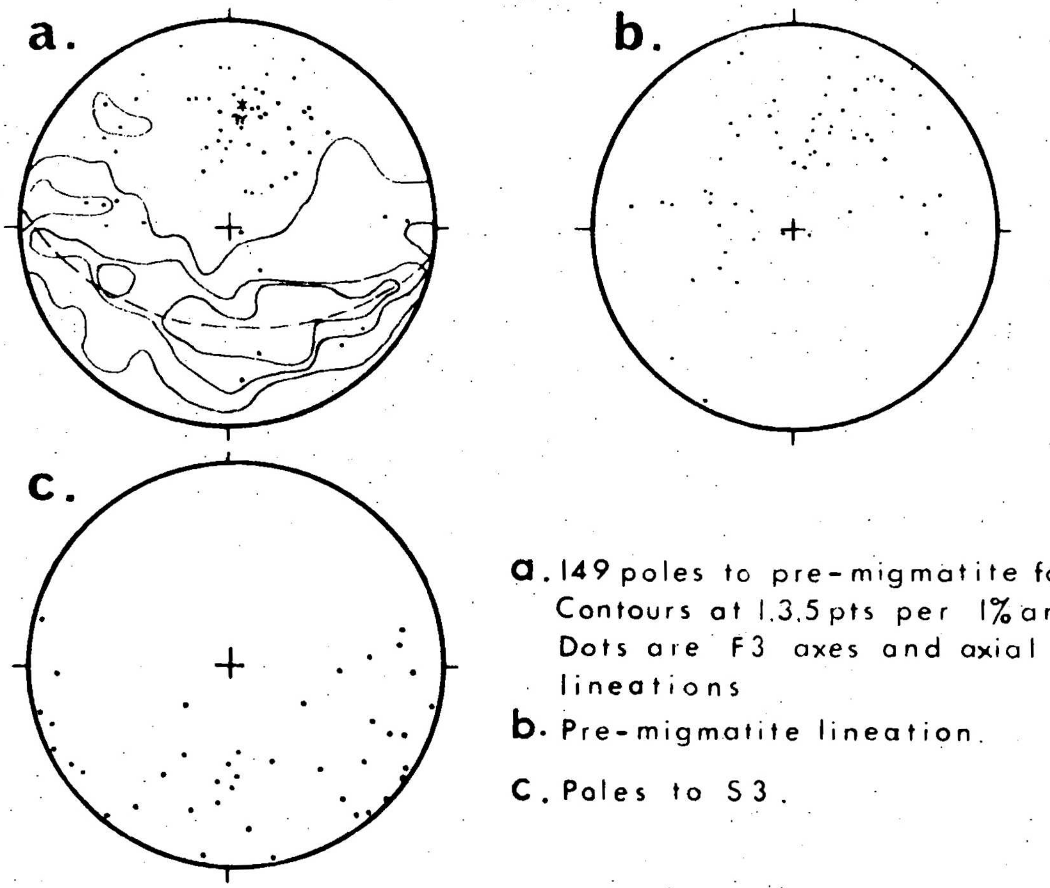
In many places within the migmatite complex, intrafolial folds occurring within the pre-migmatite layering are preserved and have been affected by F_3 folds (Figs. 19 and 22). Axial lineation to these early intrafolial folds ($\equiv L_2$) is also commonly preserved, and is refolded by F_3 folds. Internal deformation without folding of the pre-migmatite layering is recorded by the distortion of the early linear structures (Fig. 20). Quartzofeldspathic streaking or a mineral-orientation lineation (L_3) is usually developed parallel to the axes of the folds so defined. These folds must result from flow within the layer, and are indicative of high mobility. They are very similar in style to folds assigned to F_3 which occur along the southern margin of the Chewings Range (P.20).



a. 149 poles to pre-migmatite foliation. Contours at 1,3,5 pts per 1% area. Dots are F3 axes and axial lineations

b. Pre-migmatite lineation.

c. Poles to S3.

Fig. 21. Orientation data in the ORMISTON ZONE.

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Orientation data for the Ormiston Zone are shown in Figure 21. Figures 21a and 21c illustrate the wide scatter in orientation of S_3 and L_3 structures, probably as the result of high mobility at the time of deformation. Variability in S_3 is also partly the result of the common development of conjugate F_3 folds with two marked axial directions which, however, do not form recognizable sets which can be identified over more

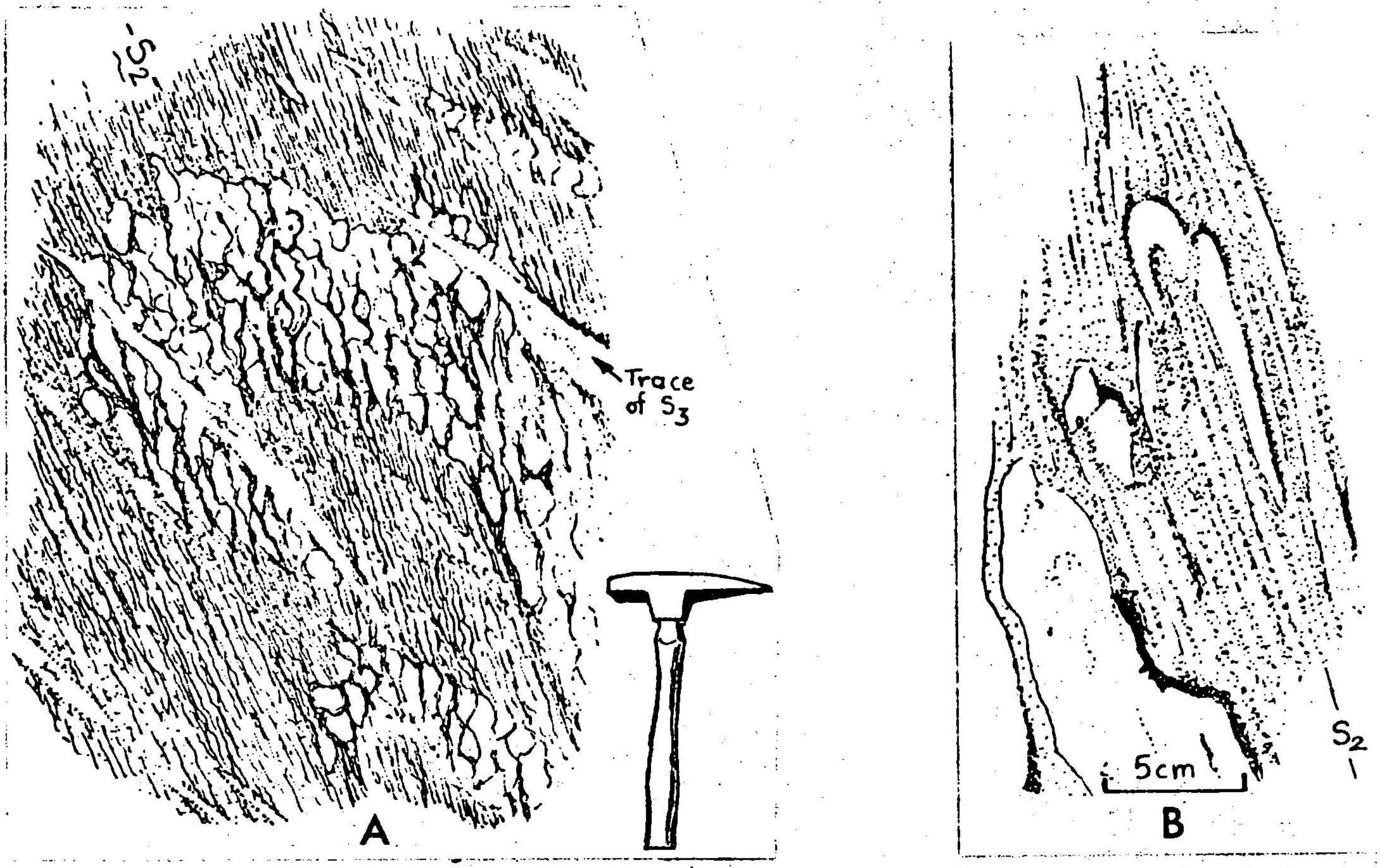

Fig. 19. Pre-migmatite intrafolial folds in the Ormiston Zone.
A. Quartz-feldspar-boitite gneiss with coarse feldspathic layers. Note cross-cutting pegmatite parallel to S_3 Locality II
B. Banded migmatite Fold nose picked out by quartzofeldspathic material. Locality KK

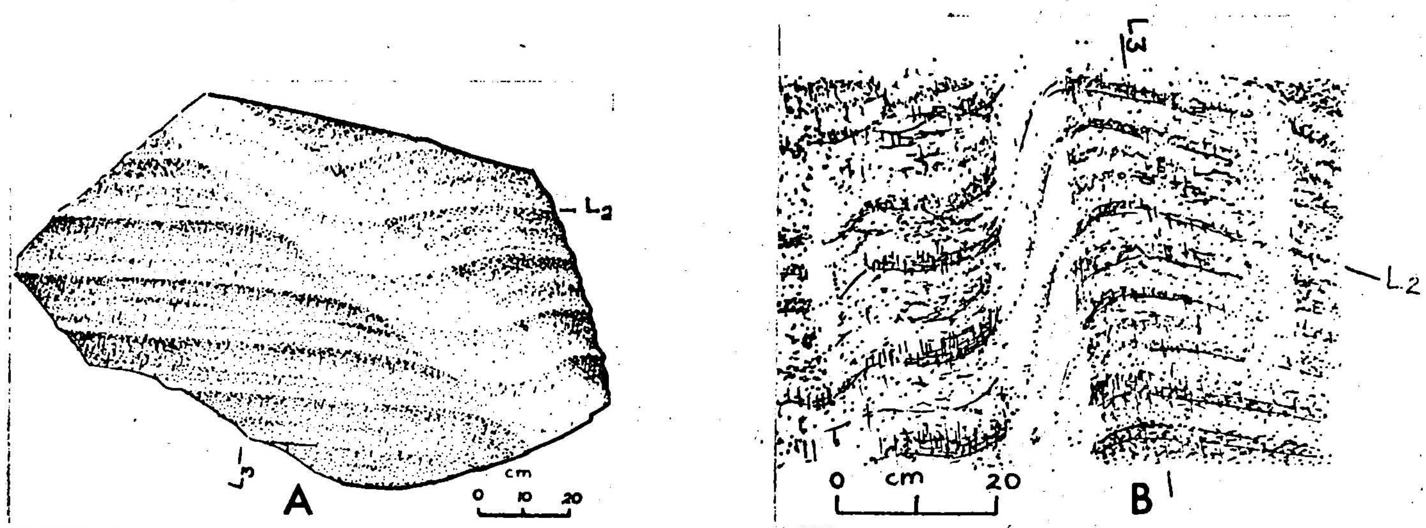

Fig. 20. Early lineation (L_2) on an S_2 surface refolded by F_3 without folding of S_2.
A. Quartz-feldspar-biotite gneiss.' Locality LL.
B. Quartz-feldspar-biotite gniess. Locality MM.

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than a few square metres of outcrop.

In spite of the variability of S_3 and L_3, poles to the pre-migmatite foliation define a broad great-circle girdle indicating a regional F_3 axial direction of 40° to 006°. The mean F_3 orientation in the Ormiston Zone is thus comparable to the mean F_3 orientation in the Redbank Zone, but the scatter in axial direction is greater (cf. Figs. 21a and 11a). As a consequence of the widely variable F_3 axes, the pre-F_3 lineation in the Ormiston Zone shows a greater scatter as a result of refolding than does the pre-F_3 lineation of the Redbank Zone.

Petrography

In typical specimens of coarsely banded migmatite the leucosome consists predominantly of microcline, orthoclase, and quartz. These minerals have ragged irregular margins against each other, and although the general texture of the rock is approximately granoblastic, very large grains of quartz and potash feldspar are common, and partly enclose small grains of quartz, plagioclase (oligoclase-andesine), and biotite. In places a well developed granoblastic-polygonal texture of quartz, orthoclase, and plagioclase is preserved; this is probably a relict texture and is similar to that of unmigmatized felsic gneiss of the Chewings Range. Biotite may be randomly oriented, but generally has a weak preferred orientation parallel to the layering in the rock.

A specimen from the eastern part of the granite at Ormiston Pound has an alkali-granite composition, and is composed of about 50 percent microcline and orthoclase, the remainder of the rock consisting of plagioclase (An_{10-18}), quartz, biotite, and muscovite; hornblende, zircon, apatite, and iron oxides are accessories. The texture differs from that of the granitic migmatite leucosome described above; plagioclase commonly occurs as large euhedral or subhedral tabular crystals, and typically shows zonation; these features indicate formation from a granitic melt. Quartz and potash feldspar occur interstitially and also as large irregular grains partly enclosing quartz and plagioclase, and suggest late-stage potash metasomatism in the formation of the granite. The biotite has no preferred orientation, and occurs randomly throughout the rock; it is pleochroic from olive-brown to pale reddish brown in contrast to biotite from the migmatite or felsic gneiss, which is pleochroic from dark brown to pale yellow-brown. The biotite may thus also be of magmatic origin.

Origin of the Migmatites

Migmatite is a descriptive term proposed by Sederholm (1907) for a rock whose original structure and composition are modified by a new phase of generally granitic aspect. Since this first description, four hypotheses have been advanced to explain the formation of migmatites:

1. Injection of granitic magma
2. Partial melting or anatexis
3. Metasomatism
4. Metamorphic differentiation

With suitable material, chemical analysis can show whether migmatisation takes place under isochemical conditions or whether the mobilisate has a composition appropriate to that expected for a partial melt. Chemical analysis is potentially capable of distinguishing between migmatites derived by metasomatism, metamorphic differentiation, or anatexis (White, 1966). Such analysis was beyond the scope of this project, but a qualitative assessment of gross chemical changes during the progressive migmatisation of the area could be made by observing changes in mineralogy. Structural and petrographic criteria are also capable of providing limits on the possible origins of migmatitic rocks. More than one process may have operated within a migmatite complex, and different processes may have been dominant at different stages in its development. With progressive migmatisation it is possible to assume that changes observed across the strike of the complex indicate time changes in the development of the complex at any one place.

Abundant large potash-feldspar porphyroblasts have grown within the deformed rocks of the northern part of the Redbank Zone, suggesting potash metasomatism; this is most likely to have occurred at the time of migmatization in the Ormiston Zone. Rocks of similar composition southeast of the migmatite complex, such as the felsic gneiss, show little sign of feldspar blastesis. Metasomatism was thus probably controlled by the deformed structure of the Redbank Zone. Beach (1973) described potash enrichment in small shears cutting the Scourian rocks of northwest Scotland and proposed that the enrichment was caused by metasomatizing fluids which were able to ascend along easy channelways in the deformed rocks. Although on a much larger scale, it is probable that the deformed rocks of the Redbank Zone acted in a similar way to localize metasomatic fluids derived from a source at depth, perhaps a major granitic intrusion. Potash-feldspar blastesis in the Redbank Zone is probably the most widespread effect of the migmatization event.

The migmatite front is marked by the widespread segregation of felsic and mafic material within the rock, generally so as to emphasize any strong pre-existing structures such as fold noses or foliation, or to form layers parallel to the axial plane of contemporaneous folds. Mafic-rich selvedges are common around the leucosomes and the bulk mineralogy of the rock does not appear to be greatly changed. Such structures could result from partial melting or metamorphic differentiation. Partial melting is a high-temperature and high-pressure phenomenon (Platen, 1965) which might be expected at the highest metamorphic grades within a regional metamorphic complex. The early widespread development of strongly segregated rocks in the Ormiston Zone suggests that these structures formed at relatively low temperatures and low pressures, and were probably caused by processes of metamorphic differentiation. Metasomatic processes may also have operated.

With the highest grades of migmatization, marked approximately by the 80 percent mobilizate boundary in Plate 1, the strongly differentiated structures disappear, and there is an apparent bulk change in the composition of the rock, and a marked reduction in the proportion of mafic minerals. This process can happen over large areas by in situ replacement of earlier banded migmatites so as to form nebulitic gneiss or granite. A similar transition has been described from other migmatite complexes (Sederholm, 1926). This apparent change in the bulk chemistry of the rocks indicates that metasomatic processes are dominant at this stage. The transition to nebulitic gneiss takes place over a narrower zone in the felsic gneiss than in originally well foliated rocks.

The evidence, based on field relations, thus suggests that in the development of the migmatite complex all four mechanisms of migmatite formation may have played some part. Potash metasomatism was almost certainly operative within the Redbank Zone, and may have taken place throughout the migmatite complex. Structures suggestive of metamorphic differentiation characterize the initial stages of widespread migmatization, but these structures appear to have been subsequently modified in situ by the formation of nebulitic gneiss and granite, suggesting a late-stage predominance of metasomatic processes. The nebulite grades into granite which locally shows evidence of a magmatic phase, but it is impossible to conclude whether a late-stage intrusion of granitic magma provided the granitizing agents to metasomatically alter the adjacent rocks, or whether the magmatic phase was derived more or less in place by the partial or complete melting of the already granitized rock at the peak of the metamorphic episode.

The migmatization event has been dated at 1076 $\pm$ 50 m.y. by Rb-Sr whole-rock methods (Marjoribanks & Black, 1974). The complex probably resulted from a rise in geothermal gradient within the area, coupled with the availability of metasomatizing solutions and/or granitic

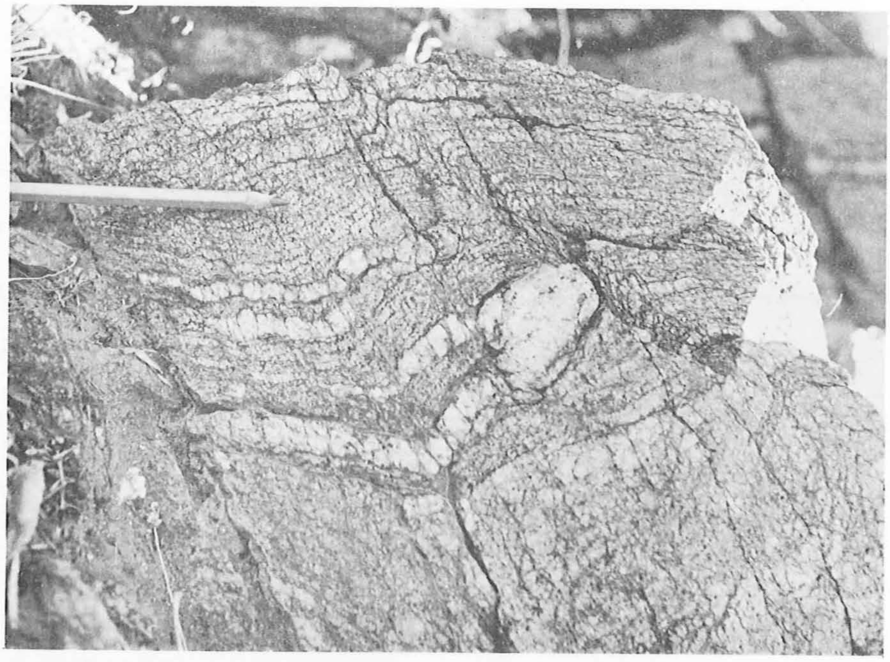

Fig. 22. Pre-migmatite intrafolial fold (F_2) in the Ormiston Zone affected by open F_3 folds. Pegmatitic material is preferentially developed within the early fold nose and the well developed S_3 foliation. Locality NN.

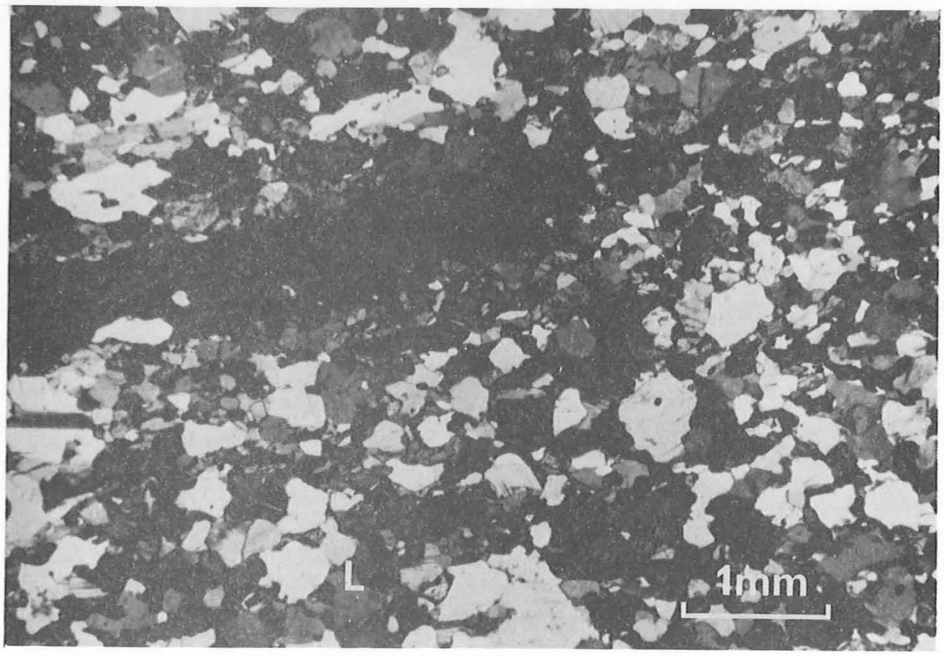

Fig. 23. Photomicrograph illustrating blastomylonitic texture in granulite-facies rock from the southern margin of Mount Hay. The rock is composed of quartz, plagioclase, and hypersthene, and lesser amounts of biotite, garnet, and orthoclase. A large polygonized ribbon grain of quartz forms a dark band in the centre of the photograph. BMR Specimen 3006. Crossed nicols.

magma, and is probably related to extensive granite intrusion at depth. Widespread granitization is preferentially developed in the area south of Redbank Zone, where the dominant initial rock type was probably poorly foliated felsic gneiss. The lack of migmatization within the Chewings Range Zone is difficult to explain, as the Zone consists of rocks similar to those extensively affected outside the Zone. It may be that the larger granite bodies mapped in the Ormiston Zone represent to a large extent original granitic magma whose intrusion served to localize the migmatization.

The northern margin of the Chewings Range Zone is marked by thrusts of Alice Springs Orogeny age, but these thrusts follow the original migmatite front (Page 62). The migmatite front in this area is parallel to the axial plane of a large F_3 fold in the Chewings Range Zone (Pl. 3.2). Similar relations between contemporaneous F_3 folding and granitization exist in numerous small F_3 folds throughout the complex.

Mount Hay/Mount Chapple Zone

Field Relations

In the field and on aerial photographs, rocks in the Zone appear dark, principally owing to the abundance of dark grey-blue plagioclase which, with quartz and mafic minerals, are their major constituents. A fine even-grained granular texture is also characteristic of the Zone, and the rocks are almost invariably massive and lack fissibility. Along the southern margins of both Mount Hay and Mount Chapple a fine laminar northerly-dipping foliation is defined by a regular compositional banding in which streaks or eyes of leucocratic quartz-rich material alternate with darker layers. Porphyroblasts of garnet up to 5 mm across and of untwinned white feldspar up to 3 cm long, and fine flakes of biotite are common in the southern margin of the Zone, but die out progressively northwards. The feldspar porphyroblasts are typically lenticular or rounded, and the foliation sweeps around them.

In the southern part of the Zone, a north-plunging lineation developed in places is defined by streaks of leucocratic material on the foliation surface, and by the elongation of biotite flakes or, where present, of feldspar porphyroblasts. The lineation is similar to that developed in the Redbank Zone, but not as prominent nor as extensively developed. Over large areas of the Mount Hay/Mount Chapple Zone no lineation can be distinguished.

North of the southern margin, the fine foliation is replaced by a coarse irregular compositional banding marked by leucocratic quartz-rich layers, 3 cm to 3 m across, which interrupt the dominant homogeneous dark grey granular rock. The banding is parallel to the fine foliation of the marginal zones, and in places has a north-plunging streaky lineation upon it. The banded rocks yield northward to generally unlayered, relatively quartz-poor dark grey rocks in which few or no structures can be seen. Such rocks compose the northern half of the Mount Hay ridge and the greater part of the Mount Chapple ridge.

At one locality (J) dark grey granular rocks of the Zone are extensively veined and disrupted by coarse leucocratic quartzofeldspathic material so as to form an agmatitic gneiss. It is probable that the agmatitic development is associated with extensive migmatization in the Redbank and Ormiston Zones to the south.

Rare small folds observed on the southern flanks of Mount Hay can be ascribed to two phases. The first phase consists of north-plunging reclined intrafolial folds which at one locality (K) have an axial direction parallel to the streaky lineation. The second phase has refolded the foliation of the Zone. Observed examples of second-phase folds are fairly open, and plunge generally north. Commonly diffuse patches of quartzofeldspathic material are developed in the axial regions of the later folds. This style of folding is similar to that of the F_3 folds south of the Zone, and on this basis it is probable that the late folds of the Mount Hay/Mount Chapple Zone are equivalent to the F_3 phase to the south.

Petrography

Rocks of the Zone have a mineralogy characteristic of a granulite-facies metamorphic assemblage. They are composed principally of labradorite (measured range An_{48} - An_{66}) and quartz, and up to 30 percent hypersthene (Fig. 23). Pale pink garnet, biotite, and orthoclase are also present in specimens from the southern part of the Zone, garnet and orthoclase occurring as augen lying within the foliation. The garnet augen tend to be concentrated into thin layers (parallel to the foliation) which contain up to 50 percent garnet. Some garnets form euhedral inclusion-filled crystals which interrupt, and thus probably postdate, the foliation. Hypersthene occurs throughout the rocks of the Zone as aggregates of granoblastic crystals associated with accessory iron oxides and apatite.

The textures shown by quartz, labradorite, and hypersthene throughout the Zone are polygonal and granoblastic, with a generally even grainsize averaging 0.2 mm. In specimens from the southern marginal regions, a blastomylonitic texture is developed in which differences of grainsize, orientation of biotite flakes, and lenticular eyes of orthoclase, or coarse polygonal quartz-labradorite aggregates emphasize the fine compositional layering. In addition, the polygonal grains of quarts and feldspar which make up most of the rock tend to be slightly elongated parallel to the foliation (Fig. 23).

The growth of the granulite-facies assemblage must have either postdated or accompanied the development of deformation textures in the southern margin of the Zone. If the blastomylonites are related to those of the Redbank Zone, as seems probable, then the start of the Redbank Zone deformation must provide a maximum age for the granulite-facies metamorphism in the Mount Hay/Mount Chapple Zone. A minimum age for the metamorphism is given by the agmatitic structures and open folds, of probable D_3 age, which affect the southern margin of the Zone.

Correlation of deformational and metamorphic events

Metamorphic and deformational sequences based mainly on superposition criteria have been established in separate Zones within which exposure is reasonably continuous. Ormiston Phase structures can be recognized in all Zones. Deformational events antedating the Ormiston Phase cannot with certainty be correlated across the area because of the obscuring effects of the migmatization, and the presence of wide belts of superficial cover. Results from isotopic dating of the granulites, and information gained from mapping adjacent areas may in the future help to solve these correlation problems.

In the Chewings Range, Ormiston, Redbank, and Mount Hay/Mount Chapple Zones, a single major fold phase, producing isoclinal folds and strong axial foliation and lineation, preceded the D_3 event. These structures are tentatively correlated on the basis of similarity of style. In the Chewings Range the deformation was accompanied by amphibolite facies metamorphism which has been dated by Rb-Sr whole rock methods at 1620 $\pm$ 70 m.y. (Marjoribanks & Black, 1974). In the Redbank Zone the deformation was also syntectonic with amphibolite facies crystallization, and in the Mount Hay/Mount Chapple area granulite facies metamorphism may have accompanied the deformation. This correlation implies a complex regional orogenic event at around 1620 m.y.

The intrusion of hypersthene gabbro into the Redbank Zone, and dolerite dykes into the Redbank, Ormiston, and Chewings Range Zones postdates the Ormiston Phase migmatization. These intrusions are assumed to be of the same age. They are the last event that can be recognized before the deposition of the Amadeus Basin sediments.

The correlations outlined above are presented in Table 1, and further discussed under the heading 'Summary of Geological History'.

COVER ROCKS AND THE ALICE SPRINGS OROGENY

At some date after 1076 m.y., the basement was downwarped and a thick sequence of arenite (Heavitree Quartzite) was laid down, succeeded by dolomite and shale containing rare evaporite beds (Bitter Springs Formation); stromatolite fossils indicate that the Bitter Springs Formation is 650-950 m.y. old (Glaessner, Preiss, & Walter, 1969; Preiss, 1972). The sediments are thus coeval with type Adelaidean rocks of South Australia (Dunn, Plumb, & Roberts, 1966).

After the deposition of the Bitter Springs Formation, the depositional basin deepened during the Adelaidean and Palaeozoic and received about 9000 m of dominantly clastic sediments derived from the north. A series of intraformational unconformities (Wells et al., 1970; Jones, 1972) indicate successive periods of uplift and peneplanation north of the present basin margin. These uplifts culminated in the Late Devonian to Early Carboniferous Alice Springs Orogeny (Forman, 1966; Stewart, 1971), during which a thick wedge of synorogenic molasse-type sediments, the Brewer Conglomerate (Wells et al., 1970), was deposited along at least 500 km of the northern margin of the basin, reaching its greatest thickness of 3000 m at 10 to 15 km south of the southern margin of the study area (Jones, 1972). The Brewer Conglomerate transgresses northwards across all the underlying basin sediments, and probably originally rested upon Arunta Complex rocks (Jones, 1972). Jones (1970) estimated that to provide the sediments of the Brewer Conglomerate a source area between the Amadeus and Ngalia Basins would have had to be uplifted and eroded by an average of at least 2.35 km. Thus during the Alice Springs Orogeny, considerable differential vertical movements totalling about 5 to 6 km between basement underlying the northern part of the Amadeus Basin, and basement to the north of the Basin are indicated.

Stratigraphy

Sections were measured through the lower and middle Heavitree Quartzite members at North Ormiston Gorge and at South Ormiston Gorge. An estimate was made of the thickness of the upper Heavitree Quartzite south of Damper Gorge (Locality M) based on its outcrop width and measured dips. These stratigraphic sections are presented in Figure 24.

Lower Heavitree Quartzite member. This unit consists of generally well bedded, pale yellow-brown sandstone and quartzite with many pebbly, conglomeratic, or gritty layers and numerous thin shale partings. Cross-bedding and ripple marks are common, and provide useful way-up criteria. At the northeastern end of Ormiston Pound adjacent to the Chewings Range, the lower member is estimated to be 30 m thick, but it thins both to the east and west away from the Range. At South Ormiston Gorge it is 20 m thick; farther west, at Mount Sonder, only a few metres of pebbly and gritty sandstone at the base of the Heavitree Quartzite can be correlated with the lower Quartzite member.

Immediately overlying basement, a thin conglomerate bed contains rounded or subangular pebbles of vein quartz or quartzite. At South Ormiston Gorge and at Camp Creek (Localities N and O), the succession begins with a local development of dark grey lithic arkose and arkosic siltstone.

Adjacent to the Chewings Range, there is a strong overstep of the lower Heavitree Quartzite and the lowest part of the middle Heavitree Quartzite onto the Chewings Range Quartzite. This overstep is clearly seen in Plate 2. At one locality (P), a thick wedge of quartzite-boulder breccia containing angular quartzite boulders to 0.6 m across occurs immediately adjacent to the Chewings Range. This breccia must have been derived from the Chewings Range Quartzite as a cliff-base deposit. The outcrop width of the unit is generally too narrow to be shown in Plate 1.

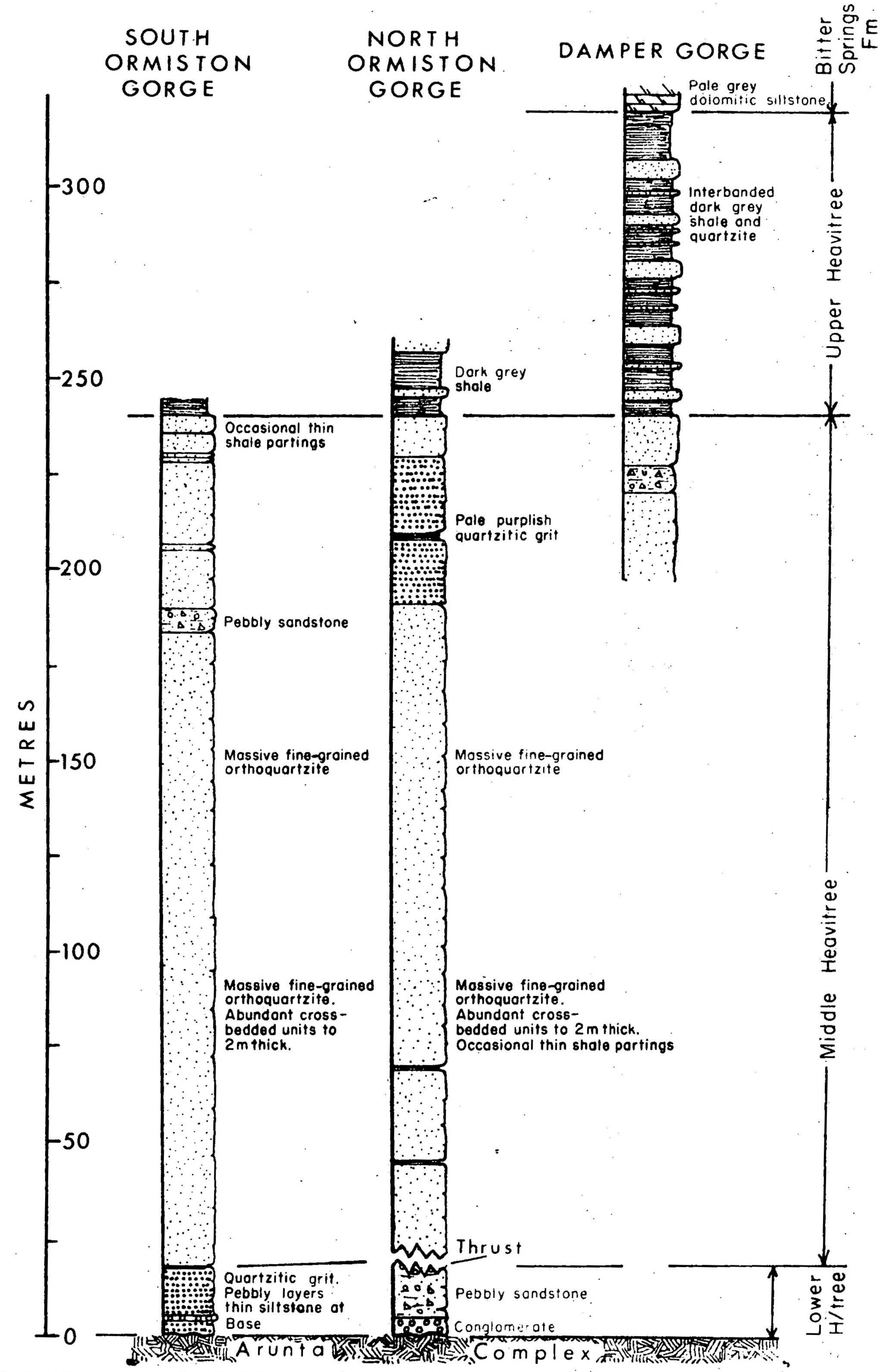

Fig. 24 ESTIMATED SECTIONS IN HEAVITREE QUARTZITE AT ORMISTON POUND.

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<u>Middle Heavitree Quartzite member.</u> This unit comprises the greater part of the Heavitree Quartzite, and is about 220 m thick at South Ormiston Gorge. It consists of pale grey fine-grained orthoquartzite. Small grainsize variations and thin shale partings mark a regular but weakly developed bedding; up to 150 m of the middle part of the unit is massive. Cross-bedded layers up to 1.5 m thick are developed in the lower part of the unit but sedimentary structures are generally rare. In the top 60 m the quartzite becomes pale purplish and coarser-grained, and has a more gritty texture; some layers of pebbly sandstone occur, and shale partings (to 0.1 m thick) are more common. It was not possible to correlate these gritty or pebbly layers between the measured sections in North and South Ormiston Gorges.

In the lowest part of the middle Heavitree Quartzite member adjacent to the Chewings Range Quartzite, thin layers of grit or pebbly sandstone are developed which die out away from the Chewings Range. However, the greater part of the middle Heavitree Quartzite member shows no lithological change across the Chewings Range, and it is evident that by middle Heavitree Quartzite time the Chewings Range Quartzite had ceased to exercise any control on sedimentation.

Clarke (1973) divided the Heavitree Quartzite at Simpson Gap, near Alice Springs, into four formal Members which together correspond to the lower and middle Heavitree Quartzite members described here. The thin pebbly sandstone and siltstone beds and dark quartzitic coarse-grained sandstone and granule conglomerate towards the top of the middle Heavitree Quartzite member correspond approximately to Clarke's Fenn Gap Conglemerate, but no member bed in the Ormiston area allows a convenient subdivision of the middle Heavitree Quartzite member.

<u>Upper Heavitree Quartzite member.</u> This unit is about 80 m thick at Ormiston Pound, and consists of dark grey shale interbedded in the ratio of about 2:1 with numerous quartzite layers 1 cm to 5 m thick.

Each quartzite layer consists of pure orthoquartzite, and is generally a single homogeneous bed without sedimentary structures. The shale is very fine-grained, and over much of the area either does not crop out or has been converted into slate and phyllite with a strong cleavage parallel to the axial planes of Alice Springs Orogeny folds. Thin quartzite layers within the shale sequence are more numerous in the lower part of the unit.

Bitter Springs Formation. The type section for the Bitter Springs Formation is at Ellery Creek, 25 km east of Ormiston Pound; the section is described by Prichard & Quinlan (1962, p.11). At Ellery Creek, 60 m of siltstone crops out between the main quartzite (corresponding to the middle Heavitree Quartzite member) and the lowest dolomite bed of the Bitter Springs Formation. Part of the siltstone is thought to be equivalent to the upper Heavitree Quartzite member. Prichard & Quinlan placed the contact between the two formations at the top of a quartzite bed within the siltstone. There is no such quartzite marker in the Ormiston area that can be correlated with that described by Prichard & Quinlan. Quartzite layers occur throughout the shale of the upper Heavitree Quartzite member, and the base of the Bitter Springs Formation has been placed at the base of the lowest dolomitic bed within the siltstone sequence.

The Bitter Springs Formation is composed of crystalline dolomitic limestone and minor dolomitic siltstone and sandstone; layers of gypsum and halite have also been described (Wells et el., 1970). Prichard & Quinlan (1962) gave the thickness of the Formation at Ellery Creek as 2500 ft (750 m) and described its stratigraphy in detail.

Alice Springs Orogeny

Structures in cover. The geometry of the structures resulting from the Alice Springs Orogeny along the northern margin of the Amadeus Basin are graphically presented in the serial sections of Plate 4, in the block diagram of Figure 26, and in Figures 28 and 33. A shallow regional westerly plunge across most of the area brings the deeper fold structures to the surface in the east, and preserves the uppermost structures in the west. In order of superposition, the major fold structures which can be recognized are:

Razorback Nappe (Uppermost structure)

Mount Sonder Anticline

Ormiston Pound folds:
- Ormiston Thrust Deformed Zone
- Unnamed folds
- Ormiston Fold
- Unnamed folds

The distribution of these structures is shown in Figure 25.

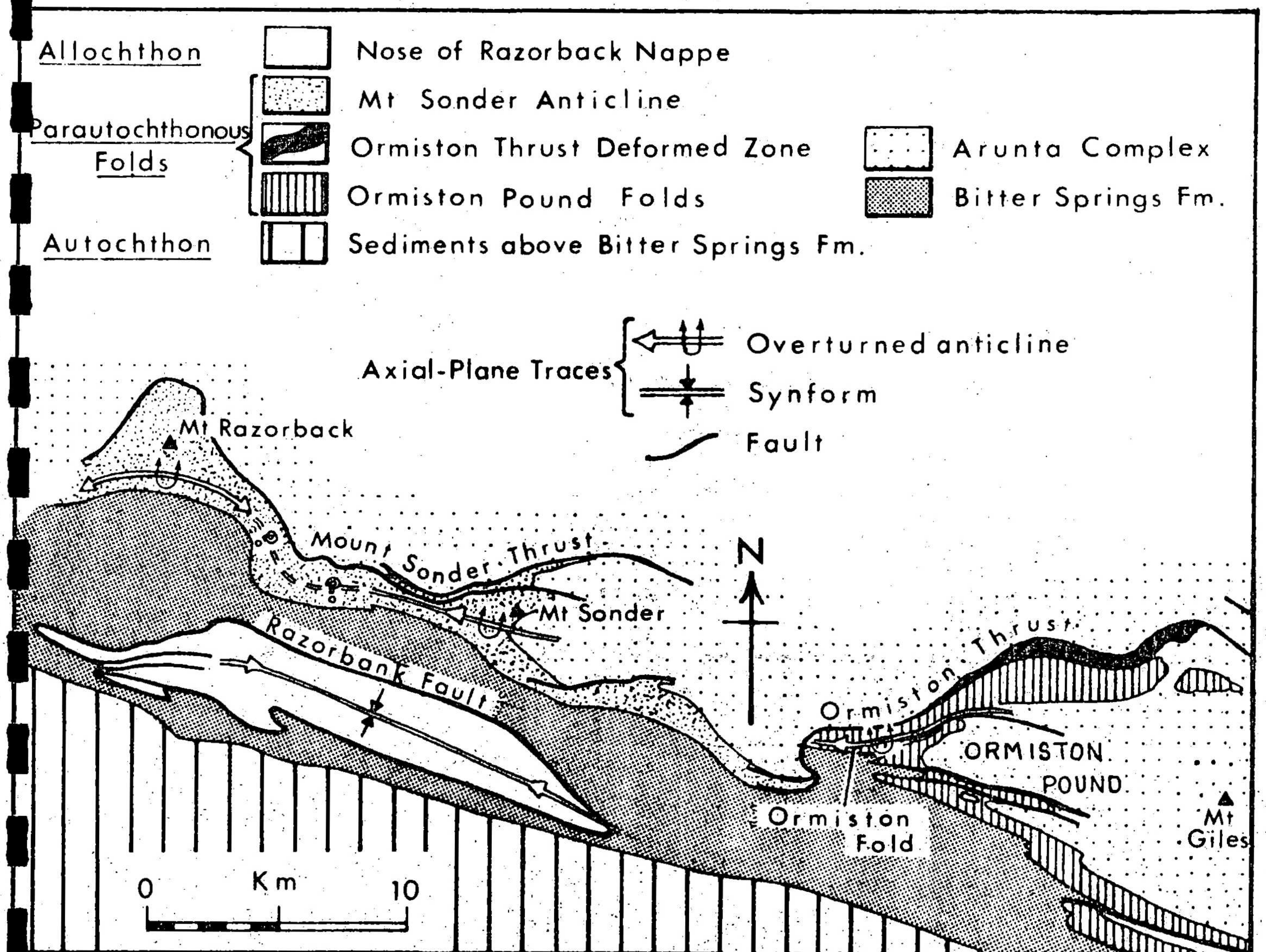

Fig. 25 Simplified map of the northern margin of the Amadeus Basin showing major structures in the cover.

Razorback Nappe

South of Mount Sonder and Mount Razorback within the main outcrop of the Bitter Springs Formation, a synformal keel or klippen of Heavitree Quartzite was identified by Forman et al. (1967) as the nose of a large recumbent fold which they called the Razorback Nappe; this interpretation is confirmed by the present study. The quartzite in the synform contains cross-bedding and pebbly and gritty layers, and probably belongs to the lower part of the Heavitree Quartzite. At several localities (for example, Q and R) it can be demonstrated that the beds are inverted. Arunta Complex rocks probably overlie the Heavitree Quartzite and occupy the central part of the klippen, but they are only exposed at its western end where their relations with the adjacent rocks are obscured by alluvium.

Most of the quartzite in the nose of the Razorback Nappe is highly fractured and sheared. In addition, marginal shearing has removed the upper Heavitree Quartzite and much of the middle Heavitree Quartzite members from the klippen, and along parts of the northern margin of the structure the entire quartzite sequence is probably missing. This deformation is the result of movements along faults which completely surround the quartzite, and were the means by which it was intruded into the Bitter Springs Formation. The fault on the lower (northernmost) surface of the happe is a thrust, and that on the upper (southernmost) surface is a lag. Both faults are labelled 'Razorback Fault' in Plate 1. They were probably wide zones over which shear movement took place, rather than separate fault planes.

Forman et al. (1967) suggested that the lower limb of the Razorback Nappe re-appears between Mount Sonder and Mount Razorback as the upper limb of a tight synclinal structure in the Heavitree Quartzite. The present study shows that the Heavitree Quartzite between Mount Sonder and Mount Razorback is truncated by a thrust fault - the Mount Sonder Thrust - which dips 40° to 50°N, and brings basement southward over the

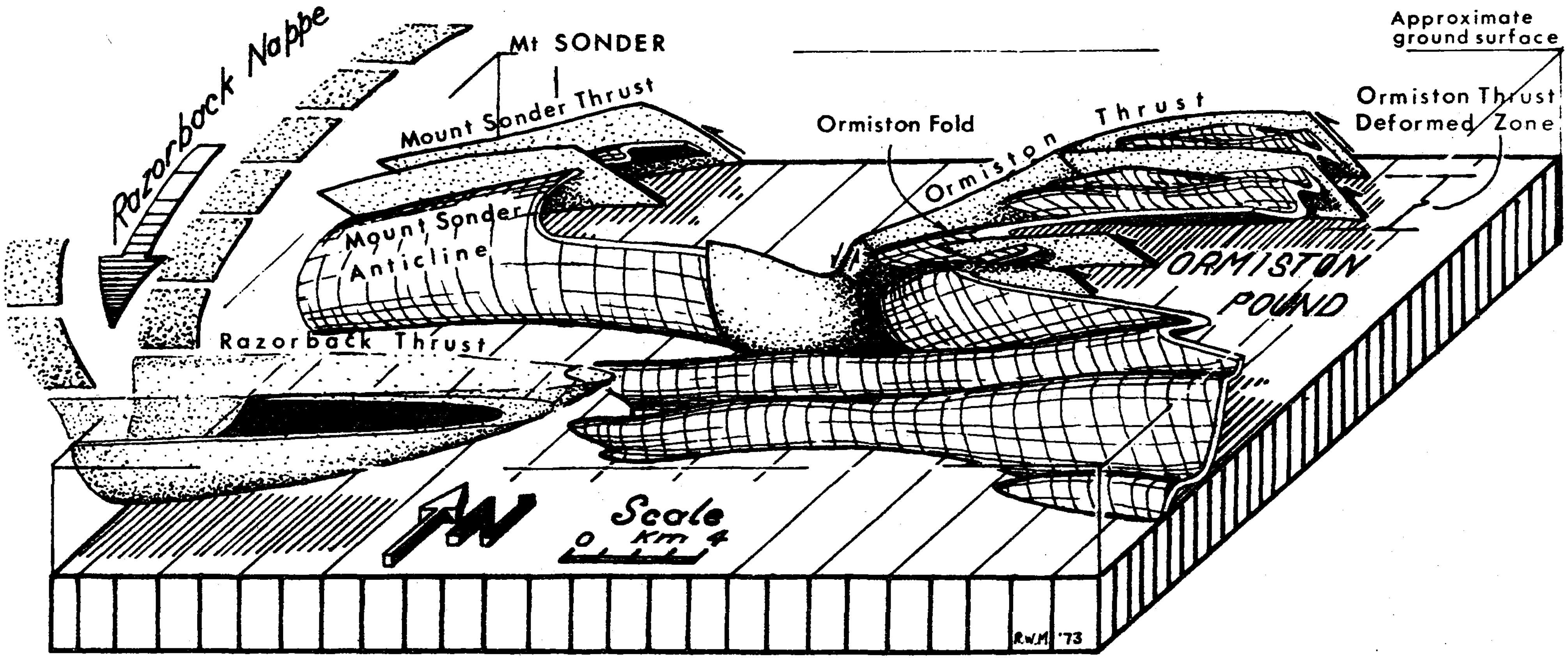

Fig. 26 Block diagram of the basement-cover contact in the Mount Sonder Ormiston Pound area.
The Heavitree Quartzite is shown as single horizon; its contact with the Arunta Complex is coloured black; its contact with the Bitter Springs Formation is shown with a grid pattern. Fault surfaces have a dot ornament. (The scale is approximate.)

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Heavitree Quartzite. This Thrust may be the same as the Razorback Thrust, thus implying a minimum southward movement for the nose of the Nappe of about 9 km. However, the Mount Sonder Thrust cannot be traced within the Arunta Complex 6 km east of Mount Sonder, and a horizontal movement of 9 km along it near Mount Sonder seems unlikely. The root zone for the Nappe is therefore probably much farther north, and may lie within the Redbank Zone. This interpretation is illustrated in Figure 33.

Mount Sonder Anticline. The anticlinal nature of the Heavitree Quartzite at Mount Sonder, with a flat-lying or north-dipping upper limb and a vertical or overturned south-facing limb, was recognized by Prichard & Quinlan (1962). The upper limb is truncated by the Mount Sonder Thrust (Pl. 4, Section 3) which can be traced from Mount Sonder for 20 km until it is lost under recent cover west of Mount Razorback; east of Mount Sonder the Thrust dies out into the Arunta Complex. The outcrop width of the Heavitree Quartzite narrows west of Mount Sonder because of the westward plunge of the anticline and a progressive truncation of its upper limb by the Mount Sonder Thrust. At Redbank Gorge the upper limb of the anticline is completely sheared out; at this locality numerous minor thrusts related to the major Mount Sonder Thrust separate tightly folded slices of quartzite which have a strong mylonitic foliation parallel to the thrust surfaces, and a northward-plunging quartz-elongation lineation. Similar deformed rocks are developed immediately south of the Mount Sonder Thrust along the greater part of its outcrop.

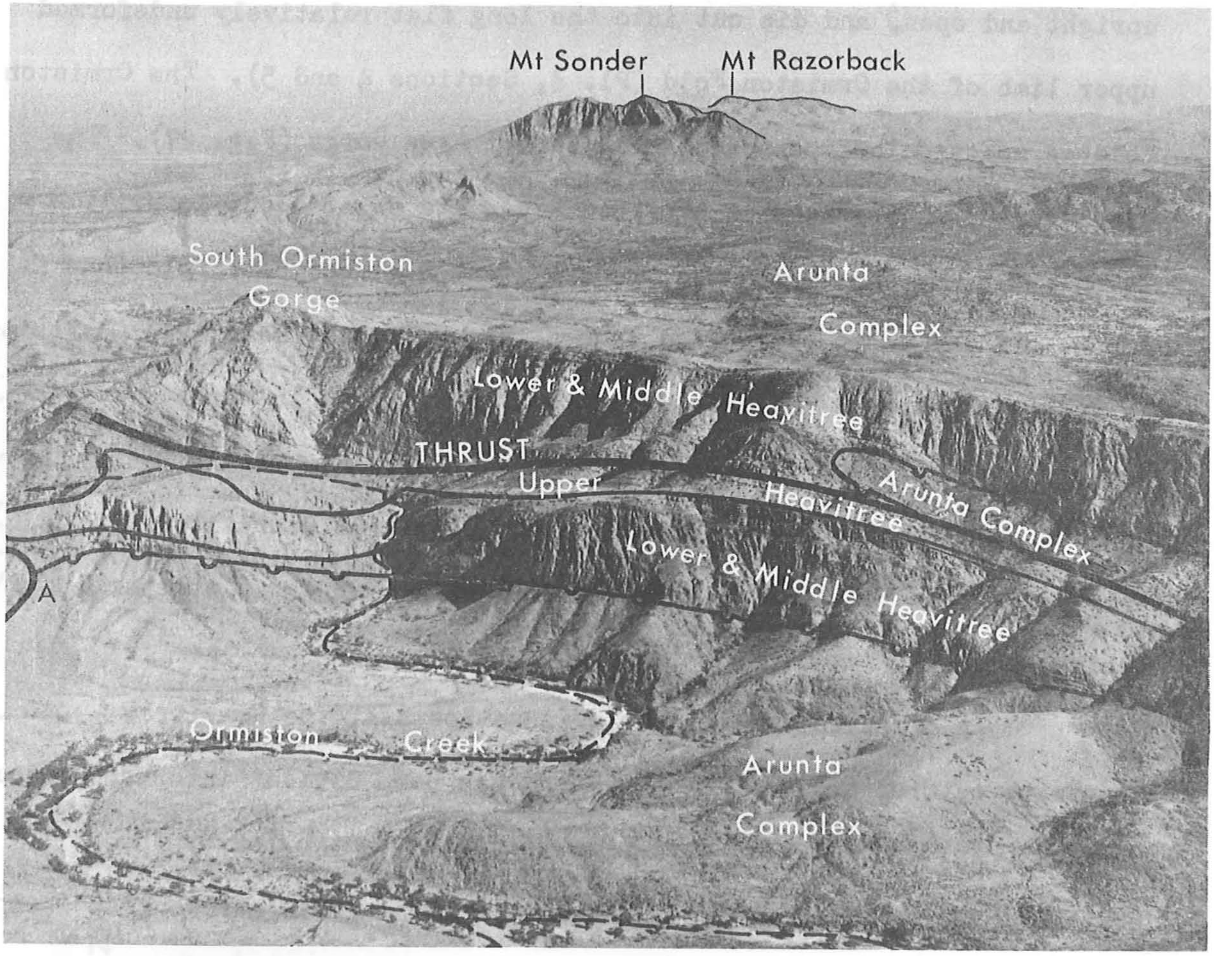
West of Redbank Gorge the outcrop of the Heavitree Quartzite widens again owing to a reversal of the regional westerly plunge. The rocks in this area are generally poorly exposed, and have not been examined in detail. In the section through Mount Razorback (Pl. 4, Section 1), the large anticline immediately south of the Mount Sonder Thrust is in a structural position equivalent to that of the Mount Sonder

Anticline. Although the major fold structures of the region are not strictly cylindrical and cannot be reliably projected along plunge for large distances, the anticline at Mount Razorback is probably the same fold as the Mount Sonder Anticline. Folds occurring between the Mount Razorback anticline and the nose of the Razorback Nappe are in the same structural position as the Ormiston Pound folds, and may be equivalent to them.

East of Mount Sonder, the steep limb of the Mount Sonder Anticline is progressively overturned; at dips greater than 70°N the quartzite is tectonically thinned by the development of north-dipping thrusts (for example, at Rockybar Creek 4 km southeast of Mount Sonder). The faults are associated with the local development of tight overturned folds and strong axial-plane mylonitic foliation. Two areas of overturning and shearing are developed on the steep limb of the Anticline east of Mount Sonder. In the easternmost area the quartzite is completely sheared out by the Ormiston Thrust. About 3 km west of Ormiston Gorge, the Ormiston Thrust passes into a north-trending near-vertical dextral tear-fault with a displacement of about 2 km before passing again into a north-dipping thrust fault. The Ormiston Thrust brings Arunta Complex rocks southwards to rest upon Heavitree Quartzite north of Ormiston Pound. It can be traced westwards for about 25 km before dying out within the basement.

Orientation data for the structures of the Mount Sonder Anticline (Domain N, Fig. 28) are shown in Figure 29f. The bedding-plane -girdle defines a regional fold-axis plunging at 20° to 286°. Axial planes trend eastsoutheast, and dip steeply north. The vertical or near-vertical east-southeast-striking limb of the folds in Domain M is parallel to the steep-dipping beds of the northern edge of the Amadeus Basin which can be traced for about 350 km. These steep dips have been termed the Macdonnell Range Homocline (Quinlan & Forman, 1968).

Ormiston Pound folds. The folds underlie the Ormiston Thrust, and are exposed around Ormiston Pound. Adjacent to the Thrust, the Heavitree Quartzite is folded into isoclinal folds with near-horizontal axes (Pl. 4, Sections 4, 5, and 6).



Aerial Oblique of Ormiston Gorge

Fig. 27 South Ormiston Gorge and Ormiston Fold (oblique aerial photograph looking west).

The axial planes of the folds are parallel to the northward-dipping thrust surface, and to a well developed mylonitic foliation; a generally northward-plunging quartz-elongation lineation is developed in places within the mylonitic rocks, especially adjacent to the Thrust. Deformation increases in intensity towards the Ormiston Thrust. The isoclinally folded Heavitree Quartzite with well developed mylonitic foliation is termed the Ormiston Thrust Deformed Zone. Towards the northeast of Ormiston Pound, the Ormiston Thrust overrides the Deformed Zone in such a way as to flatten and lie within the shale of the upper Heavitree Quartzite member upon the back of the upper limb of the Ormiston Fold.

South of the Deformed Zone, folds progressively become more upright and open, and die out into the long flat relatively undeformed upper limb of the Ormiston Fold (Pl. 4, Sections 4 and 5). The Ormiston Fold is spectacularly exposed at South Ormiston Gorge (Fig. 27). The displacement of the nose of the Fold along its sheared-out lower limb is only 0.5 km, and it is more properly termed a recumbent fold than a nappe. In the short overturned limb of the Fold, the Heavitree Quartzite is strongly foliated and deformed; the basal thrust is concave upwards and steepens northwards into the Arunta Complex.

South of the Ormiston Pound the Heavitree Quartzite is folded into large open relatively upright folds which have their steeper limbs facing south.

In order to analyse the orientation data, the Heavitree Quartzite outcrop around Ormiston Pound has been divided into homogeneous Domains (Fig. 28), the boundaries of which are controlled by the northward variation in fold style and by the change in strike from west

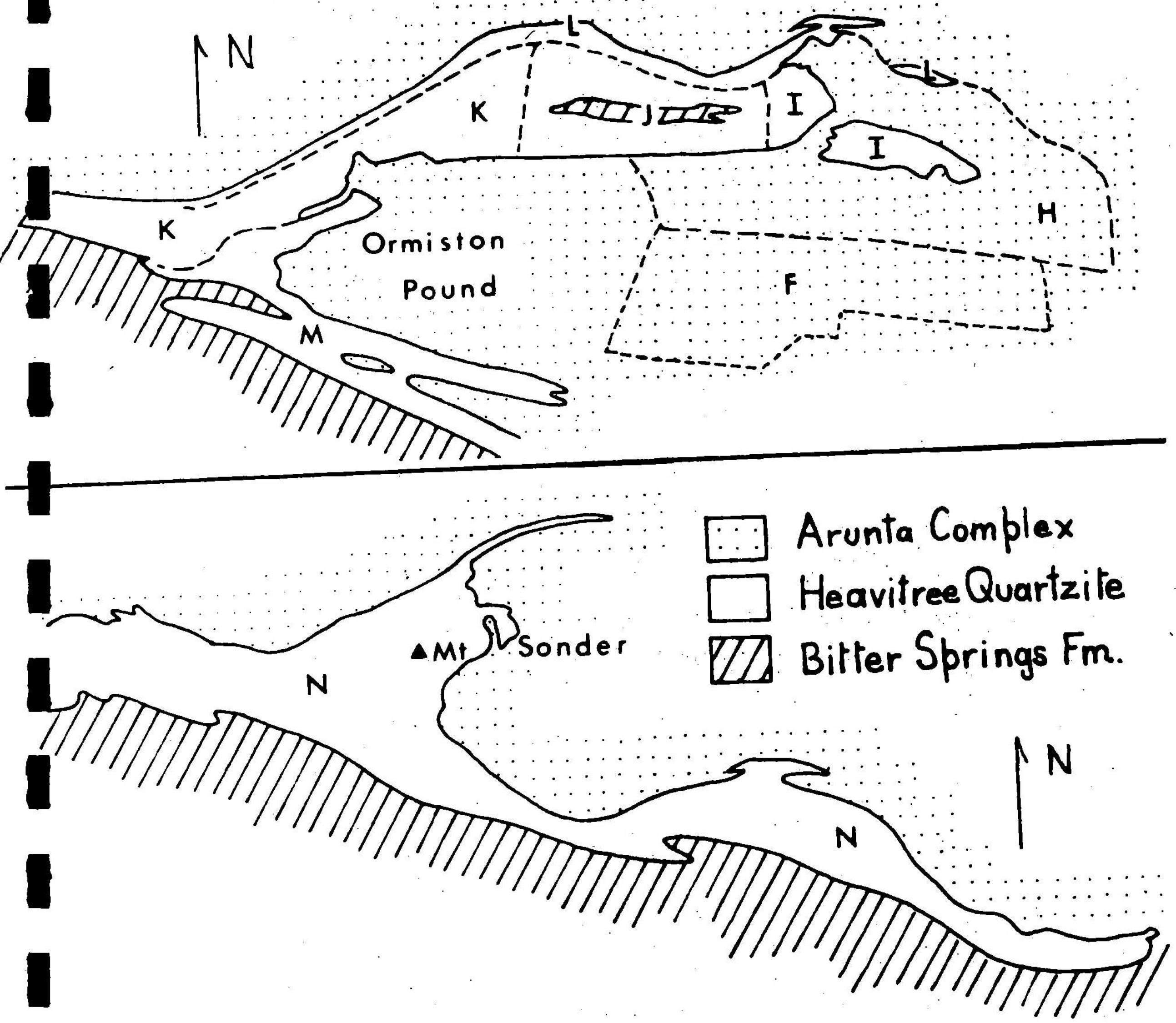


Fig. 28. Simplified map of the northern margin of the Amadeus Basin showing structural domains.

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to west-southwest across the area. The Domains are:

Ormiston Thrust Deformed Zone	....	Domain L
Folds overlying the Ormiston Fold Ormiston Fold	}	Domains I, J, K
Folds underlying the Ormiston Fold	....	Domain M

The orientations of fold axes and of poles to bedding, axial planes, and mylonitic foliation are shown in the equal-area stereographic projections of Figure 29. The strike of fold axial planes ranges from west in Domain I to west-southwest in Domain K; in each Domain, dips range from near-vertical to about 35°N. The range in axial-plane dips within each Domain reflects the development of more upright, less asymmetric folds from north to south. This feature is further illustrated by the synoptic plot of Figure 29d which shows the poles to mylonitic foliation in Domain L (Deformed Zone) and the poles to axial-plane cleavage in Domains J and K. The mylonitic foliation is an axial-plane structure to isoclinal folds, and it has a consistently shallower northward dip than the cleavage in the Domains to the south.

Fold axes plunge at up to 20° to either east or west in Domain J. and at up to 20° to 060-070° or 230-260° in Domain K. This reflects gently curving fold axes, within unfolded axial planes, which were observed in the field.

In Domain I, the axial-plane cleavage has a fairly uniform orientation, but the fold axes plunge at up to 55° to 320° on the western side of the Chewings Range, and up to 34° to 065° on the eastern side of the Range (Fig. 29a). The steep plunges are caused by the steep dips of the Heavitree Quartzite away from the Chewings Range as the result of the strong overstep of the Heavitree Quartzite onto the older quartzite from both east and west, and probably accentuated by differential compaction of the younger sediments across the Range. To produce the observed fold plunges, the initial bedding-

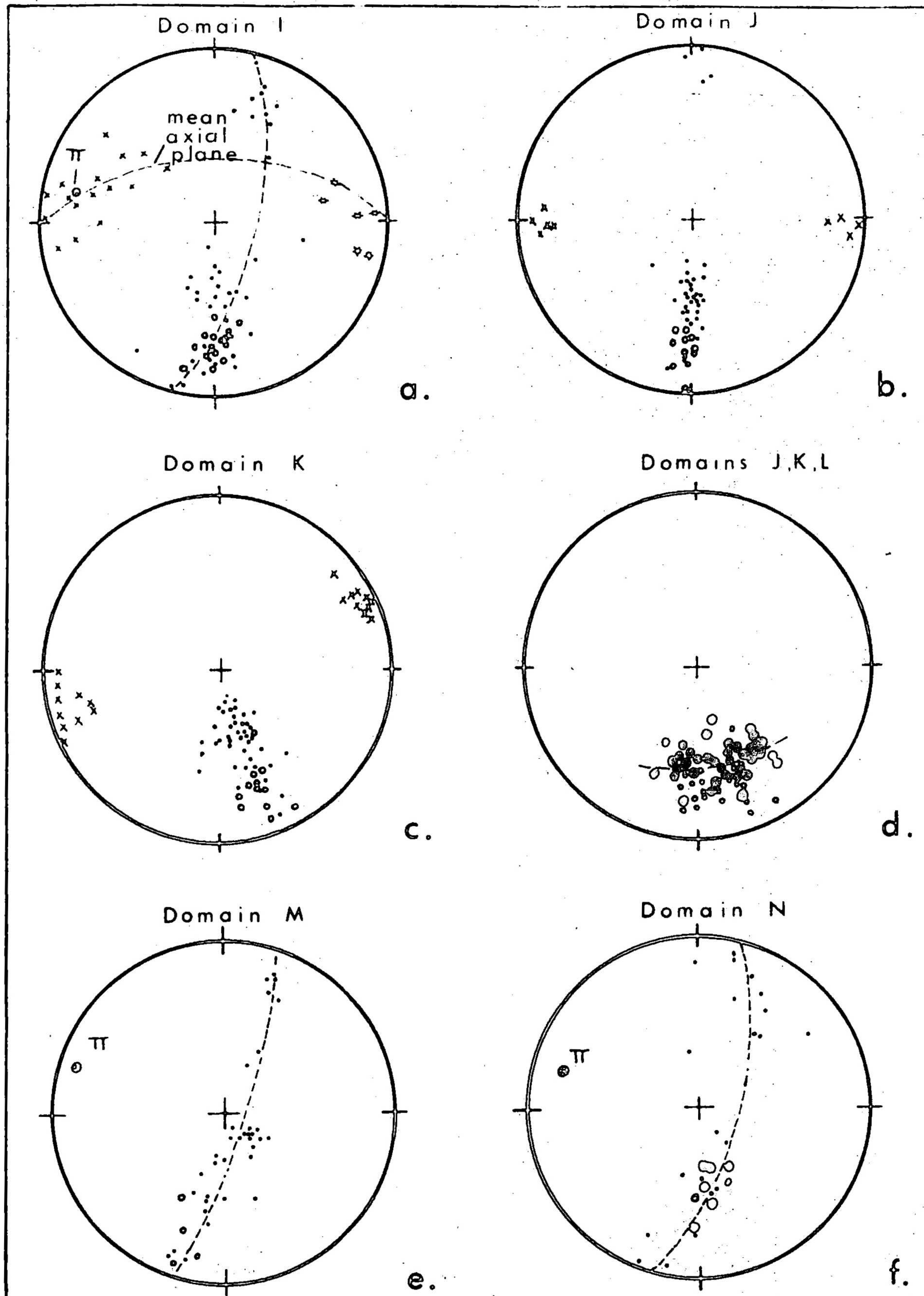

Fig.29. ORIENTATION OF STRUCTURAL ELEMENTS IN COVER AT ORMISTON POUND

Light dot = pole to bedding; heavy dot = pole to mylonitic foliation; open circle = pole to axial-plane cleavage; crosses = fold axes to west of Chewings Range; stars = fold axes to east of Chewings Range.

M(Pt)174

plane dips must locally have been up to 65°W on the western side of the Chewings Range, and up to 35°E on the eastern side. These are rather high initial dips, and it is possible that some of the scatter in measured fold axes in Domain I is due to the development of curved fold axes, as described from Domains J and K.

Structures in basement

During the Alice Springs Orogeny, renewed movement probably took place within the Redbank Zone. This deformation is difficult to distinguish from earlier deformation of the Zone. Narrow discontinuous belts of fine-grained, relatively little-recrystallized 'ultramylonite' lie within the Zone (Fig. 30), and have a foliation and lineation parallel to that of the adjacent coarser-grained blastomylonites. These belts mark the sites of late-stage retrogression and probable fault movement, and may be of Alice Springs Orogeny age. The ultramylonites tend to occur adjacent to the edge of the main Arunta scarp against the Burt Plain, and are probably related to a major deformed zone of Alice Springs Orogeny age beneath the Plain, which would explain this sharp linear feature.

In the migmatite complex immediately south of the Redbank Zone there is little refolding or refoliation associated with the Alice Springs Orogeny. However, quartz and epidote veining and, in thin section, the occurrence throughout the complex of slight undulose extinction of quartz and sericitization of feldspars are probably related to the Orogeny. Rb-Sr isotopic biotite ages yield a date of 400 m.y. for migmatites within the Redbank Zone, and about 830 m.y. for migmatites farther to the south (Marjoribanks & Black, 1974). These dates are caused by a partial isotopic resetting, probably at the time of the Alice Springs Orogeny, and indicate a rise in geothermal gradient northward across the area at this time.

About 500 m north of the Ormiston Thrust, a new foliation parallel to the Thrust surface begins to be evident and becomes more widespread and strongly developed towards the south. In thin section the foliation is marked by the cataclasis and alteration of feldspar, the development of deformation bands in quartz, and the growth of fine new muscovite flakes. Abundant new strain-free quartz grains also appear, growing along the margins of older grains. Immediately adjacent to the Ormiston Thrust the migmatitic gneiss of the Ormiston Zone has been converted into a mylonitic gneiss. The lithological banding of the migmatite is either parallel to, or at a low angle to, the mylonitic foliation.

South of the Ormiston Thrust, the dominant foliation and lineation of the Arunta Complex (S_2 and L_2) lie at a high angle to the Thrust, and have been refolded by east or east-southeast-plunging folds of Alice Springs Orogeny age. These folds are the fifth generation of structures (D_5) within the Arunta Complex; they show the same change in style with distance from the Thrust as has been described from the folds within the Heavitree Quartzite. The axial planes of the folds are marked by a closely spaced fracture cleavage within the Chewings Range Quartzite, and by a crenulation cleavage within the mica-rich rocks of the underlying schist and felsic gneiss. The cleavage becomes more intense northward, and for a few metres immediately south of the Thrust, it is a fine mylonitic foliation on which the presence of the original S_2 layering is marked by a well developed mineral-segregation lineation.

Alice Springs Orogeny folds in the Chewings Range Zone become less intense southward away from the Ormiston Thrust, and also eastward away from the Chewings Range Quartzite. This can be explained as a control on the deformation by the thick competent Chewings Range Quartzite which buckled during north-south compression into a large-amplitude fold, forcing the adjacent schist and gneiss to accommodate themselves to the

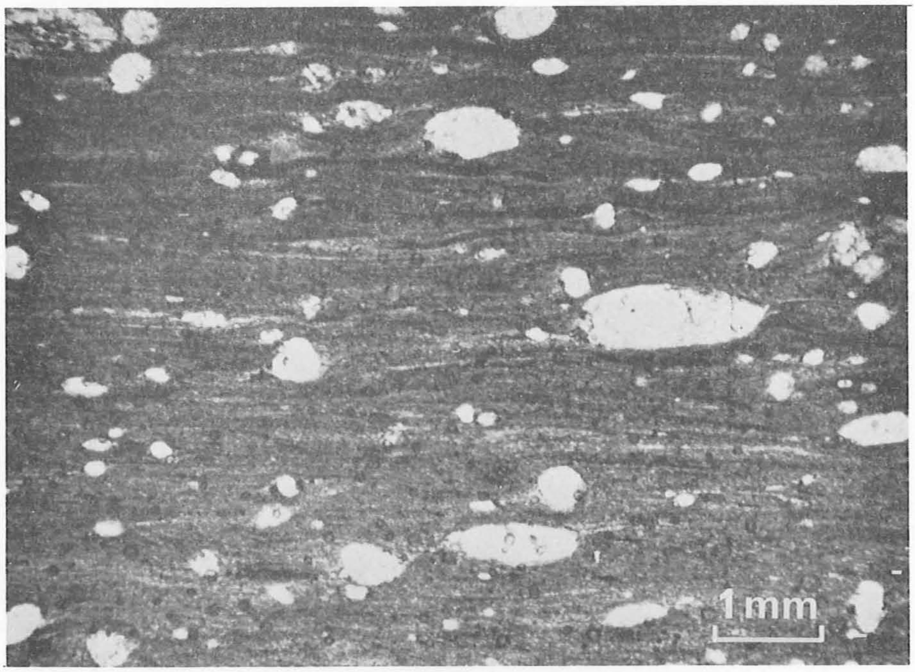

Fig. 30. Photomicrograph of an ultramylonite from the Redbank Zone. The foliation is marked mainly by finely comminuted quartz; it sweeps around porphyroclasts of quartz and orthoclase. Locality about 8 km northwest of old Redbank homestead. Plane-polarized light.

larger structure.

East of the Chewings Range, the Ormiston Thrust separates highly migmatized rocks of the Ormiston Zone in the north from unmigmatized gneiss, quartzite, and schist of the Chewings Range Zone in the south. The Thrust, however, dies out in this direction, and cannot have had a large throw. The boundary between the two Zones therefore existed before the thrust-faulting, and controlled the position of the fault. The boundary was probably a narrow transitional zone, or migmatite front, similar to that now preserved north of the Ormiston Thrust at its eastern end; these transitional rocks were sheared out by movement along the Thrust.

Orientation data for basement rocks with the most widespread development of superposed Alice Springs Orogeny structures (Domain H) are shown in Plate 3.6. On the same diagram, for comparison, data from Domain F immediately to the south are also shown.

In Domain F, the lithological banding and dominant foliation (S_2) trend approximately north; easterly dips range between 2° and 76°, probably as a result of gentle open F_4 folds with near-horizontal axes. The northerly trend of the Arunta Complex continues in Domain H, and is shown in Plate 3.6.a by strong S_2-pole maxima, very similar to the S_2-pole maxima from Domain F. In Domain H, S_2 is folded about easterly-plunging Alice Springs Phase folds (F_5), yielding a broad π-girdle about an axis plunging at 35° to 082°. The π-axis lies near the centre of the field of plotted F_5 axes and axial lineation. The wide scatter of Alice Springs Phase fold axes and axial lineation is consistent with that of a single generation of folds, when the wide range in initial orientation of S_2 and the variation of S_5 are considered.

In Domain F, L_2 lineation is near-horizontal and trends about 010°. In Domain H, L_2 is deformed by F_5 and plots in a broad, poorly defined vertical great-circle girdle (Plate 3.6.d). This distribution could be produced by either shear or flexural-slip folding, acting upon a lineation initially about 90° to the fold axis (Ramsay, 1960). Alice Springs Orogeny folds in Domain H are parallel in style, and generally show little suggestion of similar-fold geometry. The folds were developed from well foliated rocks, and in the pelitic and semi-pelitic units from which most measurements were taken, they are characteristically kink or chevron. The dominant mechanism for F_5 folding in Domain H was thus probably flexural-slip.

In Domain A, immediately east of Domain H, S_2 and L_2 are refolded by eastward-plunging folds. These folds become more abundant and less open with approach to the major D_5 thrust-fault which marks the northern boundary of the Domain and of the Chewings Range Zone. In the south of Domain A a north-trending dolerite dyke cuts across the folds, and is not affected by them. When traced northwards, the same dyke becomes conformable with S_2, and is affected by the folding (Fig. 32). The best explanation for this pattern is that the folds in the Domain belong to two generations. In the south, small F_3 folds are related to the major F_3 fold of Domain B, and hence antedate the dolerite intrusion; in the north, folds with a similar geometry and orientation to F_3 are related to movements along the thrust plane, and hence postdate dyke intrusion.

The attitudes of S_2 and L_2 in Domain A are very similar to those in Domain H. Poles to S_2 show the effect of coaxial F_5 and F_3 folding by defining a well developed great-circle girdle with an axis at 30° to 076°; this axis is close to measured minor fold axes in the Domain. L_2 defines a broad vertical great-circle girdle on the stereographic plot, which can be interpreted in a similar way to the deformed L_2 lineation of Domain H as indicating deformation by oblique flexural-slip folding.

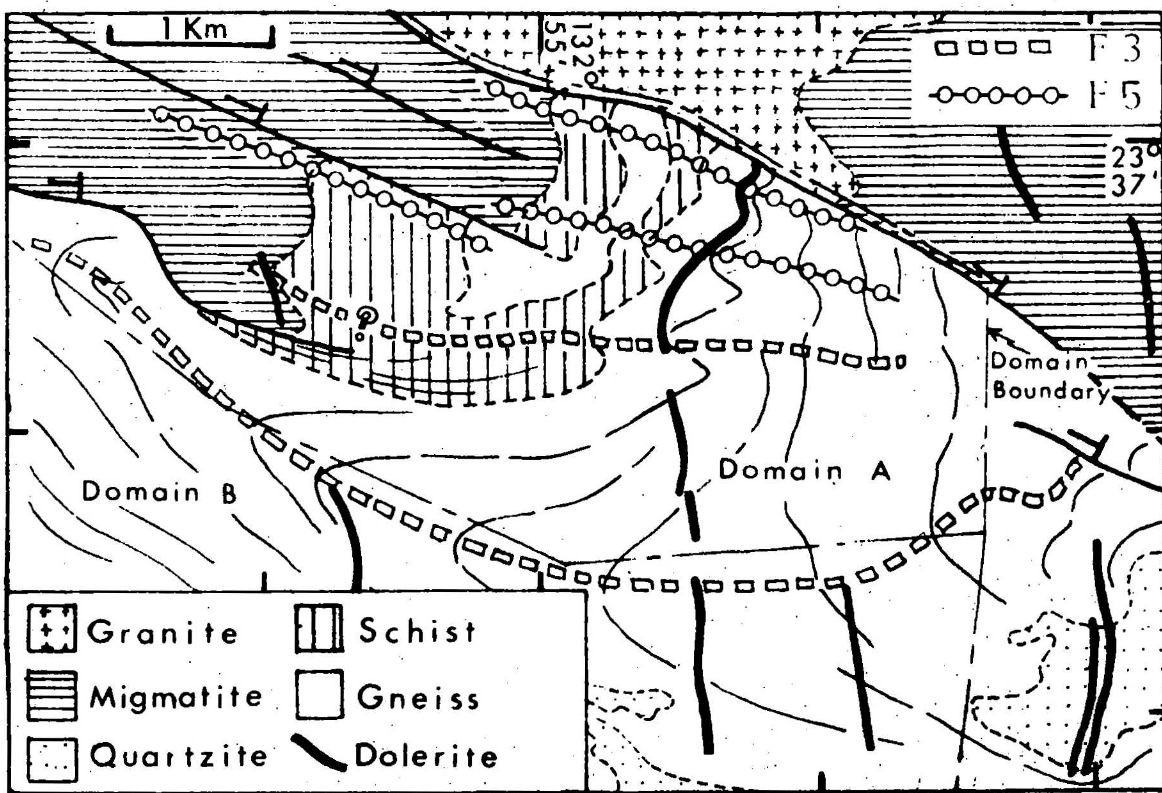

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Fig. 31. Simplified geological map of a part of the Arunta Complex showing F_3 and F_5 synclinal axial-plane traces. Dolerite dyke has been folded by F_5 folds.

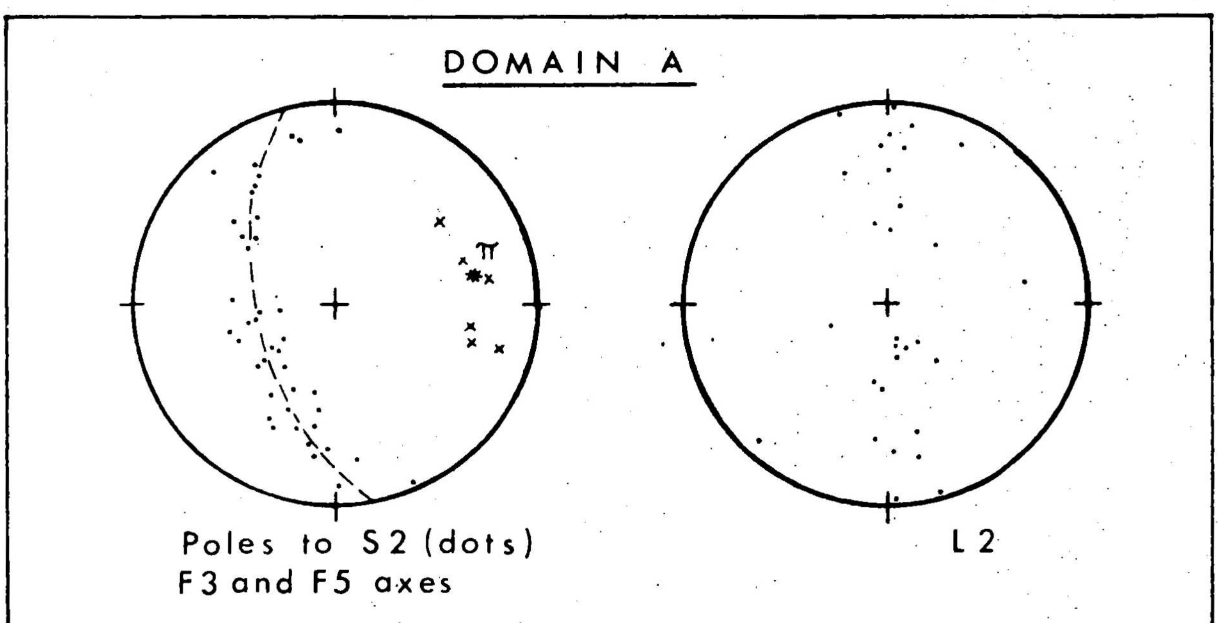

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Fig. 32. Orientation data for Domain A, showing the effects of F_3 and F_5 folding.

NNE-SSW SECTION THROUGH MOUNT SONDER

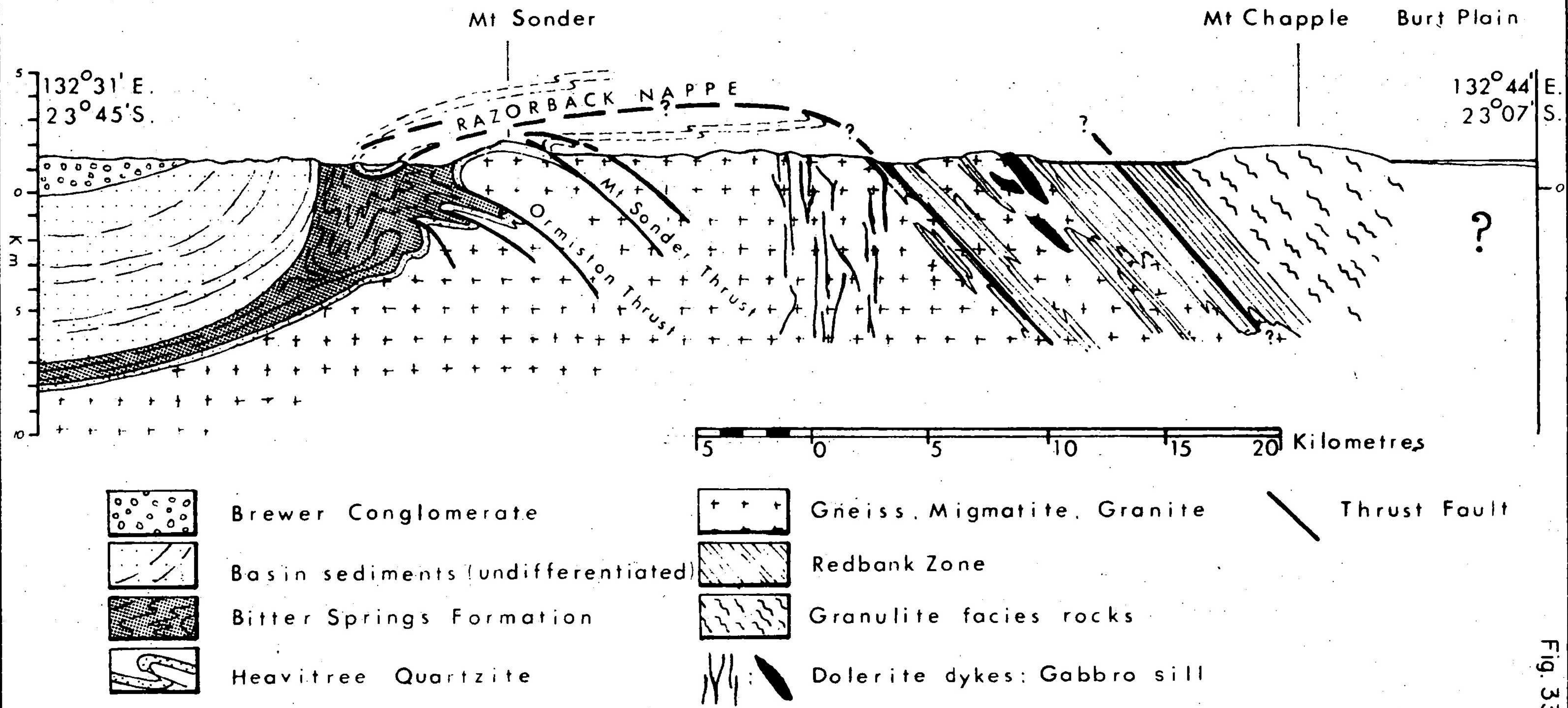

Fig. 33

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Development of the nappe complex

Figure 34 illustrates the interpretation of the development of the Ormiston Nappe Complex. It is assumed in this model that the initiation and development of the major under-thrusting of the autochthon took place during a single event (Alice Springs Orogeny) of horizontal tectonic pressure from the north.

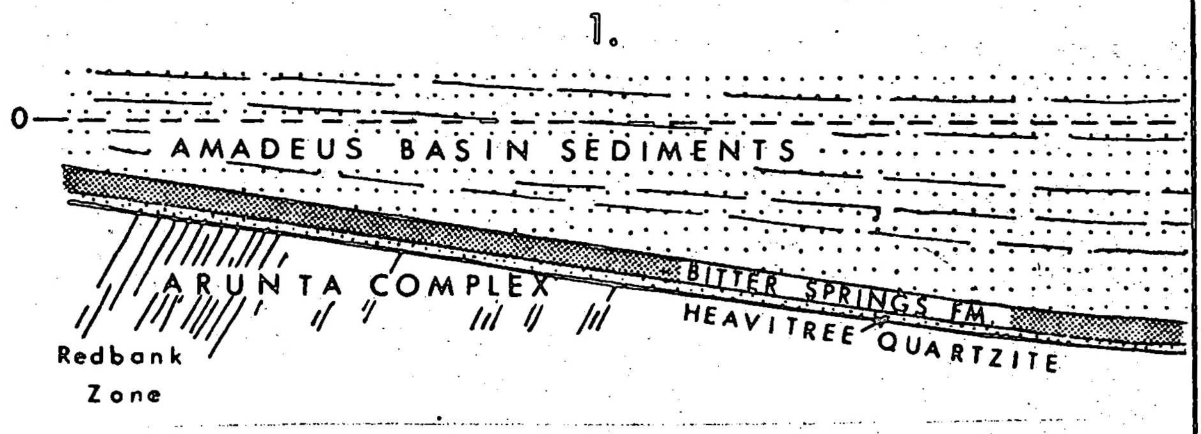
During the orogeny, deformation was controlled by the presence of major west-trending steep northwards-dipping zones of weakness within the basement rocks. The greatest of these, the Redbank Zone, was reactivated by thrust movements with a major upthrow, perhaps cumulatively of several kilometres, to the north. These thrusts broke through the Heavitree Quartzite to drive wedges of basement, with an overlying veneer of quartzite, into the Bitter Springs Formation. The thrusts then flattened and became located within the Bitter Springs Formation and did not break through the overlying beds. This was because of the extremely low viscosity of the rocks of the Bitter Springs Formation compared to that of the adjacent rocks, and probably also because the Bitter Springs decollement Zone was very nearly parallel to the shallow-dipping maximum shear-strain direction, which can be deduced for rocks under high confining pressure subjected to a horizontal stress gradient (Hubbert, 1951; Hafner, 1951). If the Bitter Springs Formation had been near the surface at the time of nappe emplacement, then the lines of maximum shear strain would have lain at a high angle to the Formation, and the basement rocks would probably have overthrust the Formation and reached the ground surface. Because ultimately during the Orogeny, uplift and erosion unroofed the Arunta Complex north of the present Amadeus Basin margin (Jones, 1972), the emplacement of the Razorback Nappe must have taken place at a relatively early stage during the Alice Springs movements.

The Razorback Nappe was driven into the Bitter Springs Formation for a minimum distance of 20 km by continued orogenic pressure from the north, and probably aided by down-slope movement. Frictional drag, which would impede movement of the wedge (Hubbert & Rubey, 1959), was at a minimum owing to the low viscosity of evaporite layers within the Bitter Springs Formation, and the transmission of shear movements through a great thickness of the Formation according to the mechanism suggested by Kehle (1970), rather than along a single narrow thrust surface.

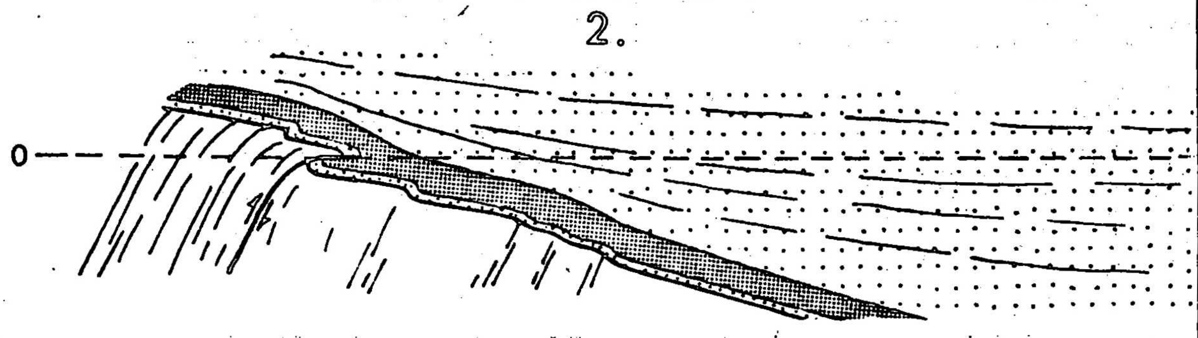
Movement of the Razorback Nappe produced contorted disharmonic folding in the Bitter Springs Formation adjacent to its flanks and advancing nose. The energy required to produce these folds, and to make space for the basement wedge as it was pushed under an increasing thickness of overlying sediments eventually stopped the movement of the Nappe. Stress within the basement block was then relieved by lesser movements on west-trending zones of weakness south of the Redbank Zone. These thrusts in their turn broke through the Heavitree Quartzite into the Bitter Springs Formation, and formed the fold-thrust complex of the parautochthon.

SUMMARY OF GEOLOGICAL HISTORY (Table 1)

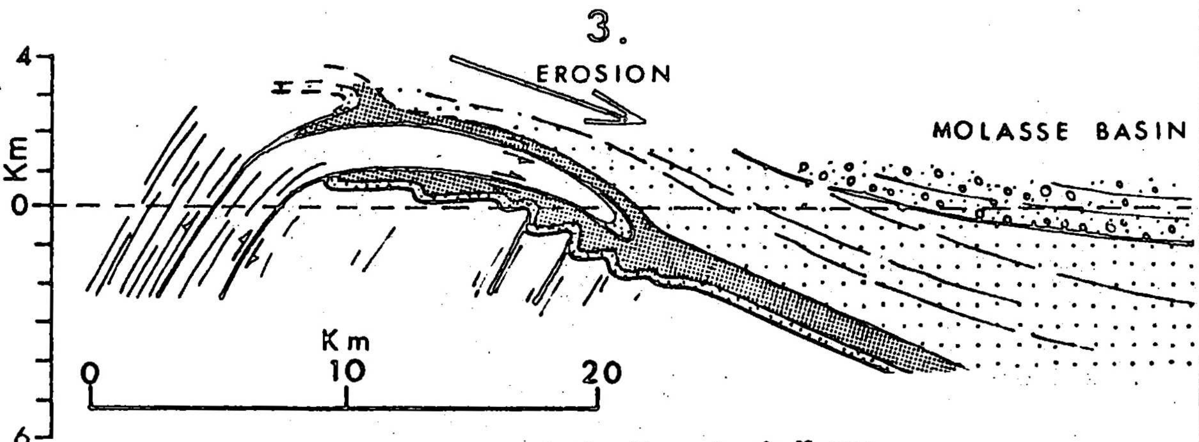
The deposition of the sediments of the Arunta Complex is the oldest event which can be confidently identified in the area, and took place more than 1620 m.y. ago. The basement upon which the sediments were deposited has not been identified, but may have been granitic, and is now represented by parts of the felsic gneiss preserved in the area. The sediments were least affected by later events in the Chewings Range, where the original arkose, mudstone, pure sandstone, and possibly basalt can be identified. Elsewhere the original nature of the rocks is obscured by later metamorphic and deformational events.



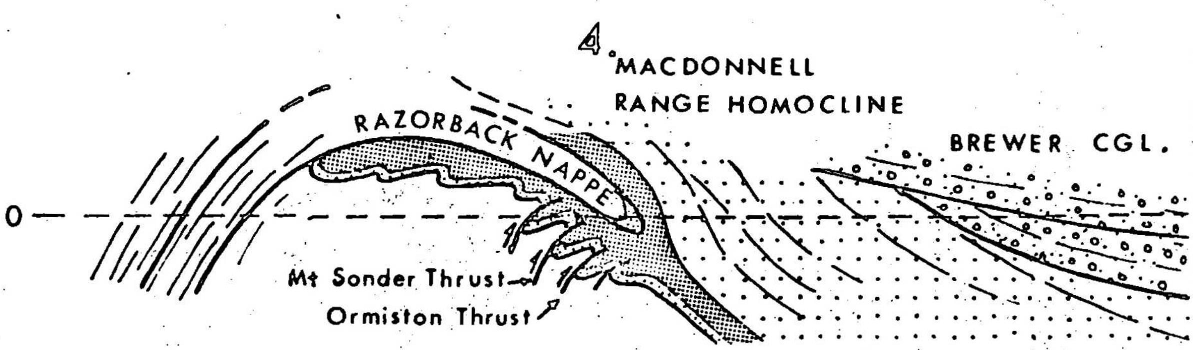
Attitude of the basin sediments before the Alice Springs Orogeny.



Uplift to the north along reactivated thrusts within the Redbank Zone.



Emplacement of the Razorback Nappe.



Formation of fold-thrust complex of the parautochthon.

Fig. 34. Sketch sections illustrating the development of the Ormiston Nappe Complex.

Vertical exaggeration 1.5X; scales approximate only.

The Arunta Complex in the Ormiston area can be divided into four zones, each of which has a distinctive structural and metamorphic history. The Redbank Zone is a linear belt of highly deformed rocks which stretches across the area and separates granulite-facies rocks of Mount Hay and Mount Chapple in the north from granite, migmatite, and metasediments, at generally amphibolite-facies grade, in the south. The dominant features south of the Redbank Zone result from two regional metamorphic events. Effects of the older event (dated at 1620 m.y.) are preserved in the Chewings Range Zone; this Zone is a map-scale palaeosome lying within the extensive younger Ormiston Zone migmatite complex which is dated at 1076 $\pm$ 50 m.y. The boundaries of the Ormiston Zone are marked largely by the migmatite front along which migmatization affected blastomylonitic rocks of the Redbank Zone, and quartzite, schist, and gneiss of the Chewings Range Zone.

In the Chewings Range Zone, five deformational and metamorphic episodes can be distinguished; the fifth episode is the Alice Springs Orogeny, and is discussed separately. The earliest event (Pre-Chewings Phase, D_1) has been largely obscured by D_2 metamorphism, but is not thought to have been widespread. D_2 (Chewings Phase) is the dominant event that affected the Zone, and produced isoclinal similar-style folds with strong axial foliation and lineation; metamorphism (1620 $\pm$ 70 m.y.) to amphibolite-facies grade accompanied the deformation.

D_3 structures (Ormiston Phase) are coeval with migmatization in the Ormiston Zone, and were probably produced by bending stresses imparted to rocks of the Chewings Range Zone by volume changes accompanying migmatization and granite intrusion in the adjacent

TABLE 1 SUMMARY OF GEOLOGICAL HISTORY

	CHEWINGS RANGE ZONE	ORMISTON ZONE	REDBANK ZONE	MOUNT HAY/MOUNT CHAPPLE ZONE
	DEPOSITION OF ARUNTA SEDIMENTARY SEQUENCE			
D1 Pre-Chewings Range Phase Date ?	Early foliation and lineation. Folding of limited extent			
D2 Chewings Range Phase 1620 ± 70 m.y.	Isoclinal folds. Strong axial foliation and lineation. Syntectonic amphibolite-facies metamorphism	Isoclinal folds. Strong axial-foliation and lineation. Syntectonic amphibolite-facies metamorphism	Start of major thrust zone, and formation of mylonitic rocks. Intrafolial N-plunging folds with strong axial lineation	Granulite-facies metamorphism. Blastomylonite formation on S margin. Intrafolial N-plunging folds
D3 Ormiston Phase 1076 ± 50 m.y.	Large E-plunging similar folds. Localized recrystallization	Migmatization and granite intrusion. Syntectonic folding with wide variety of style and orientation	Migmatization and disruption of foliation. Open to tight N-plunging syntectonic folds. Extensive recrystallization. ? Growth of large K-feldspar porphyroblasts	Local formation of agmatites. Small open N-plunging folds
D4 Mount Giles Phase	Open S-facing, asymmetric buckle-folds. Little recrystallization			
Basic intrusion	Intrusion of N-S dolerite dykes	Intrusion of E-W and N-S dolerite dykes	Intrusion of E-W dolerite dykes and hypersthene-gabbro sills	
	DEPOSITION OF AMADEUS BASIN SEDIMENTS			
D5 Alice Springs Orogeny 358-322 m.y.	Thrust faults. Narrow zones of refoliation and retrogression, open buckle-folds and crenulation cleavage adjacent to thrusts	Thrust faults. Narrow zones of refoliation and retrogression	Renewed movement along thrusts. Narrow discontinuous ultra-mylonite zones. ? Flattening of large feldspar porphyroblasts	Renewed uplift to present structural level

migmatite complex. Static recrystallization in the Zone produced the dominant granoblastic-polygonal texture and may have occurred during D_3.

The Mount Giles Phase (D_4) was a purely deformational event which produced open asymmetrical buckle-folds in the Chewings Range Quartzite. These folds are of limited extent, and disappear away from the major competent quartzite unit.

The Redbank Zone consists of blastomylonitic rocks with a steep north-dipping foliation; the rocks have a similar composition to those of the Chewings Range Zone. Amphibolite-facies metamorphism accompanied the deformation. A prominent mineral-orientation and mineral-streaking lineation plunges northward within the foliation, and is parallel to the axes of rootless intrafolial folds. The folds have a similar style to, and may be coeval with, D_2, which is defined in the Chewings Range Zone; the relations between the two Zones are now obscured by the migmatite complex. Assuming the correlation outlined above, D_2 structures in the area can be explained as having formed under a north-south stress gradient and a regional elevated temperature; dynamic processes were hence dominant in the Redbank Zone; thermal processes were relatively dominant farther south, and produced a coarser-grained rock with less defined S_2 and L_2 structures.

The Redbank Zone is thought to be associated with, and caused by the initiation of, a north-dipping complex thrust-fault zone with a major upthrow to the north; it is analogous to the zones of strong deformation, such as the Ormiston Thrust Deformed Zone, which are developed in association with D_5 thrust faults farther south. Parts of the Redbank Zone where D_2 fault movements took place are now obscured by the effects of later deformational and metamorphic events, and may be concealed by alluvial cover.

The Mount Hay/Mount Chapple Zone is characterised by a granulite-facies mineral assemblage. Most of the rocks are massive, but along the southern margin of the Zone they are finely foliated and have balstomylonitic texture. This foliation, and a mineral-elongation lineation upon it are parallel to that of the adjacent Redbank Zone, and probably resulted from the same deformation episode at about 1620 m.y. The granulite-facies metamorphism is a D_2 event, and is coeval with deformation of the Redbank Zone and amphibolite-facies metamorphism of the Chewings Range Zone. The rocks of the Mount Hay/Mount Chapple Zone lay at a greater depth during D_2 than did the rocks to the south, and hence reached a higher metamorphic grade; uplift along the major thrust or thrusts of the Redbank Zone subsequently brought them to their present juxtaposition with the rocks to the south. An unknown amount of this uplift was accompanied by renewed movements at the time of the Alice Springs Orogeny.

Orthoclase, garnet, and biotite within the southern margin of the Zone represent retrogressive mineral growth. The age of the retrogression is unknown but it was probably controlled by the introduction of aqueous fluids into the margin of the granulite belt from the adjacent deformed zone. It is considered that this is most likely to have occurred during D_3.

In the Ormiston Zone the migmatite complex resulted from a rise in geothermal gradient coupled with the action of metasomatizing fluids and the probable intrusion of granitic magma. The lack of migmatization in the Chewings Range Zone may be the result of its remoteness from large granite bodies whose intrusion served to localize the migmatization elsewhere. The migmatites are probably related to the development of much more extensive granites at depth.

After the renewal of sedimentation in the area during the late Proterozoic, both basement and cover were deformed in the Late Devonian to Early Carboniferous by an episode of orogenic pressure from the north, the Alice Springs Orogeny. On the northern margin of the Amadeus Basin, the orogeny produced a fold-thrust complex, the Ormiston Nappe Complex. The uppermost structure of the Complex is the Razorback Nappe; the nose of the Nappe is preserved in a klippen south of Mount Sonder, and the root zone had its most likely origin in the Redbank Zone of the basement to the north. The Nappe consists of a wedge of basement and attached veneer of Heavitree Quartzite which has been pushed for at least 20 km into the shale and dolomite of the Bitter Springs Formation; sediments overlying the Bitter Springs Formation along the northern margin of the Amadeus Basin were tilted into a vertical attitude, but were not overridden by the Nappe.

After the emplacement of the Razorback Nappe, stress within the basement was relieved by steep thrust-faults, probably located within pre-existing west-trending zones of weakness in the basement similar to, and south of, the Redbank Zone. The thrusts broke through the Heavitree Quartzite, bringing basement to rest upon Heavitree Quartzite or Bitter Springs Formation.

In the Ormiston Nappe Complex, deformation of both basement and cover is limited to the vicinity of the major thrusts. Underlying the Ormiston Thrust a zone of highly deformed quartzite (Ormiston Thrust Deformed Zone) up to 1km wide was developed. The Deformed Zone is characterized by isoclinal folds with generally horizontal axes, and the development of a mylonitic foliation parallel to the fold axial planes and to the Thrust surface. A north-plunging quartz-elongation lineation is commonly developed on the foliation, especially adjacent to the Thrust. South of the Deformed Zone the folds become progressively more open and upright.

REGIONAL IMPLICATIONS

Regional knowledge of the basement geology of central Australia is too sketchy to allow areas of more detailed information (such as that of this study) to be confidently correlated. The analysis of fundamental tectonic processes which may have acted must await such correlations. In spite of this, major features of the Ormiston area can be extrapolated with varying degrees of certainty beyond that area, and allow some discussion of the origin of the marked west-trending tectonic and gravity lineaments of central Australia, particularly those along the northern margin of the Amadeus Basin.

Areal extent of deformational and metamorphic events

A west-trending lineament defined by a regional gravity gradient and physiographic features can be traced parallel to the northern edge of the Amadeus Basin for about 350 km along strike. Within the study area the lineament lies within and is parallel to the Redbank Zone, and it is reasonable to suppose that deformed rocks of that Zone are largely coextensive with the linear feature.

East of Alice Springs, where the lineament weakens and becomes difficult to trace, the simple pattern of westward-trending zones within the Arunta Complex, such as has been described in this report and is believed to characterise the major part of the Arunta Complex between the Amadeus and Ngalia Basins, has not been found (Forman & Shaw, 1973; Shaw & Stewart, 1973; Rickard, pers. comm.). A wide west-northwest-trending zone of refoliation and retrogression within the basement in the Arltunga region, which has yielded K-Ar dates of

Alice Springs Orogeny age (Stewart, 1971), may have been initiated as a deformed zone at the same time as the Redbank Zone. In early descriptions of the Arltunga Nappe Complex (Forman et al., 1967; Wells et al., 1970; Forman, 1971), this retrogressed zone was interpreted as representing the root zone for the Arltunga Nappe Complex and the site of major thrust-faulting during the Alice Springs Orogeny. However, recent work by J.L. Funk (pers. comm.) has shown that little vertical movement took place along the zone at the time of Nappe emplacement; this conclusion is in keeping with the lack of any marked gravity gradient across it.

Evidence has not been found for major vertical movements within the Arunta Complex east of Alice Springs during the Alice Springs Orogeny; the eastward thinning of the synorogenic Brewer Conglomerate within the Amadeus Basin (Jones, 1970, 1972) may indicate that major vertical movement was confined to the area west of Alice Springs. The location of the root zone and the manner of emplacement of the Arltunga Nappe Complex thus remain major problems in the understanding of the Alice Springs Orogeny.

The two Precambrian metamorphic events described from the Ormiston area are widely developed in central Australia. The older event (1620 ± 70 m.y.) is comparable in age to isotopic dates of about 1700 m.y. obtained from widely separated localities in the Arunta Complex (Shaw & Stewart, 1973) and probably represents a widespread regional metamorphic and deformational episode.

Migmatisation and granite intrusion (dated in the study area at 1076 ± 50 m.y.) affecting an older gneiss sequence can be traced for at least 150 km east of the area, and are probably responsible for the published dates of 1000 to 1200 m.y. from the Harts Range and Arltunga regions of the Arunta Complex (Hurley et al., 1961; Riley, 1968; Stewart, 1971). Between 100 and 350 km to the west of the area, extensive intrusive granites into the basement south of the major west-trending lineament in the Mount Liebig and Mount Rennie 1:250 000 Sheet areas may be related to the migmatization. South and southwest of the Amadeus Basin, intrusive granites cutting the basement gneiss have been dated at 1100 to 1200 m.y. (Compston & Nesbit, 1967; Compston & Arriens, 1968; Parkin, 1969; Thomson, 1970). These granites are referred to the Kulgeran Phase of metamorphism; they have a comparable age to the granitization event developed along the northern margin of the Basin. It is possible that granite and migmatite are continuous underneath the Amadeus Basin, and were formed during a limited time interval about 1100 m.y. ago.

Origin of the gravity lineament

The gravity lineament lies within the Redbank Zone, and corresponds to the linear scarp of the exposed Arunta Complex against the Burt Plain. The Redbank Zone is interpreted as being initiated at about 1620 m.y. ago as a northward-dipping thrust zone of crustal dimensions along which major uplift to the north took place. The thrust zone is symmetrical with the Woodroffe Thrust Zone in the Musgrave Block south of the Amadeus Basin. The Woodroffe Thrust brought granulite-facies rocks northward so as to overlie amphibolite-facies gneiss, and was probably initiated more than 1400 m.y. ago (Collerson, Oliver, & Rutland, 1972).

It is not known to what extent plate tectonic processes may have been active in producing this pattern. Considering only the Woodroffe Thrust, Davidson (1973) suggested that it was a subduction zone between two continental masses represented by the Musgrave and Arunta Blocks. However, he pointed out that the rocks to the north and south of the thrust show similar rock types and structures, and must initially have belonged to the same continental plate. Similarly, in the Arunta Complex, rocks north and south of the Redbank Zone and its probable easterly extension have comparable ages, rock types, and structures. The evidence thus suggests that the two major deformed belts of central Australia lie within a single continental plate. There is no sign of the ophiolite suite, blueschist-facies rocks, or extensive volcanic activity, all of which might be expected to mark a continent-continent collision boundary. The evidence can be accounted for in the model of Forman & Shaw (1973), in which the deformed zones represent intracontinental subduction zones with a limited amount of underthrusting, and hence little associated volcanism. However, though this latter suggestion provides a description of the deformed zones in plate tectonic terms, it provides no explanation as to the origin or driving mechanism of such zones.

Migmatization and granite intrusion at about 1100 m.y. ago probably resulted in widespread homogenization at the base of the crust in central Australia. The present-day gravity anomalies across the Redbank Zone (and to a lesser extent across the Woodroffe Thrust Zone) are thus most likely to be largely the result of anomalous density distributions in the crust caused by post-1100 m.y. movements. In the Arunta Complex the largest movement was the Alice Springs Orogeny which was caused by renewed north-south compression and resulted in a reactivation of the Redbank Zone as an Alice Springs Orogeny thrust zone. The uplift of relatively dense deep-crustal material to the north of the thrust caused the gravity high, whereas the presence of extensive low-density granitic material underlying the Amadeus Basin enhanced the gravity low in that region. The major Alice Springs Orogeny thrust zone is probably located under the Burt Plain immediately north of the Arunta scarp, with which it is co-extensive. The greatest vertical movements along this zone took place in the Ormiston area, and correspond to the most intense gravity anomaly.

Since the Carboniferous, there has been no major tectonism in central Australia, and anomalous crustal density distributions in the region have been supported since then by the inherent strength of the crust.

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APPENDIX

Co-ordinates of Localities mentioned in Text

(to nearest 5 seconds)

LOCALITY	LONGITUDE (EAST) Degrees	Minutes	Seconds	LATITUDE (SOUTH) Degrees	Minutes	Seconds
A	132	51	45	23	37	15
B	132	50	00	23	40	05
C	132	51	15	23	38	45
D	132	49	05	23	40	00
E	132	50	45	23	32	00
F	132	54	40	23	38	50
G	132	55	15	23	39	05
J	133	08	15	23	26	45
K	133	07	30	23	29	30
L	132	48	45	23	31	15
M	132	48	30	23	36	15
N	132	44	05	23	38	30
O	132	49	30	23	36	00
P	132	50	35	23	36	00
Q	132	34	40	23	38	00
R	132	35	00	23	39	10
S	132	50	35	23	40	00
T	132	50	10	23	36	05
U	132	50	20	23	39	55
V	132	54	30	23	39	25
W	132	54	30	23	39	15
X	132	55	15	23	39	00
Y	132	51	40	23	39	10
Z	132	46	40	23	25	20

LOCALITY	LONGITUDE (EAST)			LATITUDE (SOUTH)		
	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds
AA	132	48	30	23	31	40
BB	132	44	10	23	29	00
CC	132	50	05	23	31	05
DD	132	48	50	23	31	15
EE	132	45	45	23	24	40
FF	132	45	15	23	25	25
GG	132	44	15	23	31	25
HH	132	48	35	23	35	15
II	132	45	30	23	35	35
JJ	132	49	05	23	35	40
KK	132	48	30	23	34	20
LL	132	49	20	23	34	35
MM	132	50	00	23	34	30
NN	132	49	25	23	34	35

PLATE 1 — GEOLOGICAL MAP OF THE MOUNT RAZORBACK-ORMISTON POUND-REDBANK HILL AREA


PLATE 2
GEOLOGICAL MAP OF NORTHEASTERN CORNER OF ORMISTON POUND
Bitter Springs Formation
Upper
Middle
Lower
Heavitree Quartzite
Arunta Complex
(Units as on Plate 1
Axial-plane traces of Alice Springs Orogeny Synclines
Axial-plane traces of F2 Synclines
Dolerite dyke
Pegmatite dyke
Other symbols as on Plate 1
SCALE
1:11,625
Kilometre
ORMISTON THRUST
CAMP CREEK
TWOFOLD CREEK
DAMPER CREEK
EASTERN POUND
ORMISTON POUND
* Informal name
1973 R.W.M.
F53/A/37

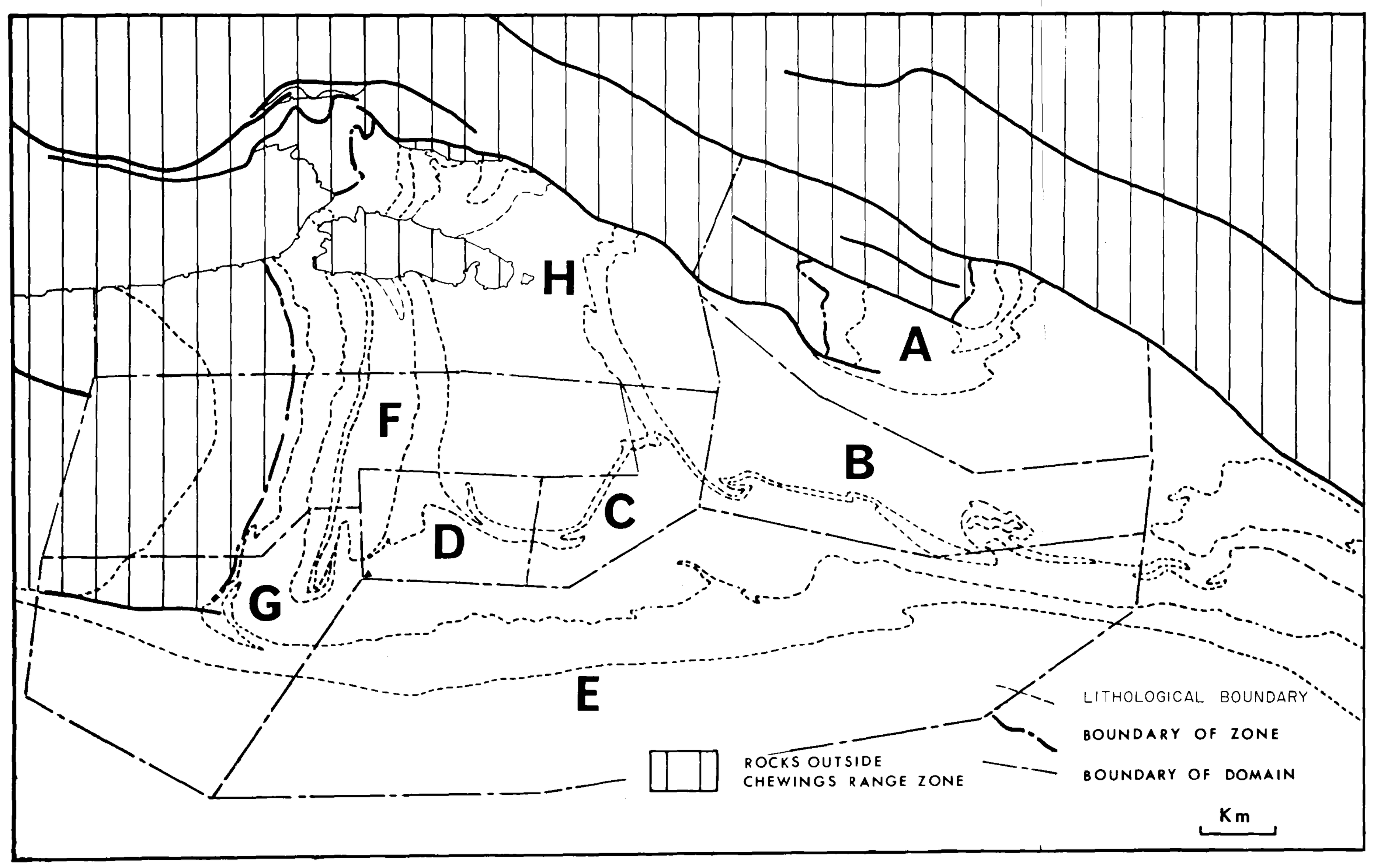
STRUCTURAL ANALYSIS OF CHEWINGS RANGE ZONE

PLATE 3

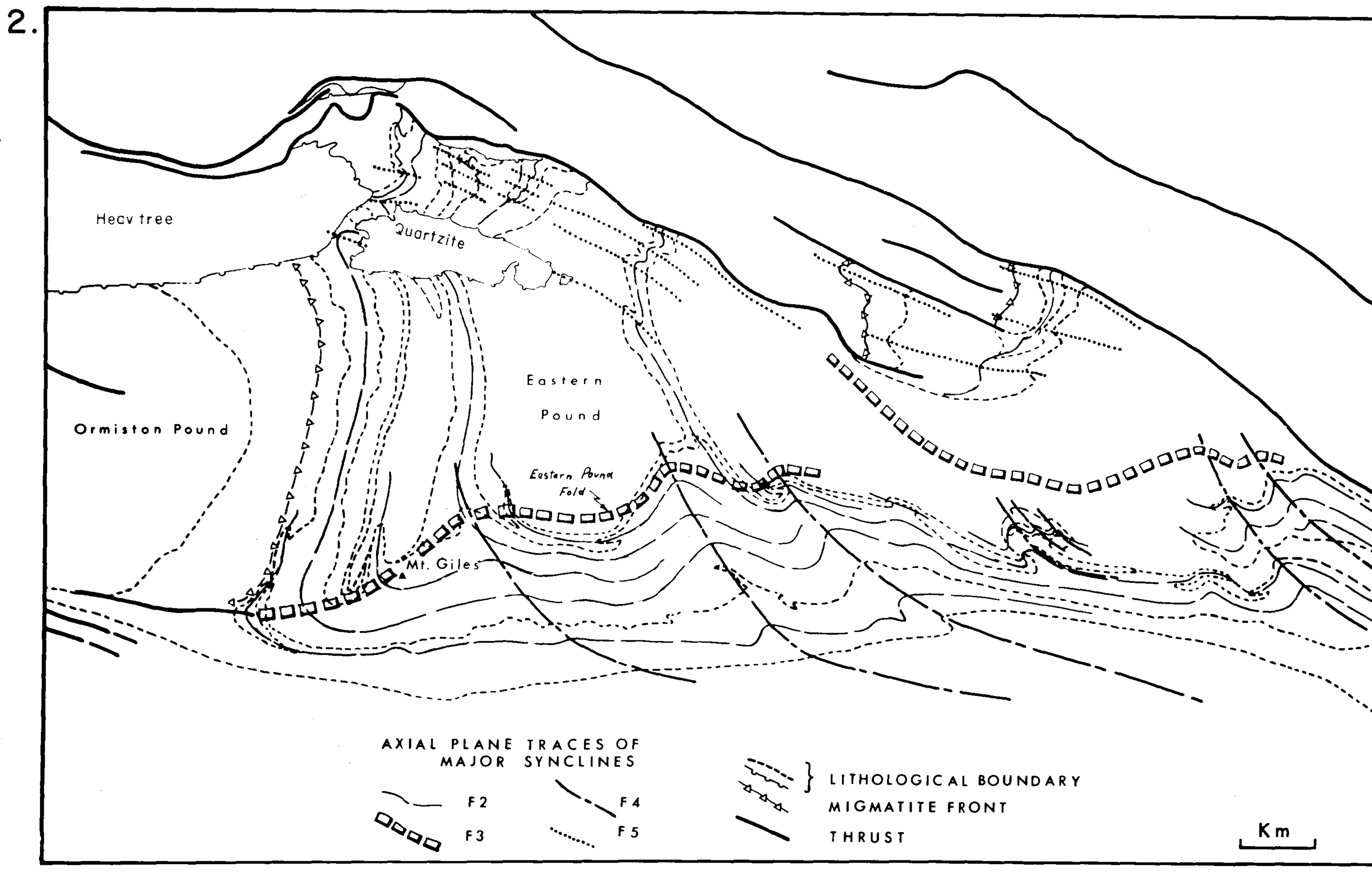
SCHMIDT EQUAL AREA PROJECTION

- Pole to S_2
- Pole to S_3
- Pole to S_5
- F_2 fold axes and L_2 axial lineation
- F_4 fold axes and L_4 axial lineation
- F_5 fold axes and L_5 axial lineation
- π-axis
- Field of plotted points from Domain

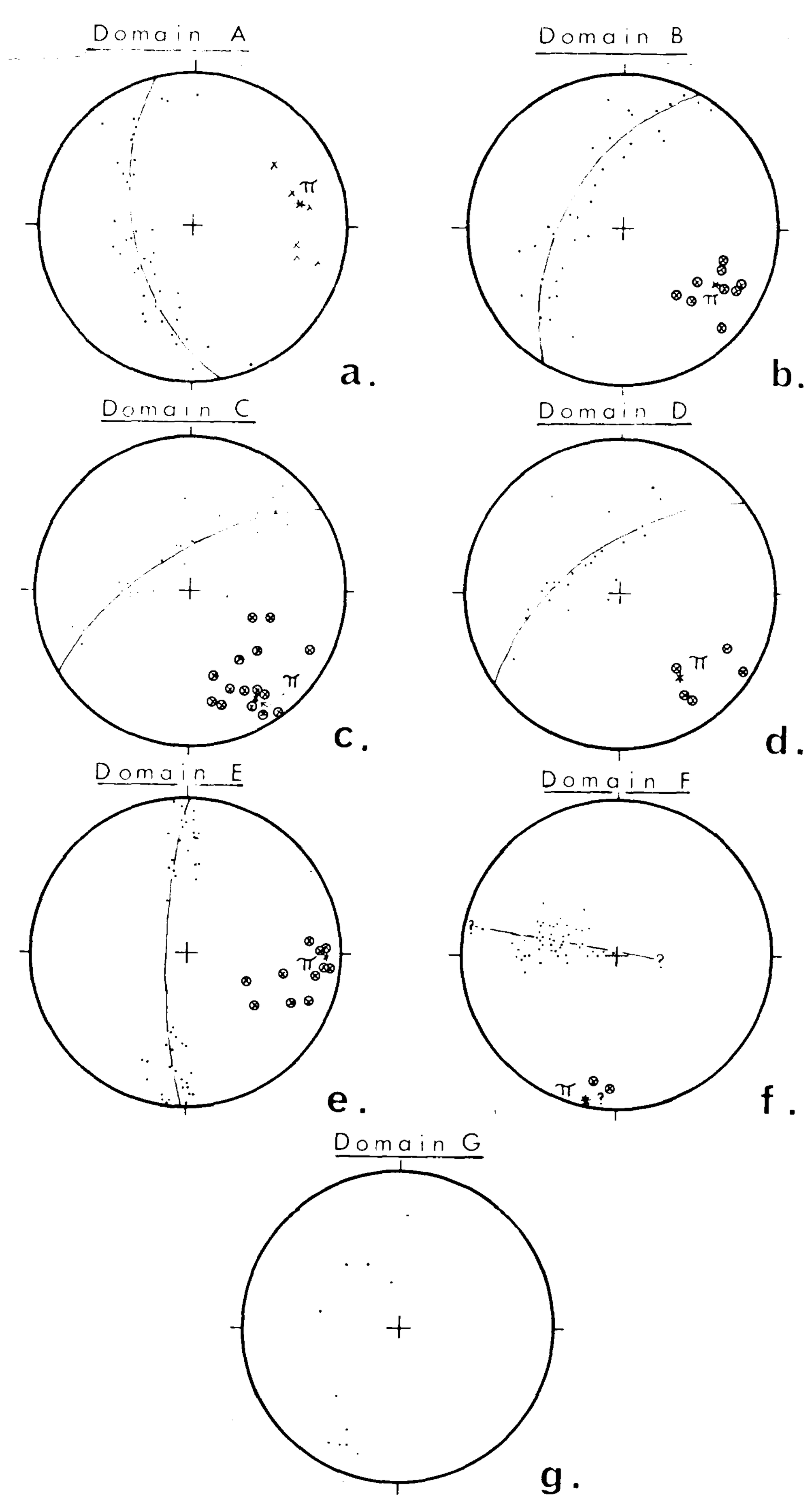
1.



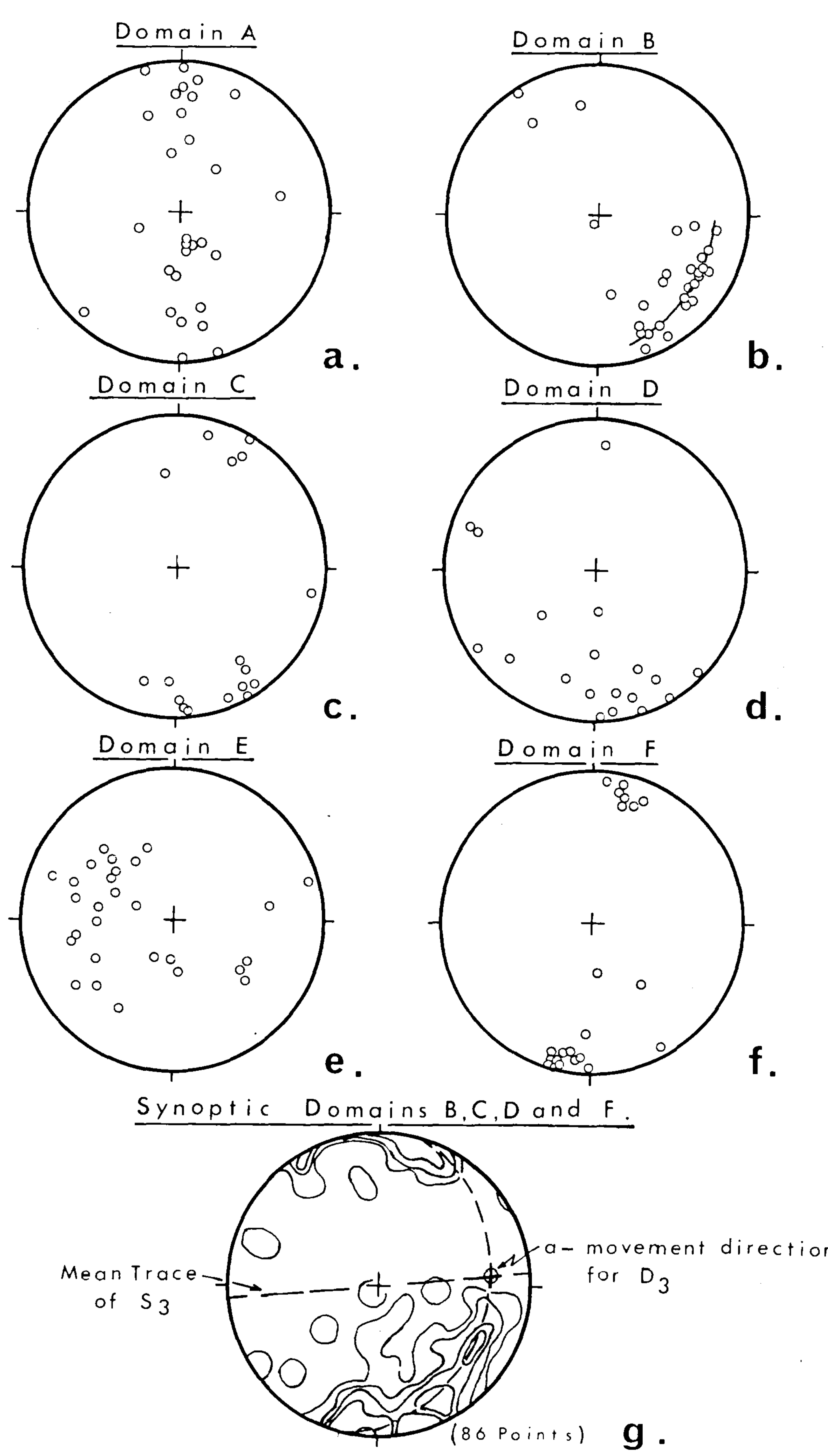
2.



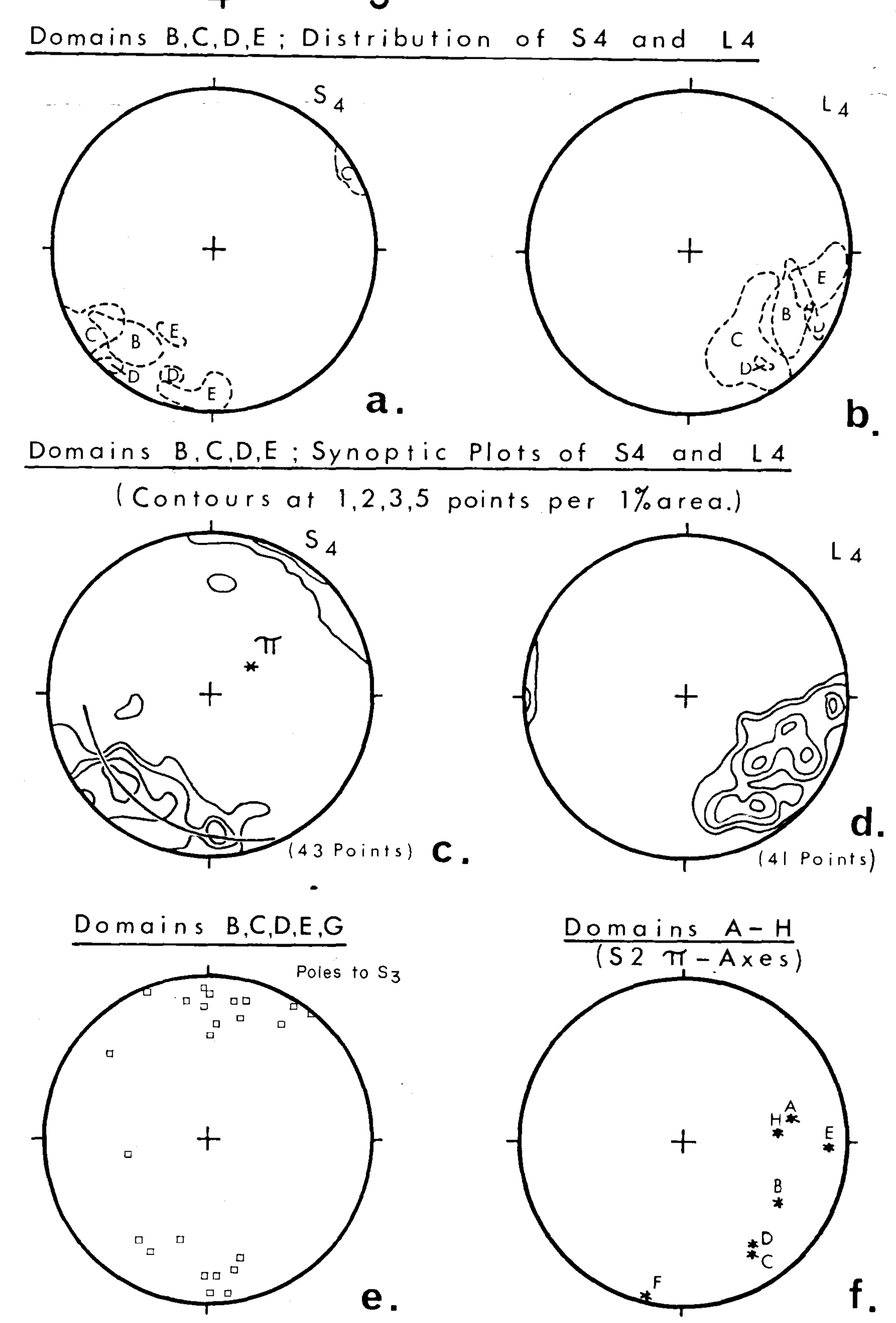
3. Poles to S_2



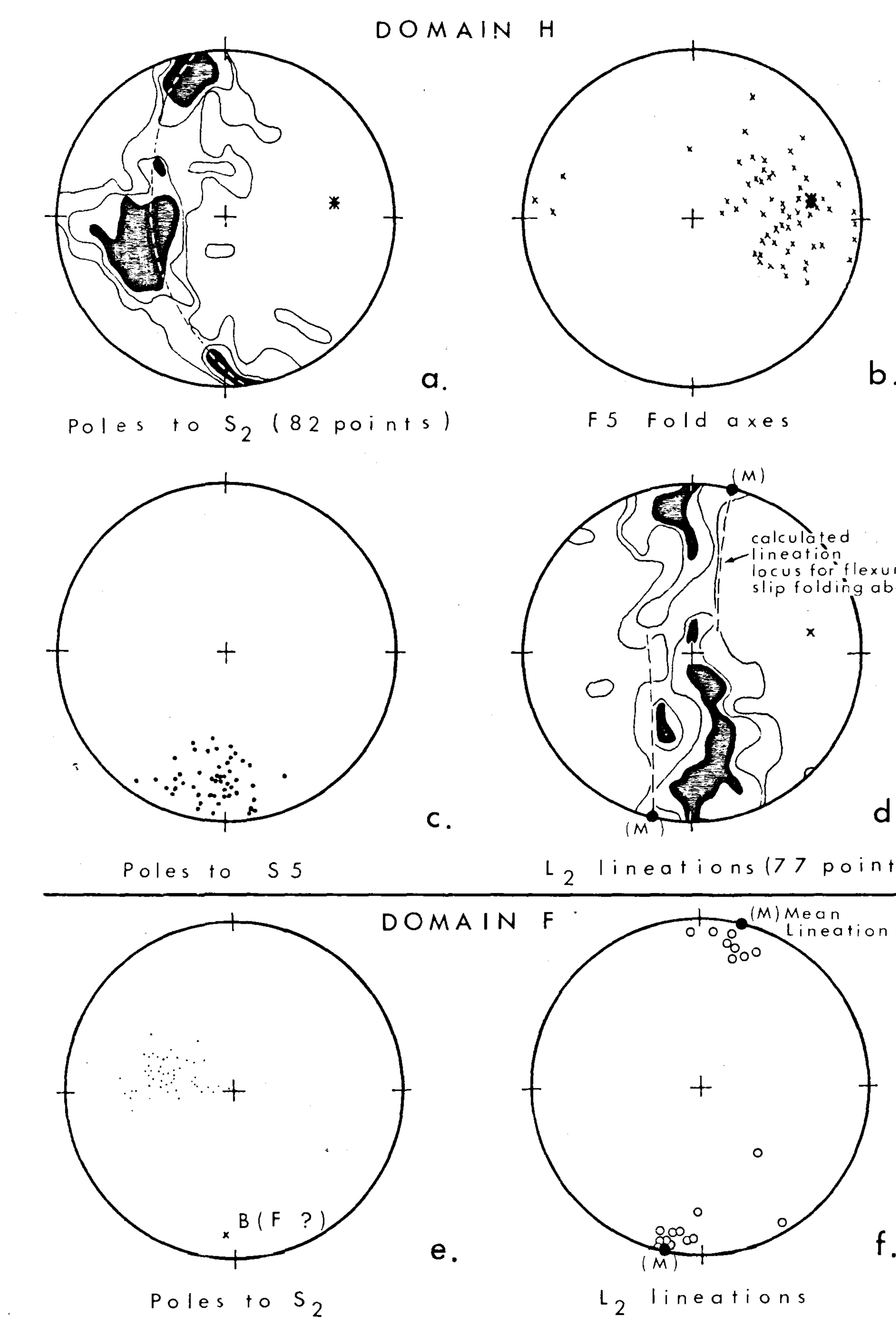
4. L_2 Lineations



5. D_4 and D_3 structure



6. D_5 structures



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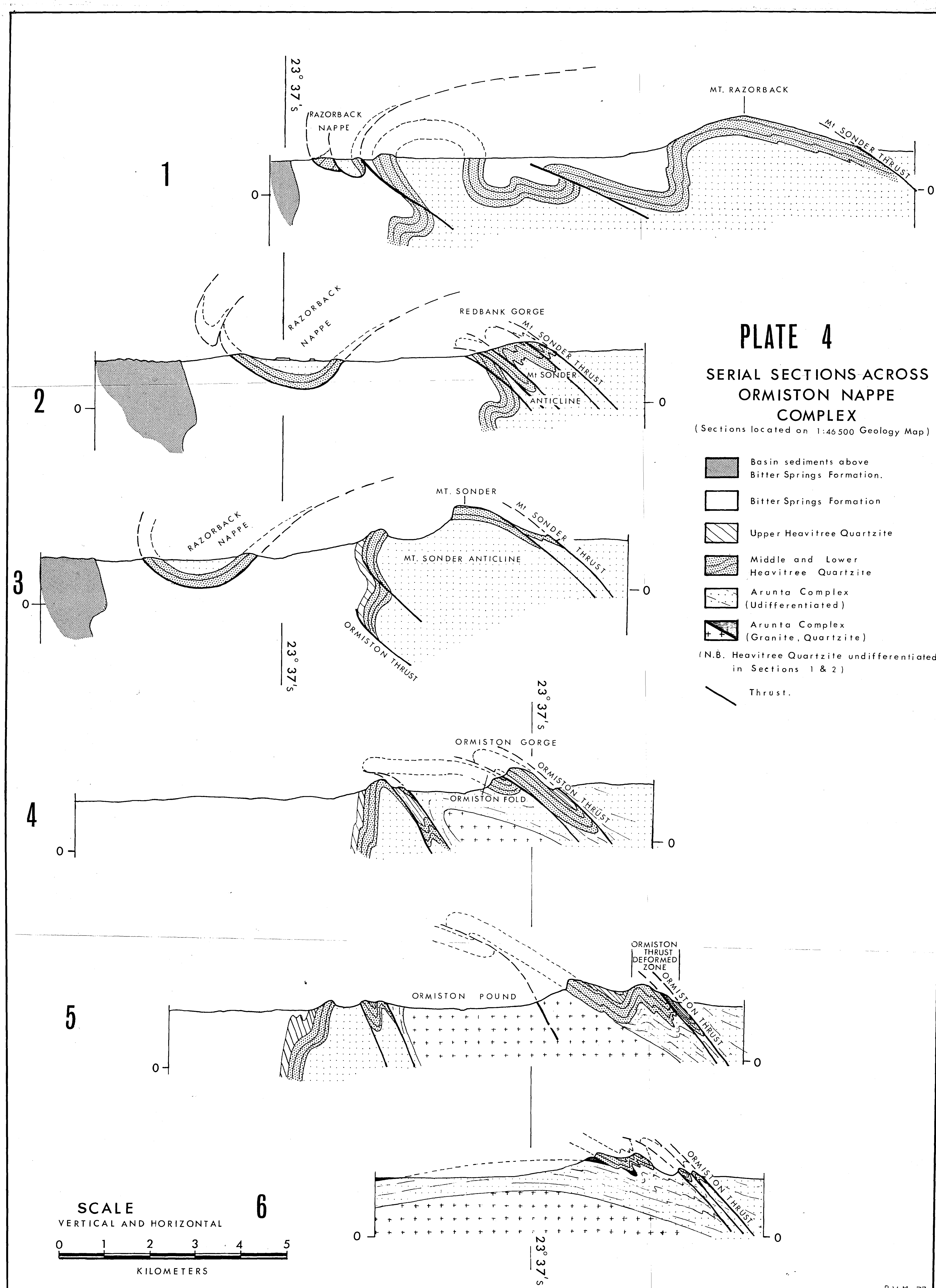

PLATE 4

SERIAL SECTIONS ACROSS ORMISTON NAPPE COMPLEX

(Sections located on 1:46500 Geology Map)

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