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EXCURSION GUIDE - ARUNTA BLOCK, N.T. CONFERENCE ON TECTONICS AND GEOCHEMISTRY OF THE EARLY TO MIDDLE PROTEROZOIC FOLD BELTS, DARWIN, AUGUST 1985

by

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PART 1:- INTRODUCTION

THE ARUNTA INLIER : Stratigraphy and tectonic evolution
(after Shaw and others, 1984 & Stewart and others, 1984)

The Aunta Inlier is the mass (200 000 km^2, roughly the size of Great Britain) of mainly Precambrian metamorphosed and deformed igneous and sedimentary rocks in the southern part of the Northern Territory of Australia (Fig. 1.1). It is surrounded on most sides by Proterozoic and Phanerozoic sedimentary cover. To the NW it merges with schist and gneiss of The Granites-Tanami Province, and to the N it merges with similar rocks of lower metamorphic grade in the Tennant Creek Inlier. Since the late 1960s the better exposed parts of the Inlier have been systematically mapped and studied by the Bureau of Mineral Resources, The Northern Territory Geological Survey (since 1979), and staff members and students of the Australian National University, Monash University, the University of Queensland and the University of Adelaide.

The Arunta Inlier differs from other Proterozoic inliers in northern Australia in the marked intensity and frequency of its deformation, the high grade of much of its metamorphism, and its abundance of granite. In these respects it resembles mobile belts in southern Africa (Kroner, 1977, 1981; Hunter & Pretorius, 1981) and the Baltic Shield (Magnusson, 1960; Geijer, 1963).

The model of Precambrian tectonics developed by Kroner (1977, 1981) explains much of the geological history of the Arunta Inlier, though further testing is required before the model can be fully accepted.

In order to produce a synthesis of the data obtained in the course of the regional studies, a **stratigraphic model** and the concept of **tectonic provinces** have been developed:

The Stratigraphic model

In the Arunta Inlier primary age data such as fossils or times of volcanic crystallization are absent, sedimentary facing is rare, and so the order of superposition is generally unknown. Stratigraphic sequences can be established locally, but because of extensive faulting cannot be extended throughout the Inlier. Consequently, it was necessary to establish a litho-stratigraphic model - the Division concept (Shaw & Stewart, 1975) - based on facies assemblages and lithological correlation.

The model uses three broad litho-stratigraphic groups called Divisions 1, 2 and 3; Division 1 being the oldest and Division 3 the youngest (Shaw & Stewart, 1975; Figs 1.1,1.2,1.3). Boundaries between the Divisions are commonly faulted, sheared, metamorphosed, intruded by granite, or concealed by superficial deposits, but in a few places unconformities between the Divisions are preserved. Rock units and rock associations are assigned to each Division primarily on lithological similarity, in places across large areas of non-exposure, and so are only tentatively regarded as chronological and stratigraphic correlatives. Each Division is essentially a group of rocks which broadly represents a lithogenetic facies.

Division 1

Division 1 comprises mafic, felsic and semi-pelitic granulites and lesser amounts of calc-silicate rock and marble, and crops out principally in the Central Province (Fig. 1.1). It represents a large volcanic facies which formed the first part of the Arunta sequence. Mafic granulite is concentrated in the lowest part of the Division, where it forms up to 70% of exposures. Analysed samples from the Strangways Metamorphic Complex, which forms much of the Stragways Range 70 km N of Alice Springs (Fig.1.1), have an iron-rich tholeiitic composition [total FeO ranges from 9.2 to 15.8%; (Shaw and others, 1979a, Table A1; Shaw & Langworthy (1984)]. The mafic granulite forms layers ranging from 3 to 10 m thick and up to several hundred metres long, separated by felsic granulite (essentially a bimodal assemblage). These have been multiply folded, suggesting that

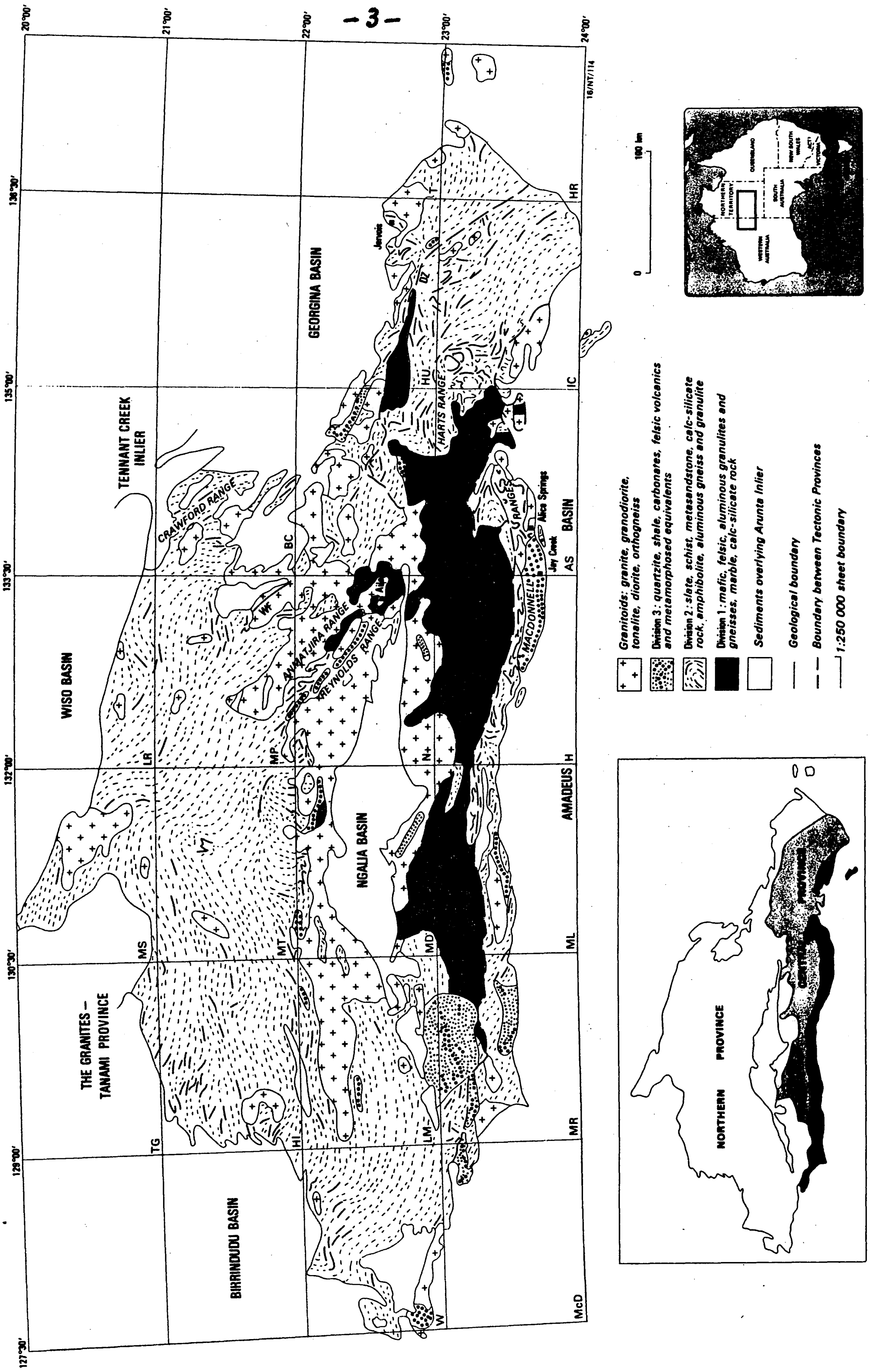


Figure 1.1 The Arunta Inlier, showing tectonic provinces and the distribution of Division 1, 2 & 3. 1:250 000 Sheet areas TG **The Granites**, MS **Mount Solitaire**, LR **Lander River**, HI **Highland Rocks**, MT **Mount Theo**, MP **Mount Peake**, BC **Barrow Creek**, W **Webb**, LM **Lake Mackay**, MD **Mount Doreen**, N **Napperby**, A **Alcoota**, HU **Huckitta**, T **Tobermory**, McD **MacDonald**, MR **Mount Rennie**, ML **Mount Liebig**, H **Hermannsberg**, AS **Alice Springs** IC **Illogwa Creek**, HR **Hay River.**

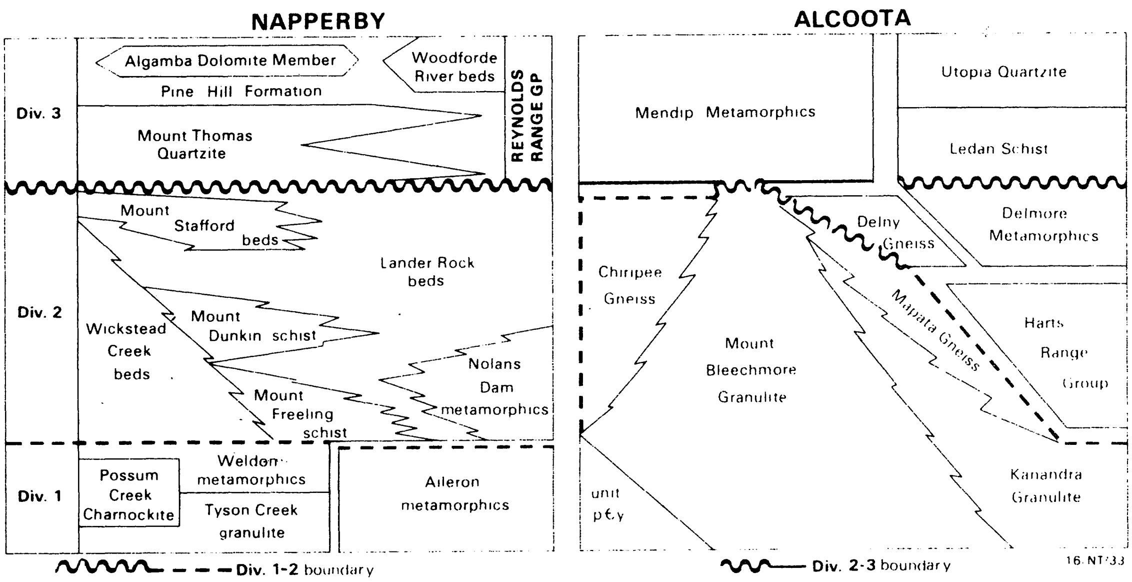


Figure 1.2 Stratigraphic relationships in the **Napperby** and **Alcoota** 1:250 000 Sheet areas.

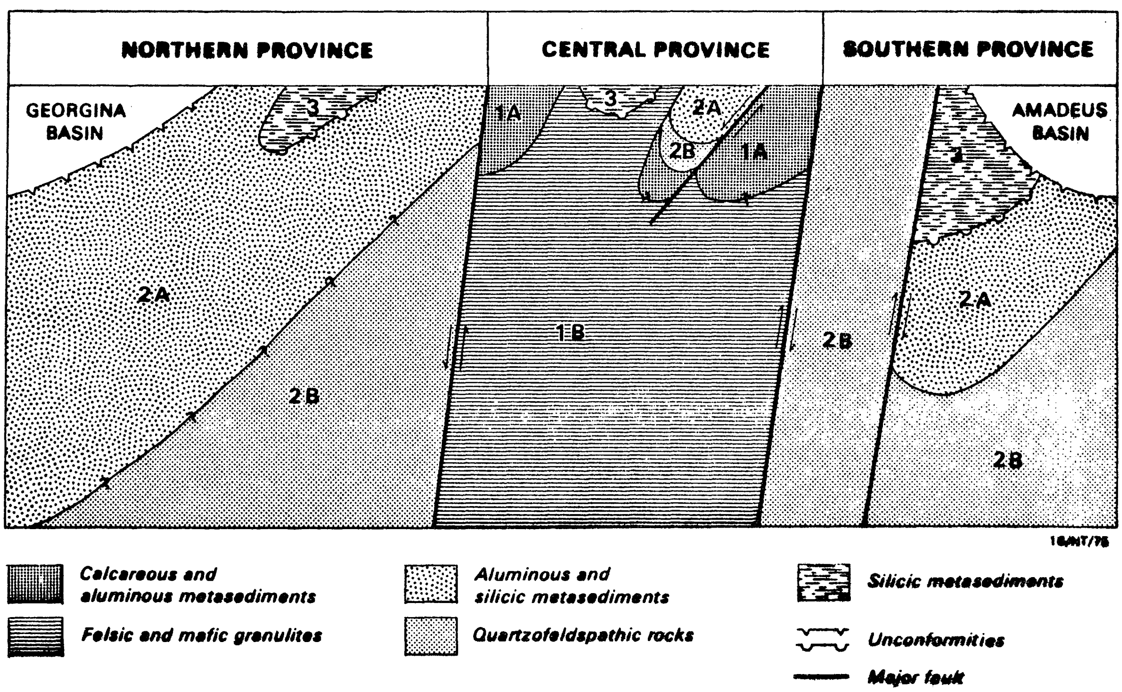


Figure 1.3 Schematic cross sections showing the relationships between Divisions 1, 2 & 3 in the northern, central and southern tectonic provinces.

the mafic layers are primary tabular masses, and so are interpreted as basalt flows, although no relict igneous textures survive. The felsic granulite layers are mainly of granite to granodiorite composition, but some large homogenous masses are of intermediate composition, and may be intrusions (e.g., Utnalanama granulite). Higher in the sequence in the Strangways Range, semi-pelitic granulite is interlayered with the mafic and felsic granulites, and contains abundant cordierite. Some mafic granulite at this level forms thin, laterally persistent layers 5 cm thick, the origin of which is unknown. Small pods and lenses of sapphirine-bearing silica-undersaturated rocks are interlayered with cordierite-bearing granulites at a few localities. The upper part of the Strangways Metamorphic Complex is dominantly metasedimentary.

Windrim and McCulloch (1983) and Black and McCulloch (1984) obtained Sn-Nd ages of 2015+120 Ma and 1980+190 Ma, respectively, for the fractionation from the mantle of the primitive magmas which later crystallised as the volcanics of Division 1.

The first detected metamorphism of Division 1 occurred at about 1800 Ma (Iyer and others, 1976; Black and others, 1983) in the Central Province, and at about 1670 Ma in the Reynolds Range.

Division 2

Division 2 is the most extensive of the three Divisions, and makes up nearly all of the Northern and Southern Provinces, and the eastern third of the Central Province (Fig.1.1). In the Northern Province, it represents the flysch-like facies of the Arunta Inlier. In the Southern Province, the rocks appear to have a significant felsic volcanic component.

In the Northern Province, Division 2 comprises abundant aluminous and silicic metasediments, lesser calcareous rocks and a few mafic flows or sills. The most extensive unit is the strongly folded Lander Rock beds (Fig. 1.2), which crops out throughout the N and NW of the Arunta Inlier. In the Jervois region of **HUCKITTA**, a gneissic granitoid complex is overlain by schist and intercalated amphibolite and calc-silicate rock (the Bonya Schist; Fig. 1.2). [The names of 1:250 000 Sheet areas are indicated as **HUCKITTA** and are shown in Fig. 1.1] These rocks are intruded by granites metamorposed at 1800 Ma; consequently, Division 2 in the Jervois region must be this age or older. The rocks are separated from Division 1 to the S by granite, by areas of non-exposure in the centre and W, and by a major fault zone [the Delny-Mount, Sainthill Zone (Warren, 1978)] in the E (Fig. 1.1).

In the eastern part of the Central Province (Fig. 1.1), Division 2 is mainly aluminous sediments and minor mafic igneous rocks (the Harts Range Group) metamorphosed to amphibolite facies. Abundant quartzofeldspathic gneiss at the base of the sequence is a mylonitized granite (Shaw and others, 1985). In the Harts Range itself, the Harts Range Group overlies Division 1 unconformably (Fig. 1.2).

In the southern Province, E of Alice Springs, the bulk of Division 2 crops out in the Wigley, Narbib and Ankala Blocks where it is represented by compositionally layered, amphibolite-facies gneisses. Their stratigraphic position is unknown, but they are provisionally placed in Division 2 because they are of lower metamorphic grade than, and are overthrust from the N by, Division 1 along the Redbank and Harry Creek Deformed Zones (Marjoribanks & Black, 1974; Marjoribanks, 1975). The gneisses could equally well be the upper part of Division 1, or even a separate division between Divisions 1 and 2. The gneisses are mainly of granite to granodiorite composition forming uniform layers up to several tens of metres thick, which separate less abundant amphibolite, sillimanite gneiss and calc-silicate rock. Similar rocks (the Albarta Metamorphics) occur much farther E (Fig. 1.1). The origin of the granitoid gneisses is unknown; their uniformity of composition suggests they are metamorphosed felsic volcanic flows or sills (Offe & Shaw, 1983).

To sum up, Division 2 consists of immature terrigenous metasediments, calcareous metasediments, minor mafic igneous rocks and, in the S, gneisses of granitoid composition as well. The time of formation of the Division is not known; its first metamorphism occurred before 1750 Ma.

Division 3

Division 3 (Figs 1.1, 1.2), the least extensive of the three Divisions, is characterised by orthoquartzite, and represents the platform facies of the Arunta Inlier. The Division is best known in the Northern Province, where it is represented by the Reynolds Range Group (Stewart and others, 1980). This is a weakly metamorphosed shallow-marine quartzite-shale-carbonate sequence about 1800 m thick, and occupies gently plunging synforms resting with an angular unconformity on Division 2 (Lander Rock beds). The unconformity is best exposed along the NE flank of the Reynolds Range, though in the SE, the discordance is largely obliterated by increasing metamorphic grade. The Reynolds Range Group is intruded by, and is therefore older than, the Napperby Gneiss, which has given an imprecise age of 1600-1500 Ma (Stewart and others, 1980).

In the Central Province, Division 3 overlies Division 1, implying an unconformable relationship. A regional unconformity is evident in central **ALCOOTA** (Shaw & Warren 1975)], and in **MOUNT RENNIE**, where magnetic interpretation (Mutton & Shaw 1979) suggests Division 3 adjoins Division 1 (Fig. 1.1). In the Southern Province near Alice Springs (Fig. 1.1), Division 3 comprises a sequence of silicic and aluminous metasediments and a basal conglomerate nonconformably overlying orthogneiss of Division 2. Metamorphism of these rocks is dated in the adjoining **HERMANNSBERG** area at about 1600 Ma (Majoribanks & Black 1974). Between Alice Springs and Jay Creek, the metasediments are intruded by orthogneisses which may represent granitic sills (Offe & Shaw 1983).

In the small unmapped Arunta Inlier S of **ILLOGWA CREEK** (Fig.1.1), Leitch and others (1970) briefly described an unconformity between rocks which are assigned to Divisions 2 and 3 on the basis of their composition.

The Tectonic Provinces

The Arunta Inlier is divided into three tectonic provinces (Fig.1.1). These are separated by major faults and shear zones (inferred beneath areas of poor outcrop from geophysical features), where relationships are exposed, the Central Province is either faulted against the Northern Province or separated from it by granite, and is brought up along a major high-angle reverse fault against the Southern Province. The southern Province is the smallest of the three in area. Despite its complex history, the tectonic framework of the Arunta Inlier has remained remarkably constant. Narrow fundamental zones of weakness or faulting were established early, localized subsequent deformation, and divided the Inlier into three tectonic provinces. Each province has a fundamentally different stratigraphic, structural and metamorphic history (Figs 1.3).

The tectonic provinces are cut by the NW-trending Weldon Tectonic Zone and by several other oblique tectonic lineaments which are apparent in the gravity map of the region (Fig. 1.4). Major deformed zones and retrograde schist zones occur within and between the tectonic provinces.

Northern Tectonic Province

The Northern Province is a region of aluminous and silicic Division 2 sediments that were metamorphosed to generally low grade during the Strangways and Aileron Events. Volcanic and high-grade metamorphic rocks are subordinate. Lithological layering trends NW in the E of the Inlier, curving around to E and ENE trends in the centre and W [Fig. 1 of Stewart and others (1984)]. To the NW, the Province grades into low-grade metamorphosed greywacke, siltstone and mafic volcanics of The Granites-Tanami Province (Blake 1978).

Extensive granites intruding the Northern Province range from older rapakivi types and orthogneisses emplaced between 1750 and 1500 Ma to younger, commonly porphyritic granites and subvolcanic porphyries emplaced at 1500-1400 Ma.

Major faults in the Northern Province are parallel to foliation trends, and form an arc convex to the N. The S part of the Province underwent mid-Palaeozoic moderate to high-angle faulting accompanied by narrow zones of greenschist facies retrogression near the N margin of the Ngalia Basin (Wells 1972; Well & Moss 1983). Faults up to 100 km long in **MOUNT THEO, MOUNT PEAKE** and near Jervois (**HUCKITTA**) contain hydrothermal quartz \ fluorite, and have undergone repeated brecciation and quartz-filling. The faults cut late Proterozoic sediments in the Jervois area (Hill 1972).

Central Tectonic Province

Rocks in the Central Province (mainly assigned to Division 1)were metamorphosed at deeper crustal levels (to 30km)than those of the Northern Province during the Strangways Event at 1800-1750 Ma. Mafic and felsic meta-igneous rocks are inter-layered with and locally overlain by subordinate aluminous and calcareous metasediments. Thin sequences of Division 2 metasediments are locally overlain by quartzite and schist of Division 3. Multiple folding with widely varying axial plane traces is typical of the zone (Rickard & Shaw, 1972; Rickard, 1975; Shaw & Langworthy, 1984; Shaw and Rickard, 1985), resulting in complex interference patterns of lithological layering, which contrast with the more regular trends of the Northern Province. Small bodies of anatectic granite formed at the peak of metamorphism in the cores of last-formed folds. Metamorphism during the Aileron Event at 1700-1600 Ma occurred locally, adjacent to the boundary with the Southern Province. Retrograde schist zones containing kyanite and staurolite are numerous in the Central Province, and are localized along faults cutting Division 1 rocks. The schist zones may be contemporaneous with the 1050-900 Ma migmatitic Ormiston Event in the Southern Province (Shaw & Warren, 1975), They are probably the same age as the Harry Creek Deformed Zone, which locally separates the Central and Southern Provinces, and which was cut at 990 Ma by the Gum Tree Granite (Allen & Black, 1979). K-Ar-mica and ^{40}Ar-^{39}Ar ages suggest reactivation of the zones in the early Carboniferous.

Southern Tectonic Province

The Southern Province is characterized by quartzofeldspathic gneiss, tentatively assigned to Division 2, nonconformably overlain by silicic and aluminous metasediments assigned to Division 3. Division 1 rocks are absent. Granites are abundant and are commonly syntectonic or pre-tectonic (orthogneisses). Deformation in the central-W of the zone was accompanied by amphibolite facies metamorphism at about 1700-1600 Ma (Aileron Event, Chewings phase). This metamorphism, accompanied by syntectonic granite emplacement, probably extended to the E part of the zone.

The Southern Province is characterized by abundant dolerite dykes; the N-tending Stuart Dyke Swarm near Alice Springs has a Rb-Sr age of 897 ± 9 Ma. Dykes with other trends occur in the W. Small gabbro bodies in the Redbank Deformed Zone and NE of Alice Springs may be of the same age.

The final episode of deformation in the Southern Province was extensive thrust-faulting accompanied by greenschist facies retrogressive metamorphism along the S margin of the Arunta Inlier during the Alice Springs Orogeny at 400-300 Ma. Nappes with cores of basement formed at Ormiston Gorge (Marjoribanks, 1975, 1976), Alice Springs (Stewart, 1967; Clark in Wells, 1976), Arltunga (Forman, 1971; Stewart, 1971a; Shaw and others, 1971; Yar Khan, 1972), and farther E in the Oolera Fault Zone (Shaw and others, 1982). Yar Khan (1972) demonstrated that the eastern Arltunga nappes are thrust nappes. The faulting and metamorphism also affected the lower part of the Amadeus Basin sequence. Extensive gravity sliding took place in the Amadeus Basin as a result of uplift of the Arunta Inlier (Wells and others, 1970).

Boundaries between tectonic zones

In several places the three tectonic provinces are separated by major faults or fault zones (Fig 1.1). The Redbank Deformed Zone and its W extension together with the Harry Creek Deformed Zone and its E extension mark most of the boundary between the

Southern and Central Provinces. Much of the poorly exposed NW boundary between the Central and Northern Provinces places granulite against granite. East of Aileron, the boundary between the Central and Northern Provinces has a NE trend, and interpretation of aeromagnetic data (Wyatt, 1974; Shaw & Warren, 1975) suggests that the boundary is a lithological transition between Division 1 and 2 rocks. Farther to the E the boundary is marked by the Delny-Mount Sainthill Fault Zone. In the far E the boundary between the Central and Northern Provinces is not exposed, but it corresponds to the NE margin of the Caroline Gravity Ridge (Fig. 1.4).

An elongate E-W gravity high [Willowra Regional Gravity Ridge of Fraser and others, (1977); Fig. 1.4], similar to that corresponding to the Central Province, occurs within the N part of the Northern Province, but where basement is concealed by superficial cover. The NE margin of the ridge corresponds to the Lander Fault between the Arunta Inlier and Wiso Basin. Gravity modelling by Kennewell and others (1977) suggests that the Lander Fault may extend to the mantle. The gravity ridge may be caused by dense high-grade metamorphic rocks (Flavelle 1965; Whitworth 1970), possibly of Division 1.

Redbank and Harry Creek Deformed Zones

The Redbank Deformed Zone (Marjoribanks, 1975), which separates the Central and Southern Provinces NW of Alice Springs (Fig.1.1), is a narrow E-trending steeply N-dipping zone of complex plastic deformation. It consists of greenschist facies phyllonitic and mylonitic rocks, and finely foliated, highly strained amphibolite facies gneisses containing quartz and feldspar augen and porphyroblasts which are both discordant and concordant with the foliation. The deformed zone can be traced E towards the Arltunga Nappe Complex, where it is disrupted by granite intrusion and transected by the Harry Creek Deformed Zone. From correlation of fold styles and isotopic data, Marjoribanks and Black (1974) suggested that deformation started at about 1600 Ma and was overprinted by migmatization and granite emplacement at 1050 Ma. We consider that the zone is an overthrust, with the main movement parallel to the down-dip lineation.

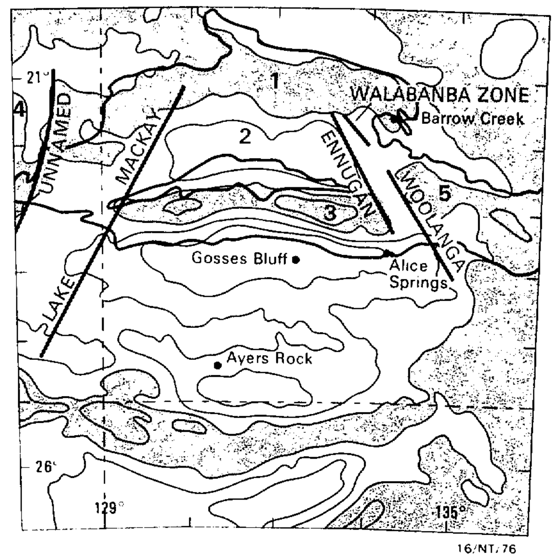


Figure 1.4 Contoured Bouger anomaly map of central Australia, showing the Arunta Inlier (outlined), regional gravity features and NE and NW trending gravity lineaments: 1. Willowra Regional Gravity Ridge; 2. Yuendumu Regional Gravity Low; 3. Papunya Regional Gravity Ridge; 4. Angas Regional Gravity High; 5. Caroline Gravity Ridge. Contour interval 40 mgals. Shaded areas indicate anomalies greater than -40 mgals.

Lithological and stratigraphic continuity across the Redbank Deformed Zone 50 km NNE of Alice Springs , and across the Illogwa Creek Schist Zone, which is the E-most portion of the Redbank Deformed Zone indicate that the Redbank Zone is not a deeply eroded cryptic collison zone in the sense of Burke and Dewey (1973) or Gibb and Thomas (1976). Instead, it may represent the reactivated S margin of the ensialic rift in which Division 1 volcanics accumulated.

Delny-Mount Sainthill Fault Zone

This 130 km long fault zone separates the Northern and Central Provinces in the NE Arunta Inlier (Fig. 1.1). It is vertical to steeply dipping with a down-dip lineation, and brings granulite in the S against amphibolite facies to the N, indicating S-block-up displacement, i.e. normal faulting (Shaw & Warren, 1975). The fault zone consists of discontinously exposed slices of deformed rock, commonly 0.5 km wide, separated by high-strain zones (Warren, 1978). In places the axis of the zone contain schistose and granular rocks showing retrogression along narrow discontinuous slivers, first to amphibolite facies and then to greenschist facies. The zone also contain mylonitic quartzite.

GEOPHYSICS

Regional gravity features in central Australia are dominated by three east-west trending highs and lows (Fig. 1.4) with extremely large gradients. These are terminated to the east by the Weldon Tectonic Zone (made up of two gravity lineaments, the Woolanga and Ennugan features) and to the west by the Lake Mackay Lineament. Forman and Shaw (1973) showed that regions of high metamorphic grade in central Australia correspond to Bouguer anomaly ridges, and suggested that major overthrust faults of late Proterozoic age sliced through crust into the mantle. The gravity anomalies to be expected on this model, which have been computed by Mathur (1974, 1976), compare quite well with the observed gravity though the computation takes into account neither surface density contrast across major crustal faults, nor the presence of dense granulite at the surface.

Anfiloff and Shaw (1973) explained the gravity features in central Australia by compositional heterogeneities in the upper crust alone although the density contrasts they used may be slightly too high. They recognized that the Bouguer anomaly gradients can be caused by juxta-position of dense mafic granulite against metasediment and granite. Anfiloff and Shaw (1973) and Mathur (1974, 1976) showed that this density contrast extends to a depth of at least 20 km, because the gravity ridge corresponding to the Central Tectonic Province (+45 mgals flanked by - 100 mgal troughs) is too large to be caused by near-surface rocks alone. Wellman (1978) showed that the density contrast could extend to the mantle. Barlow (1979), on the basis of a detailed gravity study of the Gosses Bluff area (Fig. 1.1), agreed with Langron (1962) that either there was little density contrast at the northern margin of the Amadeus Basin, or that the Basin sediments in that area continue under basement which is overthrust to the S. The Arunta Inlier is crossed by several major gravity lineaments oblique to the latitudinal structures. These are most apparent at the E and W ends of the Inlier (Fig. 1.4). The regional magnetic interpretation of the SW part of the Inlier (Mutton and Shaw 1979) revealed numerous NW-trending geophysical lineaments which may be major faults. Breaks in gravity and magnetic trends suggest that similar features may be more common than is shown in geological maps.

Woolanga Gravity Lineament

This lineament marks a decrease in Bouguer anomaly values at the E end of the Papunya Regional Gravity Ridge (Anfiloff & Shaw 1973; Shaw & Warren 1975; Fig. 1.4). A corresponding magnetic discontinuity is evident in the BMR **ALICE SPRINGS** total magnetic intensity map. The gravity lineament cannot be precisely located, but the magnetic discontinuity corresponds with two parallel faults which extend NW for 50 km near Woolanga Bore and SE for 150 km into **HALE RIVER**. The Woolanga Lineament roughly corresponds with the E limit of Division 1 mafic grnaulite. It is believed to be a deep crustal feature which acted as a conduit for mantle-derived magmas such as the Mud Tank Carbonatite (Black

& Gulson, 1978) and the Mordor Igneous Complex (Langworthy & Black, 1978). It also corresponds to a long narrow valley of Tertiary age which is prominent on Landsat imagery.

Ennugan Gravity Lineament

A second lineament 50 km to the W parallels the Woolanga Lineament, but differs from it in being a gravity gradient with a 30 mgal drop to the W. It marks the E end of the Yuendumum Regional Gravity Low, and to the NW ends abruptly against the Willowra Regional Gravity Ridge (Fig. 1.4). It persists to the SE as a sharp drop in gravity values near the E end of the Papunya Regional Gravity Ridge.

The gravity low E of the N part of the lineament corresponds to granite batholiths flanked by schist. The S segment of the lineament coincides with the E end of the belt of mafic, felsic and intermediate granulites; to the E are mainly granitic gneisses.

TECTONIC EVOLUTION (R.D. Shaw)

The most striking thing about the Arunta Inlier is that cycles of extension and convergence, resembling embryonic Wilson Cycles, appear to have occurred five times, at about 1800-1750, 1700-1600, 1500-1400, 1050-900, and 400-300 Ma. The first phase of extension produced a fundamental zone of weakness that nucleated subsequent mega-faulting and mega-shearing. The repeated thermal events suggests a long-lived and recurring thermal perturbation in the mantle underlying the Arunta region.The following is a model for the tectonic evolution of the Arunta region.

First cycle of extension and compression 1900-1780 Ma

The first episode of lithospheric extension-taphrogenesis-resulted in rifting (Fig. 1.5a), introduction of abundant tholeiitic magma from the asthenosphere, and eventually basin subsidence (Shaw, 1979). Underplating by insertion of a subcrustal wedge of asthenosphere (Fig. 1.5b) caused extensive metamorphism and granite production during the Strangways Event. Limited subduction of mantle lithosphere below the asthenospheric wedge (Ampferer or A-subduction of Kroner, 1979; Bally, 1981; Weber, 1981) dragged Division 1 rocks down to about 30 km (Fig. 12b), and also formed the flanking troughs wherein Division 2 accumulated. Subduction was possible because of the deepseated zone of weakness generated in the extensional phase, and resulted from delamination and sinking of large blocks of subcrustal lithosphere below the spreading wedge of partly molten and therefore less dense asthenosphere (Kroner, 1981; Fig. 1.5b).

From this time on, the upper and lower parts of the crust were detached from each other and behaved independently. The upper crust underwent thrusting and folding, whereas the lower crust below the Division 2 troughs thickened as a result of shortening induced by the subduction. Heat from the mantle was trapped in and below the thickening pile of sediments (cf. Schruilling, 1972a, 1972b; West & Mareshal, 1979), and produced granite masses and high-grade regional metamorphism peaking at about 1800 Ma, after the folding (Fig. 1.5c).

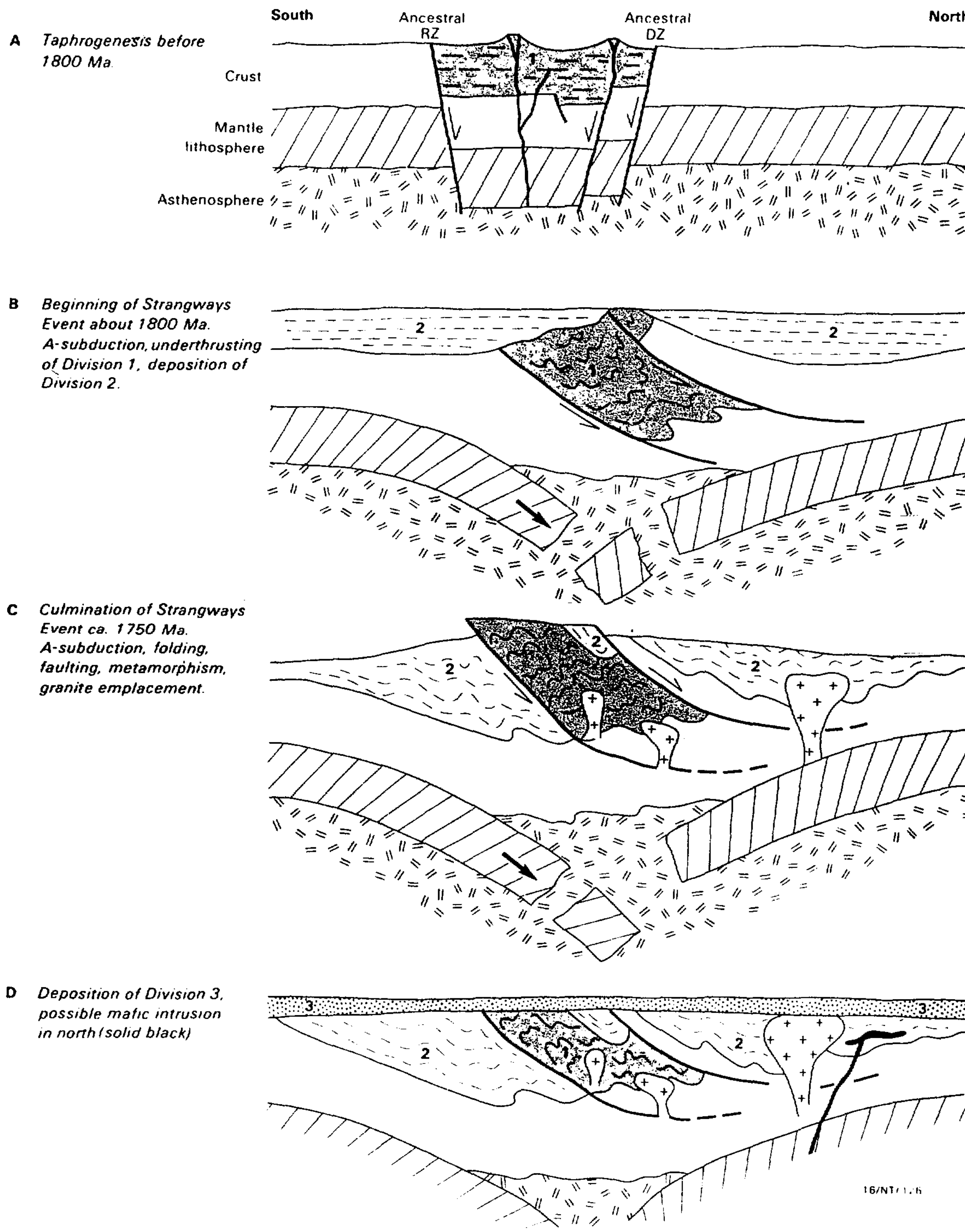


Figure 1.5(a)-(d) Diagrammatic evolution of Arunta Inlier. Numerals 1,2 & 3 refer to Divisions. RZ Redbank Deformed Zone, DZ Delny-Mount Sainthill Fault Zone.

Second cycle of extension and compression 1700-1650 Ma

The second cycle of extension and compression began with uplift and erosion of Divisions 1 and 2 as compression relaxed, and was succeeded by deposition of Division 3 and possibly by emplacement of mafic magma in the Northern Province (Fig. 1.5d). Discordance between Divisions 1 and 3 indicates that uplift of the Central Province indicates that uplift of the Central Province was substantial. The ensuing compressional phase (Fig. 1.5e) caused folding amd metamorphism during the Aileron Event at about 1700-1600 Ma, and formed the NW-trending Weldon Zone. The mafic rock in the Northern Province was metamorphosed to mafic granulite at about 1655 Ma. Tectonism was of smaller magnitude than that which accompanied the first cycle.

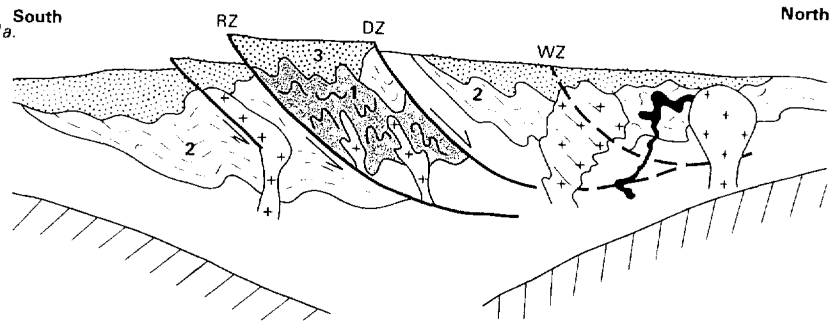
The zone of weakness produced by initial rifting (Fig.1.5a) and subsequent convergences (Fig. 1.5b, 1.5c) along the Central Tectonic Province was reactivated during the second cycle, and the Southern Province was thrust below the Central Province (Fig. 1.5e), resulting in the N-dipping schistosity characteristic of the Chewings phase of deformation.

Subsequent cycles of extension and compression

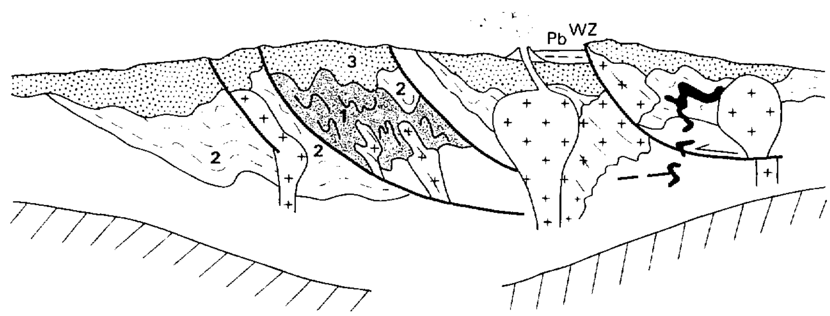
By the end of the second tectonic cycle, the crust was strong enough to resist penetration by the asthenosphere, and buoyant enough to make subduction difficult. From this time on, mafic magma rarely penetrated the crust, and granite production was meagre. Although major tectonic events occurred at about 1500-1400 (Fig. 1.5f) and 1050-900 Ma (Fig. 1.5g), only localised vertical movements occurred, because Division 3 rocks are preserved at widely scattered localities throughout the Arunta Inlier. The tectonic events may have been caused by heat build-up and hence weakening of tectonically thickened crust, or by continent-wide compression.

The overthrust faulting at 1050-900 Ma (Fig. 1.5g) may have originated in a zone of decoupling or detachment between lower ductile crust and upper brittle crust during a period of high heat flow (Armstrong & Dick, 1974). This would account for the lack of high-pressure granulites (greater than 10-12 kbar). It

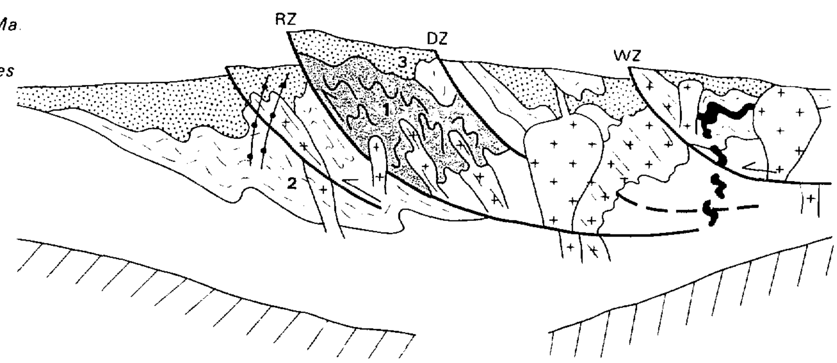
E *Aileron Event 1700-1600 Ma. Folding, shearing, metamorphism, faulting, granite emplacement.*



F *Anmatjira Event 1500-1400 Ma. Felsic volcanism, granite emplacement, faulting along Weldon Zone.*



G *Ormiston Event 1050-900 Ma. Folding, metamorphism, migmatisation, dolerite dykes in Southern province, small granites, deformation along Weldon Zone.*



H *Alice Springs Orogeny 400-300 Ma. Thrust-faulting, nappe formation, retrogressive metamorphism.*

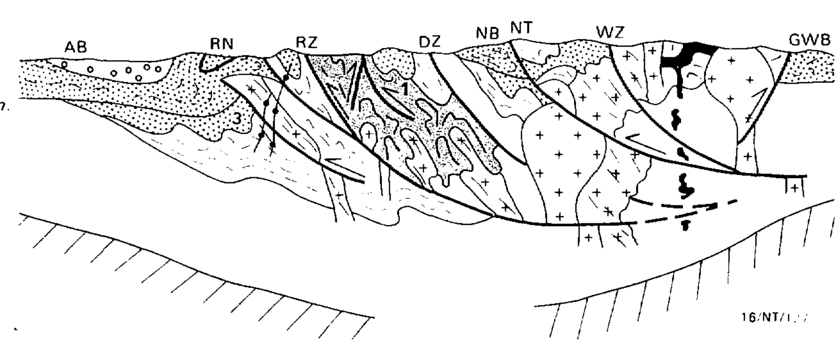


Figure 1.5(e)-(h) Diagrammatic evolution of the Arunta Inlier continued. AB Amadeus Basin, GWB Georgina and Wiso Basins, NB Ngalia Basin, NT Napperby Thrust, Pb Patmungala Beds, RN Razorback Nappe, WZ Weldon Tectonic Zone.

would also explain the magnitude of the Bouguer anomalies in the Central Province, which, although large, are not large enough to allow dense mafic granulite exposed at the surface to continue below a depth of 20 km (Anfiloff & Shaw, 1973; Mathur, 1976). A low-angle overthrust or decollement horizon at the base of the upper crust could have as its counterpart a shortened and thickened bulge in a lower crust, thereby causing a mass deficiency there. This would explain the large negative gravity anomalies in central Australia, and also reduce the extensive departure from isostatic equilibrium and the large crustal strengths implied by the models of Anfiloff and Shaw (1973) and Mathur (1976).

Latest cycle of extension and compression: development of Amadeus and Ngalia Basins

The evolution of the Amadeua and Ngalia Basins and their subsequent deformation during the Alice Spring Orogeny (Fig. 1.5h) made up the most recent cycle of extension and compression in central Australia. In the Arunta and Musgrave Inliers, mafic dyke intrusion preceded deposition, but the absence of a positve gravity anomaly associated with the Amadaus or Ngalia Basins negates the possibility of substantial extension, crustal thinning and deep-seated mafic upwelling as the cause of subsidence.

Deposition of the youngest sediments (Devonian) in the N Amadeus Basin , and deformation of the Amadeus and Ngalia Basins, were strongly controlled by the tectonic framework of the underlying Arunta basement.The main controlling structures were the latitudinal deformed zones (Redbank, Harry Creek, Oolera) which gave rise to the nappe complexes, and the Weldon Zone with its family of thrust faults splaying off to the W [one of which became the overthrust N margin of the Ngalia Basin (Fig. 1.5h)]. The deformed zones steepen in the root zones of the nappe complexes, but we suggest that at greater depth they may flatten and merge with the zone of detachment between upper and lower crust.

IGNEOUS ROCKS IN THE ARUNTA INLIER

Rocks of igneous origin, both mafic and felsic but not intermediate, make up a substantial proportion of the exposed Arunta Inlier. Nearly all igneous rocks are metamorphosed; the only exceptions being the young bodies, including the peralkaline Mordor Complex (circa 1200 Ma, Langworthy & Black, 1978), the Gum Tree Granite (1000 Ma, Allen & Black, 1979), the Stuart Dyke Swarm (897 Ma Black & others, 1980) and the Mud Tank Carbonatite (730 Ma, Black & Gulson, 1978). Age determinations on units older than these record either metamorphism or deformation. Time relationships (as summarised below) have been deduced from field relationships. The felsic meta-volcanics and granites can also be placed in a tentative time-framework using the limited amount of geochemical data available and analogies with the better-controlled studies from the Mount Isa Inlier (Wyborn & Page, 1983, Wyborn, in preparation).

Geochemical studies (whole rock) from the Arunta Inlier fall into two classes: broad brush surveys linked to regional mapping (BMR-NTGS) and detailed surveys in small areas (students from Queensland, ANU and Adelaide). A BMR survey in progress (1984-5) has been designed to improve the regional data and provide more detail in the Jervois and Reynolds Range districts. Some of the data from the regional surveys is available in reports (Shaw & others, 1979; Stewart & others, 1980; Mutton & others, 1983; Glikson, 1984).

The time-chemical framework developed in the Mount Isa Inlier can be used in the Arunta. It reveals a complex igneous evolution before metamorphism, but fits quite well with field observations. The following summary of igneous activity (from the oldest to the tyoungest) is based on available critera:-

1. Early gabbro-anorthosite complexes. There are three gabbro-anorthosite complexes in the Arunta Inlier (Fig. 2.1). These are

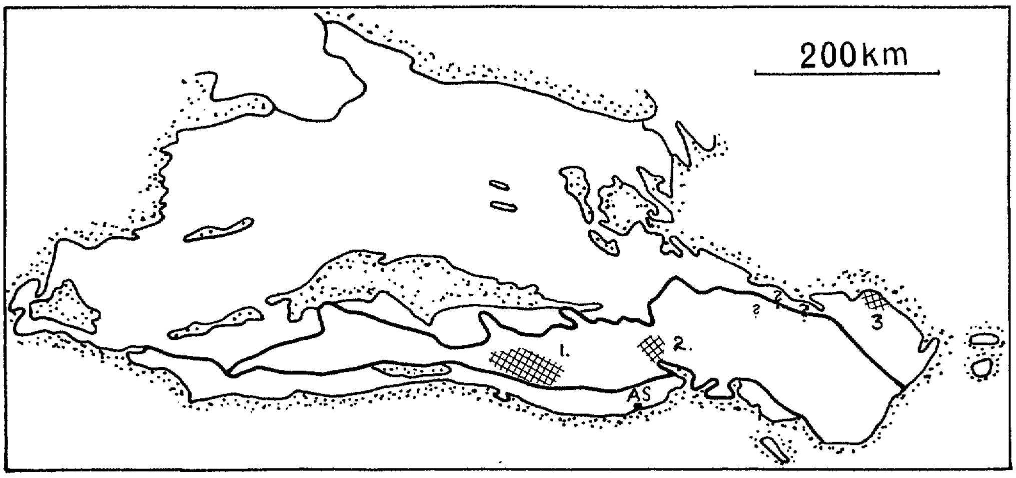


Figure 2.1 Distribution of early gabbro-anorthosite complexes : 1. Mount Hay Complex, 2. Harry Anorthositic Gabbro, 3. Attuttra Metagabbro.

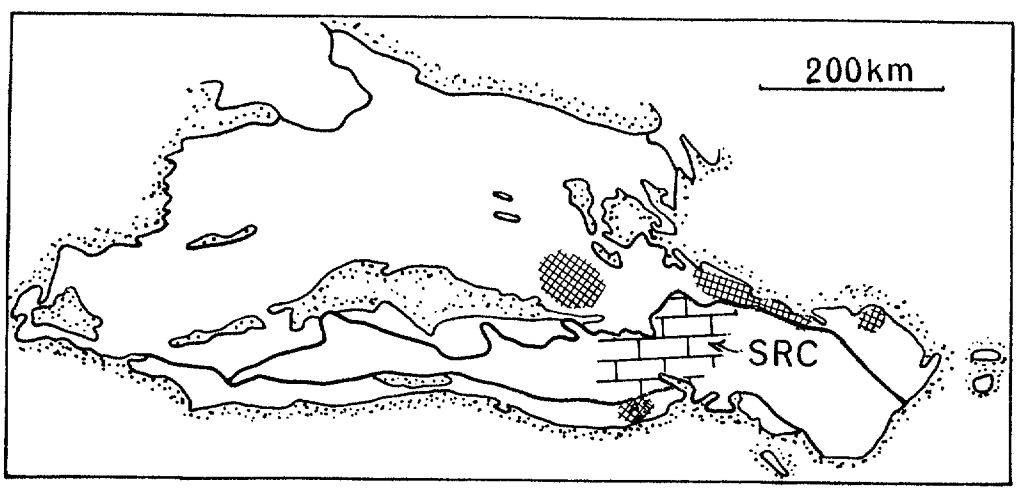


Figure 2.2 Distribution of felsic igneous rocks of the Kalkadoon-Ewen-Leichhardt association in central Australia. Granites are indicated by fine cross hatchering, metavolcanics of the Strangways Metamorphic Complex (SRC) by brick pattern.

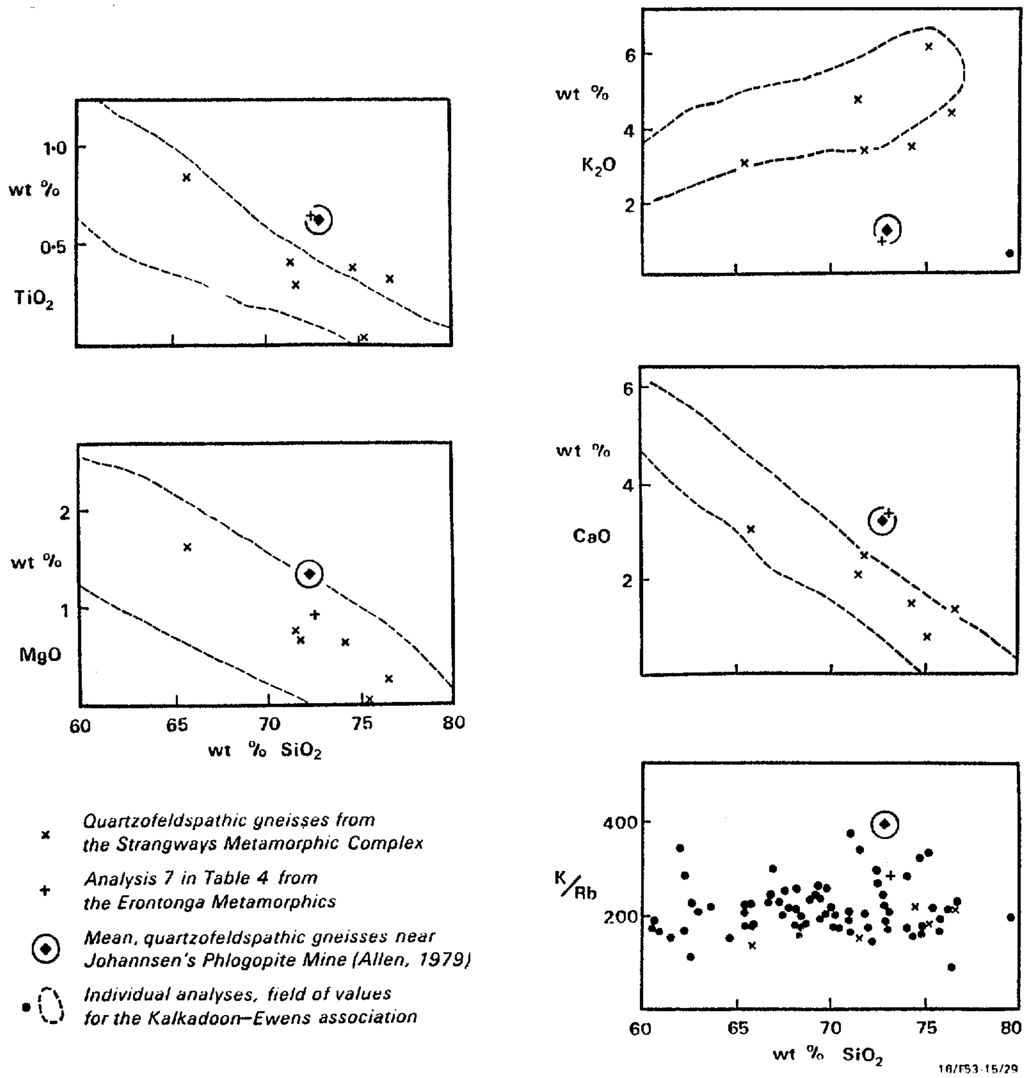


Figure 2.3 Harker variation diagrams showing the chemical 'fit' of the quartzofeldspathic gneisses (metavolcanics) of the Strangways metamorphic Complex with trends for the Kalkadon-Ewen-Leichhardt association in the Mount Isa Region (from Warren & Shaw, in preparation).

the Mount Hay complex (Glikson, 1983, this Record), The Harry Anorthositic Gabbro (Allen, 1979a, Shaw & others, 1979), and the Attutra metagabbro (Shaw & others, 1984b). Smaller and/or similar bodies may occur in the northeastern Arunta. These early gabbro-anorthosite complexes are very similar to the McIntosh Gabbro (Panton Sill) in the Halls Creek Province (Hamlyn, 1980).

The lower part of the Strangways metamorphic Complex is predominantly mafic, though it may be extrusive.

2. Felsic to bimodal igneous activity of the Kalkadon-Ewen-Leichhardt Association. Felsic rosks with the chemical signature of the Kalkadoon-Ewen-Leichhardt Association, first recognised in the Mount Isa Inlier (Wyborn & Page, 1983) are widely distributed in the Arunta Inlier (Fig. 2.2). In the northeast there are both early, strongly deformed granites (Dneiper, Copia, Crooked Hole) and later, metamorposed but relatively undeformed granites (Jervois, Marshall, unnamed units). Both types have K/Rb ratios in the range 150-200, low Nb, Y and Th. Preliminary data also indicates that some of the granites in the northwest Arunta belong to the association (Possum Creek, Boothby, part of the Napperby). Indications are that some of the felsic gneiss (strongly deformed granite or meta-volcanics) in the southern zone near Alice Springs are also part of the Association. In the central zone the felsic rocks in units of the Strangways Metamorphic Complex have been interpreted as meta-volcanics of the Association (Warren & Shaw, in preparation, see Fig. 2.3), but the felsic rocks of the Erontonga Metamorphics are demonstratably not part of the Association and may be older basement.

Late granites (Fig. 2.4) Granites with low K/Rb ratios, enriched in K_2O, Rb, Nb, Th and incompatible elements are widely distributed across the northern Arunta. A convenient subdivision is (a) large feldspar granites, (b) leucogranites, and (c) 'A' type granites. The large-felspar granites include the Mount Swan (NE Arunta) and many of the granites in the NW Arunta. The leucogranites are confined to the extreme eastern and northeastern Arunta. Small 'A' type bodies occur in the Jervois

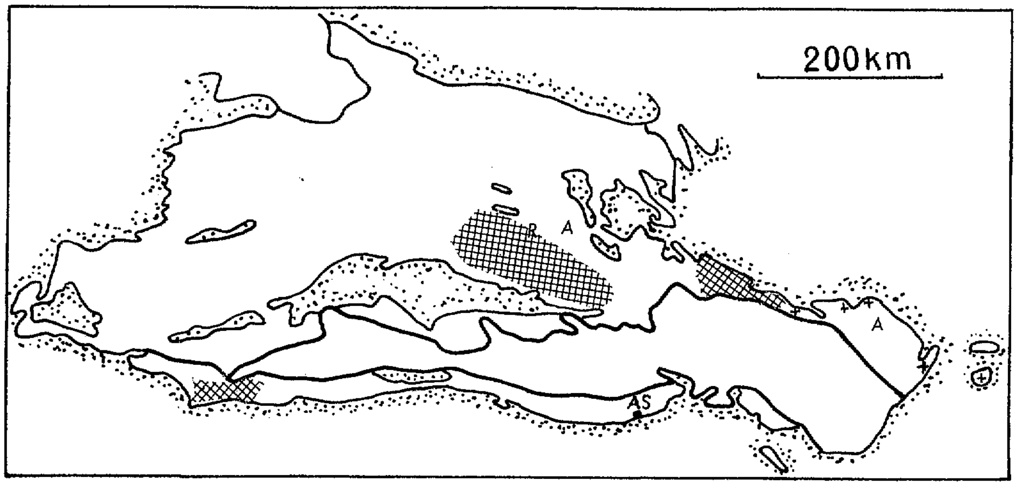


Figure 2.4 Distribution of late granites: + leucogranites, A 'A'-type granites, R rapakivi granites.

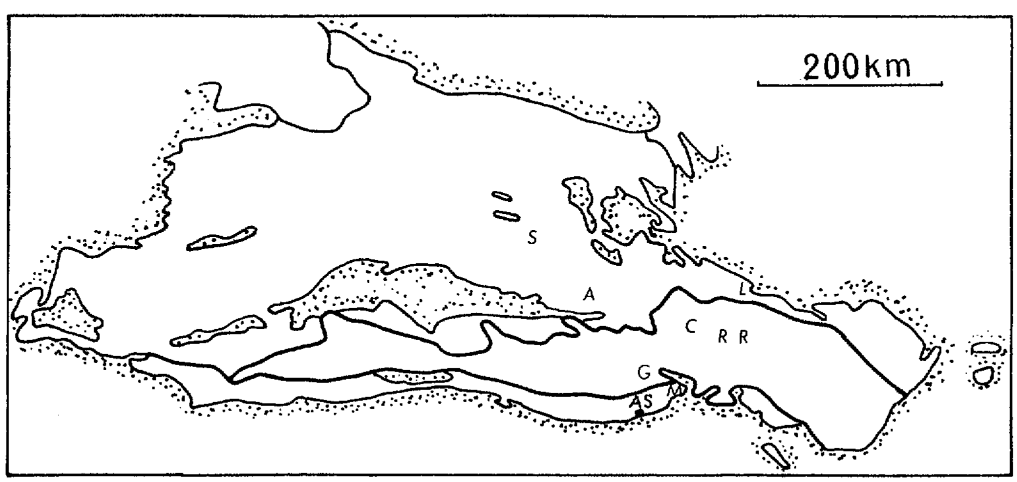


Figure 2.5 Late mafic intrusions, alkaline intrusions and granite: S metadolerite dykes in the Reynolds Range, A plugs of metanorite near Aileron, L Illappa metadolerite dykes, RR Riddock Amphibolite, C Mud Tank Carbonatite, M Mordor Complex, G Gumtree Granite.

district and larger bodies (Aloolya) in the NW Arunta where there are small tin and tungsten deposits.

In the central zone the Queenie Flat, Bruna, Inkamulla and Huckitta bodies, all intrusive into the Harts Range Group, belong (on available chemistry) to the suite of late granites. In the southern zone the only late granites so far recgnised are in the extreme west, sampled by Mutton & others (1983).

4. Rapakivi granites Granites with rapakivi texture occur in the northwest Arunta (Fig. 2.4) (Anmajira, Harverson, Yaningidjara, Mount Airy). These contain rimmed feldspars, and the Haverson also has blue quartz. Part of the Alice Springs Granite, east of the Old Telegraph Station, is a rapakivi granite, with large pink K feldspars rimmed by white plagioclase.

Late mafic intrusions (Fig. 2.5) Plugs of coarse grained meta-norite intrude the northern Arunta. Larger bodies intrude Division units in the Harts Range; the Riddock Amphibolite in the Harts Range Group may include both intrusive and extrusive units.

There are two areas with pre-metamorphic dykes in the northeastern and northwestern Arunta. The Illappa Dykes (NE Arunta) are fine-grained low calcium meta-dolerites.

6. Pegmatites The spectacular zoned pegmatites that are a major feature of the Harts Range region were formerly mined for muscovite (Joklik, 1955), and are still being prospected for mineral specimens. There is uncertainity about the age of these pegmatites, which may be as young as mid Palaeozoic (Alice Springs Orogeny). Pegmatites are also extensively developed in the northern Arunta, and here they formed circa 1680 Ma (Black, 1980) at about the same time as the metamorphism in the northwest Arunta.

METAMORPHIC EVOLUTION (R.G.Warren)

The metamorphic evolution of rocks from the Arunta Inlier follows a well defined anticlockwise PTt path (Fig. 3.1), the major features of which are summarised below. Such PPt paths have been reported from other Precambrian terrains; notably Enderby Land (Ellis, 1980; Sandiford, 1985), Broken Hill (Hobbs & others, 1984), and Namaqualand (Waters, 1984). They are in complete contrast to the Alpine or collision zone PTt paths discussed by England & Richardson (1977) and Thompson (1982); they require high heat flow and rapid burial without consequent isostatic imbalance.

Available age determinations indicate that metamorphism, reaching granulite grade in the central zone and amphibolite grade in the NE Arunta (Jervois district) occured circa 1800 Ma; granulite metamorphism in the Reynolds Range has been dated at 1680 Ma (Black & others, 1984). If these ages have been interpreted correctly, then there were two separate influxes of heat into the Arunta Inlier. Episodes of retrogression have been dated at 1680, 1450, 1000 and 400-300 Ma.

The earliest metamorphic stage throughout the Arunta Inlier is everywhere of the high-T, low-P type, though it ranges from incipient greenschist to granulite facies. The highest pressure area (probably 9-10 kbars) is in the Oonagalabi inlier in the Harts Range. The high grade metamorphism occured during or after the waning of deformation. Granulite fabrics are isotropic; in lower grade rocks a distinct preferred fabric may be present, defined by mineral orientation.

Petrographic textures indicate downwarping of the rocks in several parts of the Arunta took place at or near peak temperatures. Evidence for this includes (a) Pseudomorphs of sillimanite after andalusite in the assemblage Cd-Kf-AS-Q (several localities in the Reynolds Range); (b) Garnet including needles of sillimanite in meta-pelites (widespread); (c) coarse orthopyroxene-sillimanite in cordierite (Mount Pfitzner area);

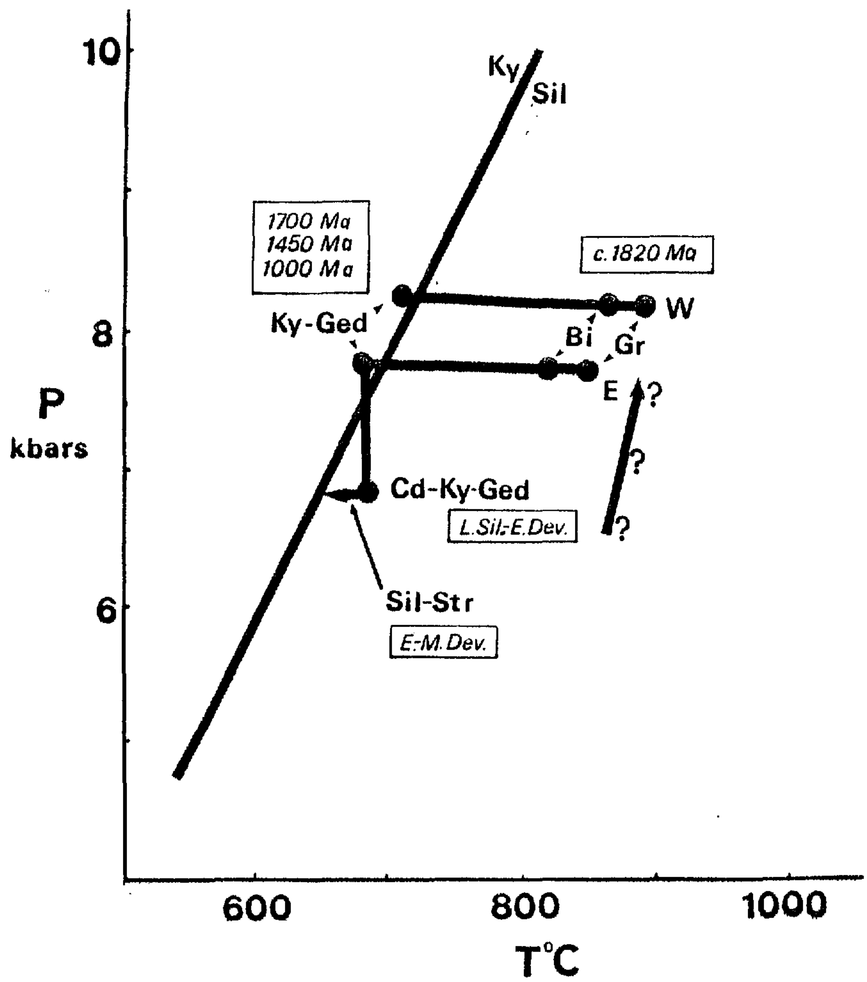


Figure 3.1 PTt path for granulites in the northern Strangways Range: W western Strangways Range, E Edwards Creek Prospect. ??? Probable early downwarping at high temperatures, Gr granulite stage, Bi early, high temperature pervasive hydration, Ky-Ged late, localised hydration, Cd-Ky-Ged first uplift stage, Sil-Str second stage of isobaric cooling. Possible ages of the metamorphic stages are as indicated (after Warren, 1983).

and (d) symplectites of spinel-orthopyroxene in the presence of cordierite (silica-undersaturated rocks with retrograde sapphirine in the Strangways Range).

Granulite metamorphism was facilitated by partition of hydrous fluids into partial melts, which generally remained in-situ, as migmatites. With cooling, the partial melts froze out, releasing the hydrous fluids into the erstwhile dry granulites so that there is extensive overprinting of orthopyroxene-K feldspar assemblages by biotite-bearing assemblages and late hornblende in mafic granulites.

The indicators of the period of near-isobaric cooling that followed the high-T stage are subtle. A widespread phenomenon is the formation of thin crusts of garnet in clinopyroxene-bearing calc-silicate rocks through the ex-solution of Ca Tschermak's molecule and Ca ferri-Tschermak's molecule from the clinopyroxene. In cordierite from the higher pressure areas, alteration along grain boundaries to fine grained orthopyroxene-sillimanite is common (also symplectites of orthopyroxene-sillimanite at cordierite-sapphirine grain boundaries); in lower pressure areas biotite-aluminosilicate has formed at cordierite grain boundaries in the presence of K feldspar. Perthite and anti-perthite occur in higher grade areas. Formation of late garnet in two-pyroxene granulites could be interpreted as yet another cooling feature, but as the localities where this occurs are invariably close to major deformation zones, it may have required deformation to nucleate the garnet.

Once cooling was complete (normal heat-flow conditions) most of the rocks in the Arunta Inlier remained more-or-less the same; but the Inlier is dissected by a network of major and minor shear zones which show a clear history of hydration and re-activation. In low grade areas, these are filled by quartz veins; in the high grade areas, they are wide zones hydrous schistose rocks, overprinted by mylonites. Petrographic studies show the earliest hydrous assemblages formed at substantialy the same pressure as adjacent un-retrogressed assemblages but much lower temperatures. Thus in higher pressure areas the prograde assemblages contain sillimanite, the retrogressive assemblages contain kyanite. In the Reynolds Range, where rotation of blocks has exposed continuous sections from higher to lower pressure, zones can be delineated by (a) prograde sillimanite and retrograde kyanite, (b) prograde and retrograde sillimanite, (c) prograde sillimanite and retrograde andalusite, and (d) prograde and retrograde andalusite. Study of the rocks in the retrograde zones also provides a record of progressive uplift and unroofing in stages with superimposed lower pressure assemblages, high level mylonites and quartz veins (commonly subsequently deformed).

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PART 2 **THE GEOLOGICAL LOCALITIES**

Proposed itinerary:

August	14	Arrive Alice Springs
	15-16	Mount Hay-Mount Chappel-Redbank
	17-18	Northern Strangways Range
	19-20	Harts Range
	21	Return Alice Springs via Bitter Springs Gorge, inspect outcrops near Stuart Highway

The Mt Hay-Mt Chapple-Redbank Hill-Mt Zeil granulite gneiss belt and the Redbank-Mt Zeil trust zone, southwestern Arunta Block, central Australia.

A.Y. Glikson

(1) Excursion notes

The southwestern and western parts of the Arunta Block consist of major northward tilted blocks separated by major thrust faults - the Anmatjira, Napperby, Redbank-Mt Zeil and Mt Sonder-Mt Razorback faults, which are associated with major Bouguer gravity anomalies. The Redbank-Mt Zeil thrust zone (RTZ) separates a granulite-facies suite to the north from a paragneiss-migmatite-orthogneiss suite to the south. It is marked by major morphological, radiometric and magnetic discontinuities, and consists of cataclastic gneiss, mylonite and phyllonite, including relict kernels of granulite, paragneiss and migmatite. The RTZ truncates all other structures and postdates all juxtaposed units. Major dynamothermal activity along the RTZ is thought to have taken place about 1.0-0.9 b.y. ago, as reflected by possibly reset Rb-Sr ages in porphyroblastic gneisses and migmatite to the north and south. Some Palaeozoic and younger movements are indicated by Devonian fan conglomerate (Brewer Conglomerate) and by morphological features along the RTZ fault scarp. Two alternative models for the RTZ are: (1) An antecedent of the RTZ existed between a northern igneous-dominated granulite block and a younger southern amphibolite facies paragneiss belt prior to about 1.6 b.y. ago; (2) Contemporaneous granulites and paragneisses representing different depth zones within a vertically zoned crust were juxtaposed by thrusting about 1.0 b.y. ago and later. The discrimination between such possibilities must await U-Pb and Sm-Nd isotopic studies.

The northern granulite block includes mafic granulites, anorthosites and interme diate restite-bearing to eutectic felsic derivatives. Mafic granulites include two pyroxene granulite (+/- amph, biot, il, mt) garnet-two pyroxene granulite, **Gnt-Opx-Plg granulite** & (minor) cpx-amph-plg (+/-meionite, sphene, calcite) calc granulites. The mafic granulites are extensively invaded by hosts of felsic to intermediate stringers, bands, lenses and metre-scale stocks of amphibolite to granulite facies orthogneiss. Large massifs of intermediate to felsic granulite and granulite facies gneiss include abundant enclaves of partly assimilated mafic granulite. Small bands and lenses of garnet-sillimanite gneiss occur throughout the terrain. A plutonic environment of emplacement of protoliths of the granulites is suggested by (1) the association of mafic granulites with layered anorthosite; (2) the occurrence of alkali element (K, Rb, Ba)-depleted, LIL-element (P, Zr, Ti, Nb, Y, Ce, La)-depleted, and siderophile element (Fe, V, Cu, Zn)-depleted high-Mg mafic granulites, and (3) the absence of clearly demonstrable supracrustal rocks. The high-Mg granulites overlap the field of mid-ocean ridge basalts (MORB) but have low strong field lithophile element (Ti, Zr, P, Y) levels and high large ion lithophile (LIL) element (Pb, Rb, Ba, Th) levels. The Qz-normative basic granulites have low Mg, Ni, Cr, and Cu, and high LIL and REE element levels as compared to MORB. As compared to chondritic compositions, light REE are relatively enriched in the basic granulites, i.e. $(Ce/Y)_N$ = 1.5-3.0, $(Ce/Nd)_N$ = about 1.5, $(Nd/Y)_N$ = 1.5-2.2. Ti/Zr ratios are clustered about or below chondritic. Marked differences occur between the Mt Hay basic granulites and the Mt Chapple basic and garnetiferous basic granulites. The latter are more strongly Qz-normative, have low Mg number (35-40), low CaO and Sr/Ba, low Ni and Cr, high total REE and $(Ce/Y)_N$ (2.5-5.0) and high V. These characteristics are particularly well pronounced in the garnetiferous granulites. The overall trend on the FAM ternary is tholeiitic. The wide compositional range of the intermediate to felsic units, from plagioclase dominated orthopyroxene and amphibole bearing dioritic-tonalitic types to K-feldspar and quartz rich biotite and garnet bearing types corresponds to increasing band size, in this order, thus reflecting progressive differentiation. The intermediate units are rich in restite and thus show generally high ferromagnesian element levels and low lithophile element levels when compared to average high-Ca and low-Ca granites. SI indices are in the range of 0.9-1.1, conforming to I-type (igneous-derived) magmas. The REE are moderately fractionated, i.e. $(Ce/Y)_N$ = over 5, $(Ce/Nd)_N$ = 1-2, $(Nd/Y)_N$ = over 3. Good regressions on Harker diagrams, i.e. CaO - SiO_2 (r = -0.85), and some trace-major element relations, i.e. Ni - Mg (r = 0.89) support melt-residue reactions between the felsic magmas and the basic granulites. A derivation of the felsic magmas by partial fusion of basic granulites, leaving residue to High-Mg granulite, and involving progressive magmatic fractionation upon upward migration, are tentatively suggested. This model, if supported by further isotopic studies, underlines the importance of deep crustal mafic layers as the source of granitic magmas in the Arunta Block. The origin of the basic protoliths may be interpreted in terms of infracrustal intrusion or subcrustal underplating of mantle derived materials. No confident criteria exist as yet to distinguish between these possibilities.

An indication of the minimum lateral and vertical dimensions of the granulite block is provided by the Papunya Bouguer anomaly (+50 mgl) which extends over an area in the order of 10 000 sq km and is inferred by gravity modelling to represent dense (> 2.9 gr/cm3) materials to a depth in the order of 20 km. Emplacement of the protoliths and granulite facies metamorphism registered by Rb-Sr isochron ages of ca 1.8 b.y. are interpreted as a continuous thermal phase during which extensive crustal anatexis and production of tonalitic to adamelitic magmas took place. The rise of these magmas to higher crustal levels resulted in the development of a geochemically zoned crustal section. Geothermometry and geobarometry conducted on selected microprobed mineral assemblages suggest PT values in the ranges of 600-900°C and 6.5-9.0 kb for two pyroxene granulites (using cpx-opx and CaTs(cpx)-An pairs), 680-770°C and 7.3-8.1 kb for garnet-two pyroxene granulites (using gnt-cpx, gnt-opx-plg-qz and gnt-cpx-plg-qz assemblages), 670°C and 5.9 kb for intermediate gneiss bands injected into mafic granulites (using gen-opx-plg-qz and gnt-biot assemblages), and 640°C and 6.4 kb for porphyroblastic orthogneisses from Redbank Hill. The results suggest a secularly declining geothermal regime, from 30-50°C/km during metamorphism of the mafic granulites to 30-40°C/km during or following the intrusion of the orthogneisses. The near isobaric cooling can be interpreted in terms of a convective heat regime genetically related to the emplacement of vast volumes of basic magma represented by the Mt Hay mafic granulite-anorthosite suite. Comparisons between the mafic granulite suite, felsic-intermediate granulite belts containing mafic enclaves, and high level granite-migmatite-supracrustal paragneiss associations, allow a reconstruction of a vertical early to middle proterozoic crustal section. It is possible that the Mt Hay suite is derived from a subcrustal mafic layer formed by extensive basaltic underplating. The existence in places of such a layer under the North Australia Precambrian Shield is suggested by seismic refraction data. Such a layer may have constituted an important source of the widespread anatectic I-type granites which invaded supracrustal sequences throughout this domain during 2.0-1.6 b.y. ago.

(2) Excursion Guide

For locality information refer to BMR Record 1984/22 and to the Glen Helen-Narwietooma-Anburla 1:100 000 Map available with the excursion guides.

August 15

The excursion leaves Alice Springs at 8 am, driving north along the Stuart Hwy for about 20 km, then taking the Yuendumu-Tanami road westward, Driving for about 70 km on the Burt Plain, the road follows the Redbank-Mt Zeil fault scarp which limits the paragneiss-orthogneiss-amphibolite terrain north of the Chewings Range and then follows north of the Mt Hay basic granulite ridge. About 70 km west of the Stuart Hwy, we take the track which follows Anburla creek immediately west of the creek bed, driving a couple of km until we reach the outcrops.

Stop A (930-1030 am)(133°12'E:23°27'S): Mt Hay basic massive/banded granulites, including Bi-Hb-Cp-Op-Plg assemblages, some Qz bearing, some sphene-bearing Cp-Plg assemblages, including felsic to intermediate neosome bands and lenses/tongues including Gnt-Bi-Kf-Plg-Qz assemblages. A distinct zone of anorthosites including Hb and Op-bearing types straddles the basic granulites, and further west interbanded granulite-anorthosite units are present. Rb-Sr isochron ages for the granulites were measured at 1768+/-20 my (Ri=0.7085) and 1728+/-65 my (Ri=0.706)(Black et al., 1983). For further petrographic/geochemical information refer to Record 84/22 pp. 15-18.

From Anburla Creek we proceed on the Tanami road for 22 km WNW, stopping at low hills crossed by the road.

Stop B (1100-1130 am)(133°02'E:23°19'30"S): Mt Chapple bimodal and basic-intermediate-felsic granulites including Mt Hay type basic granulites (Bi-Hb-Op-Cp-Plg) forming bands and lenses interspersed with Gnt-Bi-Kf-Plg-Qz neosome units ranging from thin bands to discrete bodies of gneiss. Basic granulites of the Mt Chapple range include Gnt-Op-Cp-Plg assemblages typically of high Fe/Mg and Rb/Sr and low Ca. The overall ratio of felsic to mafic granulites at Mt Chapple is higher than at Mt Hay, and the ridge includes large terrains of Opx-bearing felsic-intermediate charnockites and thin bands of Gnt-Sillimanite gneiss. For further detail refer to Record 84/22 pp. 18-22, 68-69.

From locality B drive about 32 km WNW on the Yuendumu-Tanami road reaching the intersection with the Papunya road. Take the Papunya road and drive about 22 km WSW reaching the entrance gate of the Narwietooma Homestead to the south, immediately north of Mt Chapple peak. From the Homestead we drive about 6 km along a fence WSW, reaching a station track which leads around Mt Chapple S and then SE toward bore no. 6, about 30 km from the intersection. From bore no. 6 we follow a fence for 3 km to the NE, reaching Redbank Hill outcrops.

Stop C (300-600 pm)(132°43'E:23°25'S): Redbank Hill glomeroblastic and porphyroblastic augen gneiss and entrained enclaves of basic to felsic granulites. The gneisses are in places strongly deformed, constituting possible (?) blastomylonites, and intruding a discrete oval body (1500X500 m) of Bi-Hb-Op-Cp-Plg granulite. The gneisses include Gnt-Hb-Bi-Plg-Kf-Qz assemblages and relic bands/lenses of Opx-bearing granulites. A Rb-Sr whole rock-K-feldspar isochron age of 893+/-97 my (Black et al., 1983) may represent reactivation/thermal effects associated with the Redbank-Mt Zeil thrust zone immediately to the south. For further information on Redbank Hill refer to Record 84/22 pp. 22-26, 70.

Overnight camping near bore no. 6.

August 16

Stop D (800-1200 am)(132°40'E:23°28'S): A section through the Redbank-Mt Zeil thrust zone (RTZ), about 4 km SW from bore no. 6. The section starts with outcrops of granulites, showing increasing cataclastic deformation southward, and is followed for about 2 km along a creek where classic waterfall exposures of flaser gneiss, mylonites and phyllonites will be examined. Relic bodies of granulites occur within the deformed zone, including a prominent dark hill immediately east of the creek. The hill consists of Bi-Hb-Op-Cp-Plg granulite enveloped by phyllonite and mylonite, including epidote-biotite-hornblende schists derived by retrogression of basic granulites. Proceeding south, orthogneisses and migmatites of the southern block are reached. For further information on the RTZ at this locality refer to Record 84/22 pp. 54-56.

Lunch at bore no. 6.
Proceed to the Strangeway Range via Narwietooma Homestead and Papunya and Tanami roads.

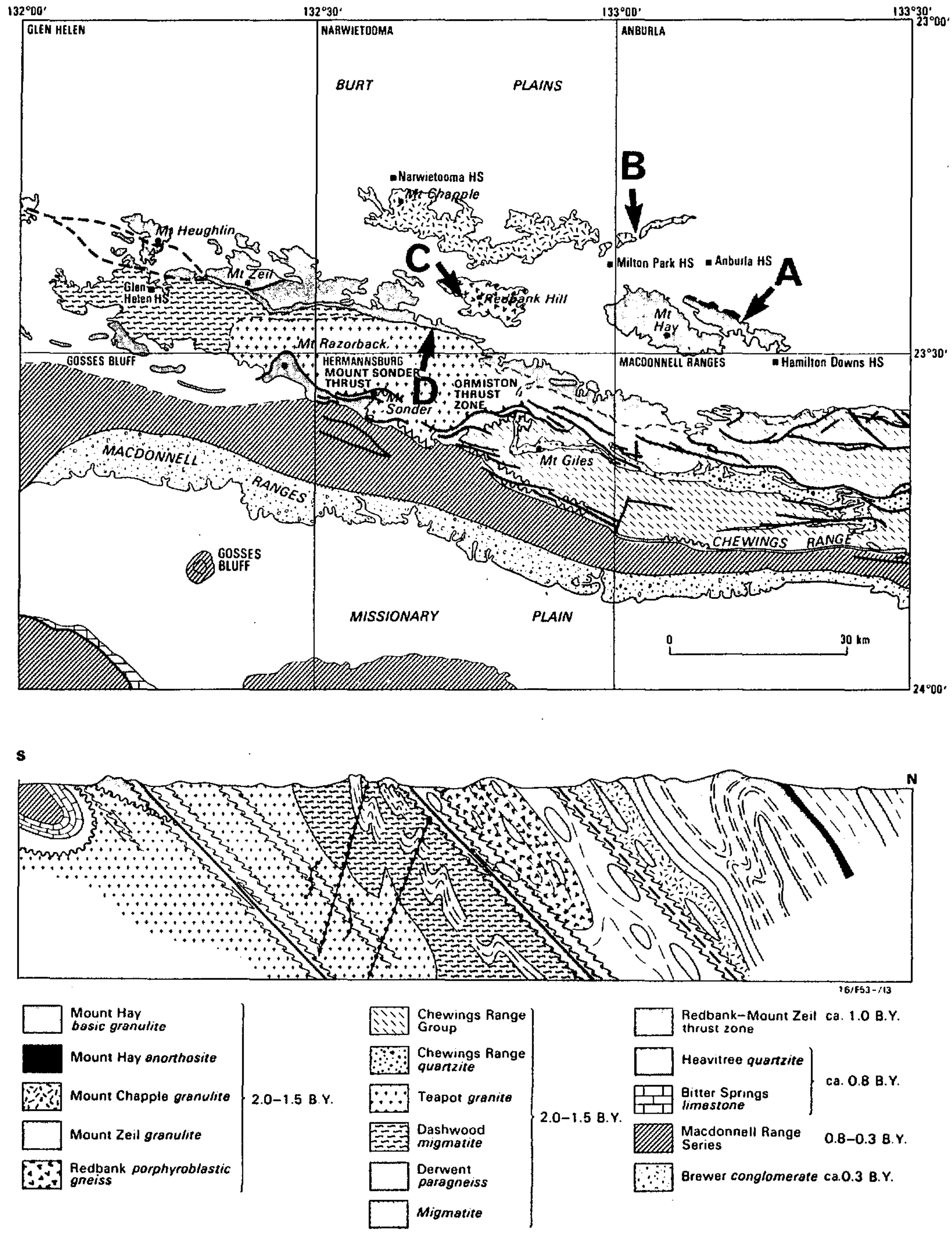

132°00'
132°30'
133°00'
133°30'
23°00'
23°30'
24°00'
GLEN HELEN
NARWIETOOMA
ANBURLA
BURT
PLAINS
Narwietooma HS
Mt Chapple
B
A
C
D
Milton Park HS
Anburla HS
Mt Heughlin
Mt Zeil
Glen Helen HS
Redbank Hill
Mt Hay
Mt Razorback
GOSSES BLUFF
HERMANNSBURG
MOUNT SONDER THRUST
Mt Sonder
ORMISTON THRUST ZONE
MACDONNELL RANGES
Hamilton Downs HS
Mt Giles
MACDONNELL RANGES
CHEWINGS RANGE
GOSSES BLUFF
MISSIONARY
PLAIN
0
30 km
S
N
16/F53-/13
Mount Hay basic granulite
Mount Hay anorthosite
Mount Chapple granulite
Mount Zeil granulite
Redbank porphyroblastic gneiss
2.0–1.5 B.Y.
Chewings Range Group
Chewings Range quartzite
Teapot granite
Dashwood migmatite
Derwent paragneiss
Migmatite
2.0–1.5 B.Y.
Redbank–Mount Zeil thrust zone
ca. 1.0 B.Y.
Heavitree quartzite
Bitter Springs limestone
ca. 0.8 B.Y.
Macdonnell Range Series
0.8–0.3 B.Y.
Brewer conglomerate
ca.0.3 B.Y.

Figure 4.1

LATERITES AND TERTIARY SEDIMENTS

Chemical weathering together with the deposition of thin fluviatile and laucastrine sediments from the late Mesozoic onwardshas played a major part in shaping the central Australian landscape north of the MacDonnell Ranges.

The Tertiary basins are probably fault controlled, but not necessarily fault bounded. The sediments infill a very irregular landsurface, similar to that in the present Strangways Range, reaching a maximum thickness close to 300 m in the south of the Burt Plain. The sedimentary basins are still evolving.

Several episodes of chemical deep weathering are shown in drill core from the sedimentary basins. However the most severe, which predates the sediments, probably began in the late Cretaceous and extended into the early Tertiary (dated as Maastrichtian-early Eocene by Idnurm & Senior, 1978). In this cycle up to 40 m of ferruginous laterite developed over crystalline rocks. This laterite has a tri-zonal form, with a lower bleached zone, an intermediate mottled zone and a ferruginous top. Exposures of the laterite are variable. In some areas the laterite forms mesas, with the ferruginous carapace as cap and the slopes in the mottled and bleached zones. Where the ferruginous zone has been eroded off, the less resistant lower zones form tiny hills a few metres high. Elsewhere the ferruginuos cap crops out as low rises within areas of Tertiary sediments where it is recognisable because of the dark red soil and iron pisolites that overlie it. Minor warping and erosion of the ferruginous profile predates Tertiary sedimentation.

A second period of deep weathering during the late Oligocene produced a siliceous weathering profile. Silcrete is not well developed in central Australia, but is important in western Queensland and northern South Australia. A still younger episode of silicification (probably still in progress in the north of the Arunta Inlier) has produced chalcedonic caps over laucastrine limestone in the Tertiary basins.

AREA SURROUNDING THE MOUNT MILTON SAPPHIRINE LENS

The Mount Milton sapphirine lens is about 1.5 km north of Mount Milton and 5 km southeast of New Bullock Bore in the southern rim of an amphitheatre of low hills. The lens is in the Yambah Granulite, part of the Strangways Metamorphic Complex (Division I). (Refer Figures 1.1, 4.1)

Most of the rocks in the area covered by Figure 4.1 are quartzofeldspathic gneisses. Mafic granulite occurs within the gneisses as folded, distorted and boudinaged layers; there are also areas of mainly mafic granulites. The outcrops include one thick unit of cordierite quartzite (with minor calc silicate rock and silica undersaturated rock) and a thin discontinuous layer of marble, calc silicate rock, and silica undersaturated rock. A small fault bounded block (labeled 3 on Figure 4.1) contains a suite of thinly layered rocks, including finely laminated mafic rock and a layer of cordierite quartzite about 1 metre thick.

The area is broken up by a network of faults and small shears. Most shears are poorly exposed features, occuring in stream valleys. No marker layers can be traced across the faults so that estimation of displacement are not possible.

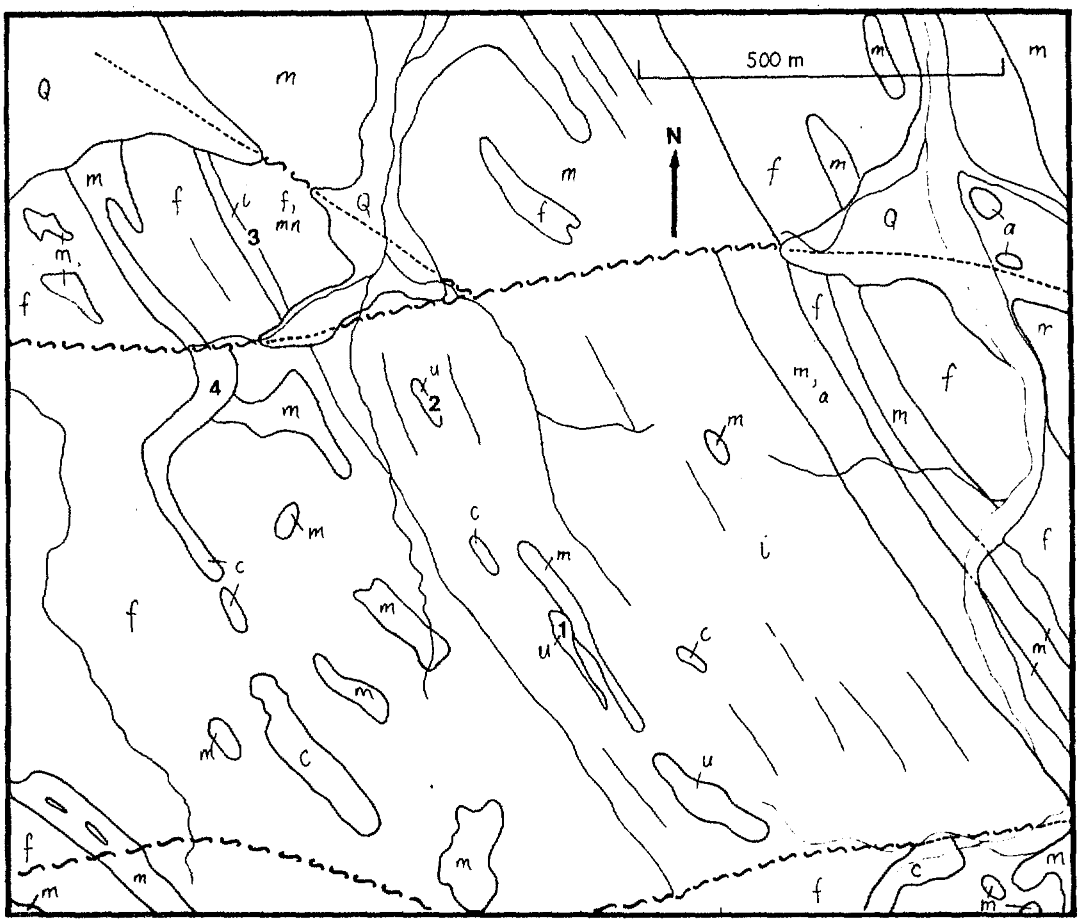
Quartzofeldspathic gneiss includes a range of textural types, all consisting of quartz, orthoclase and plagioclase with variable minor amounts of ferromagnesian minerals. Though biotite is the common ferromagnesian mineral, garnet and orthopyroxene are present in some outcrops. Migmatites are extensively developed in the more massive outcropc (to 30 percent in some exposures). The gneissic fabric is defined by concentration of the ferromagnesian minerals but biotite is not strongly oriented.

Mafic granulite consists of plagioclase and two pyroxenes with variable late hornblende and minor quartz and biotite. The more massive mafic granulite in the northern outcrops tends to be coarser grained and has a higher plagioclase content than the thinly layered bodies.

Calc silicate rocks occur as small lenses within the quartzofeldsathic gneisses and cordierite quartzite. These rocks range texturally from finely layered (generally the smallest bodies) to massive. Although there is considerable variation in mineralogy, the minerals they contain indicate they were originally dirty dolomites. The largest calc silicate unit can be traced for nearly a kilometre but it is discontinuous in outcrop. At the northern end it is conformable between quartzofeldspathic gneiss and cordierite quartzite. These outcrops have yielded assemblages of garnet-scapolite-wollastonite-calcite (high water activity). Massive marble associated with silica undersaturated rocks which occurs across a fault south of the cordierite quartzite body may be part of the same layer.

Cordierite quartzite forms the prominent ridge which contains the main saphirine lens. This ridge is divided into two by a deeply incised gully. East of the gully the outcrops are predominantly massive siliceous cordierite-bearing granofels. West of the gully the unit is more diverse: it includes garnet-cordierite quartzite and encloses lenses of mafic rock, calc silicate rock and several lenses of silica undersaturated rock. Irregularly shaped bodies of silica undersaturated rock are elongated parallel to the layering of the cordierite quartzite, but their margins against country rock may be locally discordant. These undersaturated rocks form tough, dark outcrops, which tend to be less well exposed than the surrounding quartzite. A feature of the undersaturated rocks is the existence within the lenses of small, chemically distinct, domains.

Assemblages within the silica undersaturated lenses are strongly dependant on bulk composition, particularly bulk Mg/Fe. The southern outcrops are highly magnesian, shown by the light colours of the minerals, including sky-blue sapphirine. The main sapphirine lens is less magnesian and sapphirine from these outcrops is inky blue-black. Spinel in the same rocks is black or green-black. There are also undersaturated rocks too iron-rich to stabilise sapphirine (spinel-cordierite-orthopyroxene assemblage) and one outcrop of garnet-spinel-orthopyroxene rock.



Q	*Quaternary*
c	*Calc-silicate rock*
i	*Cordierite quartzite*
u	*Silica-undersaturated rocks*
, m	*Mafic granulite*
a	*Amphibolite*
f	*Quartzofeldspathic gneiss*

1 The Mount Milton Sapphirine lens

2 Garnet-bearing undersaturated lens

3 Thin layer of cordierite quartzite

4 Calc-silicate lens containing Scapolite-Wollastonite-garnet-diopside assemblage

Figure 4·2 Detailed geological map of the area surrounding the Mount Milton Sapphirine lens

YAMBAH RETROGRADE SCHIST ZONE

The Yambah Retrograde Schist Zone is made up of two "fault" zones, intersecting at right angles in a wide valley south of Mount Strangways. The schist zones are each about 1 km wide, with diffuse margins grading into relately undeformed granulite of the Strangways Metamorphic Complex (Yambah Granulite).

The major rock type in the schist zones is muscovite-biotite-quartz schist, in places containing garnet, kyanite and/or staurolite porpyroblasts. In composition these rocks ressemble the adjacent quartzofeldspathic gneisses and are believed to have been formed from them. Within the muscovite schists there are pods of other rock types. These include mafic schists (cf the mafic granulites in the Granulite), two pods of chlorite-garnet schist with associated calc silicate rock, and one pod of gedrite-bearing schist.

Evidence for multiple deformation and polymetamorphism can be found in these outcrops. The schistose fabric of the rocks is in places complexly refolded. The aluminosilicate in the Granulite is sillimanite, rare bent needles of which may be found in the schists; but the important aluminosilicate in the schists is kyanite. The large blue blades of kyanite commonly have faces corroded and etched by fine white muscovite, as do the staurolite porpyroblasts.

Metamorphic segregation is an obvious feature of the schists, especialy those with large zoned knots of kyanite, biotite and quartz. Iyer (1974) reported that the "aluminous" schists have lower SiO_2 and higher Al_2O_3 than the quartzofeldspathic gneisses presumed to be their protoliths. Mobility of K_2O, at least in the final stages of the formation of the schists, seems very probable, given the widespread growth of late muscovite.

Iyer and others (1976) reported a Rb/Sr age of 1820±60 Ma, initial ratio .704 (corrected for revised decay constants) using a whole rock isochron on undeformed granulites to the southwest of the schist zone. The age of the Schist Zone itself is not known.

THE EDWARDS CREEK Cu-Pb-Zn PROSPECT

The Edwards Creek Prospect is situated in low hills on the northern edge of the Strangways Range, at 23° 01'S, 133° 01E. Outcrops containing copper, lead and zinc minerals are erratically distributed along the west limb and northern axial zone of an upright south-plunging synform (probable syncline), over a total strike length of nearly a kilometre (Fig 4.2).

The prospect and surrounding rocks are in a small fault block about 4 km east-west by 1.5 km north-south. This block is bounded on the north by the Wallaby Knob Schist Zone, a wide east-west striking zone of multiply-deformed gneiss and schist; on the south by a second wide schist zone; and on the east and west by north-northwest trending faults. Minor shears and faults subdivide the block internally. Several shears pass close to or displace the wall rocks of the prospect itself. The rocks in these minor shears, like those in the Wallaby Knob Schist Zone, bear the imprint of several episodes of deformation, hydration, and retrogression.

The well-exposed cordierite quartzite, which occurs adjacent to the Cu-Pb-Zn bearing rocks, persists well beyond the prospect, so that folds can be traced out over several square kilometres using this layer as a marker.

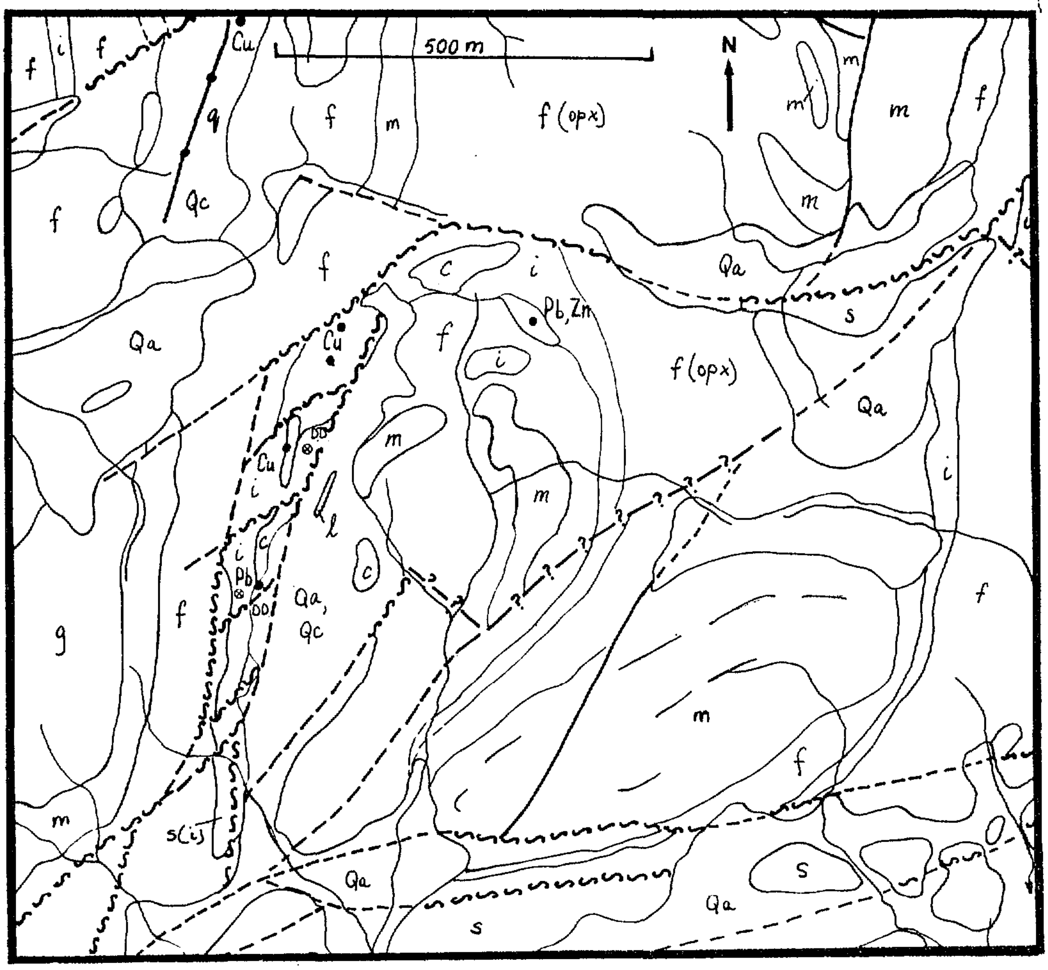
Away from the prospect, individual quartzofeldspathic and mafic units persist for considerable distances with little change in thickness, but close to the prospect, units thicken and thin markedly. Such variations in thickness are not related to the folds and so are possibly primary features.

Several small bodies of orthogneiss disrupt the well layered sequence and have margins which are localy discordant. Mesoscopic features (foliation, granoblastic fabric, myrmekite) show that the orthogneiss bodies predate the granulite stage and shared the metamorphic history of the layered sequence.

Rocks carying ore minerals crop out adjacent to the cordierite quartzite or form pods within it. Sulphides (galena, sphalerite and pyrite) occur in some of the marbles; secondary copper minerals occur in some of the gedrite rocks. The prominent siliceous ironstone, stained by secondary copper minerals, may be a true gossan or a ferruginous and siliceous cap over impure marble. Analysed samples show a wide range of metal values and ratios; from these data and field observations the Edwards Creek Prospect is best regarded as a zinc prospect in which copper and lead are partitioned into the gedrite rocks and marbles respectively.

The wall rocks of the prospect provide excellent material for the study of the superimposed retrogressions, but peak granulite assemblages are poorly preserved. Orthopyroxene-K feldspar assemblages occur in felsic rocks north of the prospect, and assemblages developed in the early hydration (including rare sapphirine) are present in undeformed rocks. Gedrite-bearing rocks are common along the shear zones, where retrogressed cordierite quartzite contains gedrite-staurolite-kyanite-quartz±cordierite assemblages. Silica undersaturated rocks include examples with corundum-staurolite-chlorite assemblages with staurolite of mg 40-42. Uplift following the gedrite-kyanite retrogression took the rocks back into the sillimanite field, before a second episode of shearing in the quartz-chlorite field.

The marbles are derived from impure dolomites, they contain calcite, dolomite, forsterite, humite, gahnite and sulphides. Forsterite retrogresses to a phyllosilicate, possibly antigorite. Coarse chlorite (to several centimetres) has been collected from weathered calcareous rocks just north of the ironstone, and nodules of chlorite to a centimetre are present in some marbles.



Qa	Soil, alluvium
Qc	Quartz scree
s	Schist
s(i)	Deformed cordierite quartzite
c	Marble, calc-silicate rock
i	Cordierite quartzite with undersaturated lenses
l	Finely layered rocks
g	Orthogneiss
f	Quartzofeldspathic gneiss
f(opx)	Felsic granulite
m	Mafic granulite and amphibolite

——	Fault
— —	Fault, inferred
- - - -	Fault, concealed
∿∿∿	Shear zone
—•—•— q	Quartz vein
• Cu	Mineral occurence Cu: Copper, Pb: Lead, Zn: Zinc
⊗ DD	Partly cored, angled percussion and Diamond drill hole

Figure 4·3 Geological map of the Edwards Creek Prospect

THE MUD TANK CARBONATITE

The Mud Tank Carbonatite, situated near the northern margin of the Strangways Range has been described by Crohn & Gellatly (1969), Gellatly, (1969) and Crohn & Moore (1984).

Three main outcrops of carbonatite are aligned in a northeastly direction over a distance of about 2 km; a fourth outcrop lies a furthur 2 km west-southwest (Fig. 4.2). Areomagnetic results (Tipper, 1969) suggest the outcrops represent separate lenticular to plug-like masses; Crohn & Moore (1984) interpreted the results of auger drilling as showing plug-like bodies of carbonate rock surrounded by poorly exposed phlogopite-carbonate rock. The carbonatite intrudes garnetiferous semi-pelitc biotite schist of the Arunta Inlier. Contacts are not exposed but have been intersected in drill core where they are somewhat sheared. There is no evidence of fenitization. Basic rocks (probable xenoliths) found as lenses within the carbonatite are amphibole-rich rocks that appear to show slight signs of metasomatism.

The only alkaline rocks associated with the carbonatite crop out as small bodies of albite pegmatite, generally less than 3 m long, within the carbonatite. Some contain traces of sodic pyroxene and amphibole.

Exposures of the carbonatite are deeply weathered. Dipping layering can be observed in some outcrops. Most of the material on the surface is a residual carapace of apatite, magnetite, and (now rare) zircon mixed with pisolites of ferruginous laterite. In drill core the carbonatite is mainly coarsely crystalline white carbonate rocks or biotite-carbonate rocks, with minor amounts of magnetite, pale yellow-green apatite, dark green chlorite, zircon, and zoned sodic amphibole. The carbonates are calcite and dolomite in near equal proportions. Ilmenite, pyrite, chalcopyrite, quartz, and pseudomorphs of possible columbite after pyrochlore are also present.

That this is an igneous carbonatite rather than a meta-sedimentary carbonate-rock is supported by the following:-

The assemblage apatite-magnetite-zircon is common in carbonatites but rare in metamorphosed limestones.

The shape and distribution of calcite inclusions in dolomite indicates exsolution from a single high temperature phase.

The zonal distribution of apatite and magnetite in the marginal parts of the dolomite grains suggests magmatic crystallization.

The size of magnetite crystals (up to 10 cm,or more) is unknown in metamorphic limestones.

Some of the phlogopite shows reverse pleochroism with maximum absorption normal to (001).

Trace elment concentrations are comparable with those from other carbonatites especially those low in niobium:-

Nb	20-450 ppm
Ba	300-1000 ppm
Sr	800-1500 ppm
Ti	200-10 000 ppm
La	100-7000 ppm
Y	80-200 ppm

Black & Gulson (1978) obtained an age of 730 Ma using U-Pb-zircon and Rb/Sr total rock methods.

Black, L.P. & Gulson, B.L., 1978. The age of the Mud Tank Carbonatite, Strangways Range, Northern Territory. BMR Journal of Australian Geology and Geophysics 3(3), 227--232.

Crohn, P.W. & Gellatly, D.C., 1969. Probable carbonatites in the Strangways Range area, central Australia. Australian Journal of Science 31, 335-336.

Crohn, P.W. & Moore, D.H., 1984. The Mud Tank Carbonatite, Strangways Range, central Australia. BMR Journal of Australian Geology and Geophysics 9(1), 13-18.

Gellatly, D.C., 1969. Probable carbonatites in the Strangways Range area, Alice Springs 1:250 000 Sheet area, SF 53/14: Petrography and Geochemistry. Bureau of Mineral Resources Australia, Record 1969/77.

Tipper, D.B., 1969. Strangways Range detailed aeromagnetic survey, Northern Teritory. Bureau of Mineral Resources, Australia, Report 136.

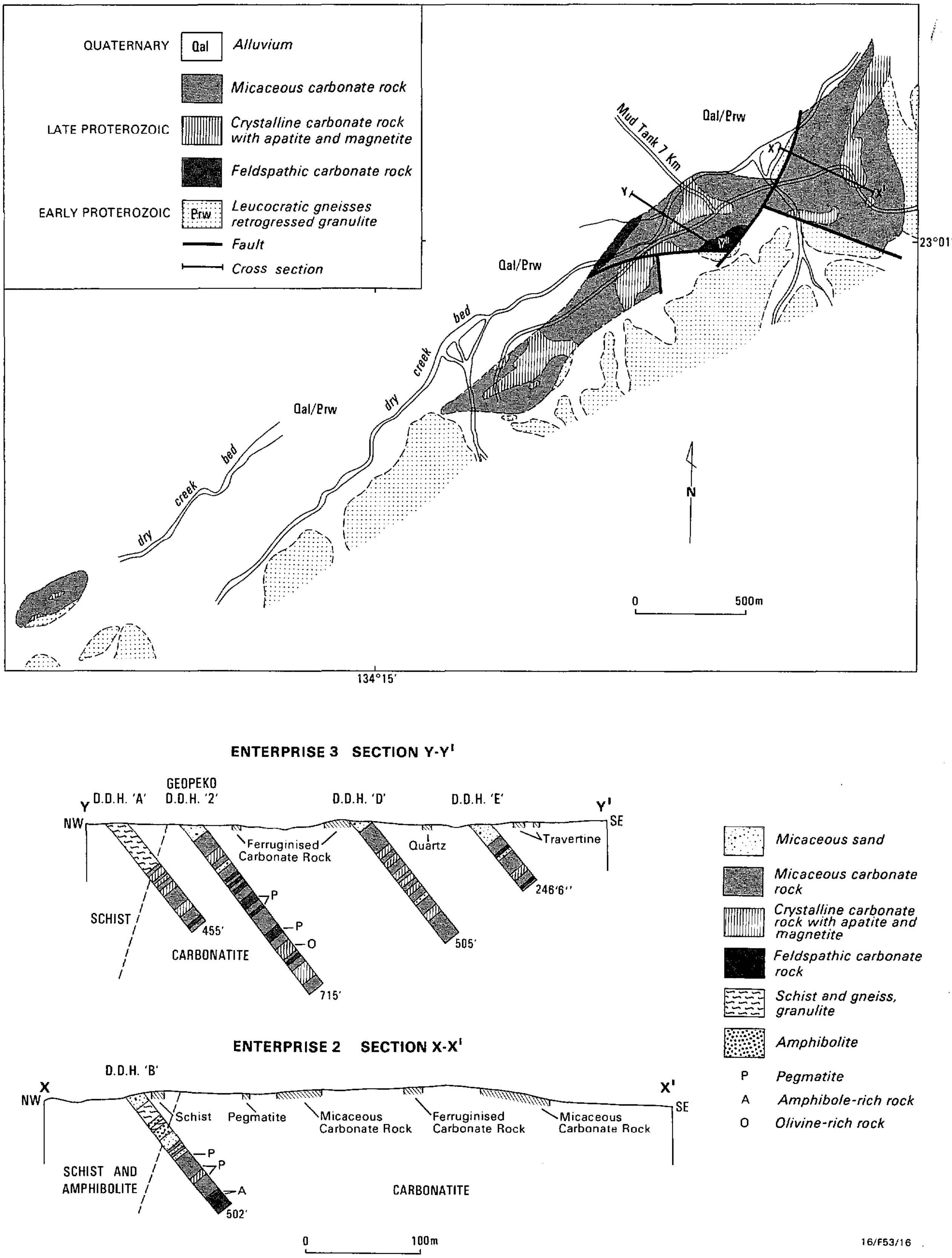


Figure 4.4 Geological map of the Mud Tank Carbonatite (after Crohn & Moore, 1984).

PEGMATITES IN THE HARTS RANGES

The pegmatites of the Harts Ranges were mined for muscovite from 1888 to 1960. During this period the pegmatites also yielded fine mineral specimens; today the pegmatites and the abandoned waste dumps are still being picked over for fine specimens of beryl, feldspars and tourmaline.

The pegmatites are younger than the peak metamorphism, and may be as young as mid-Palaeozoic has been suggested, though pegmatites in the northeastern Arunta are circa 1700 Ma. The majority of the pegmatites are fissure veins, occurring in faults, shears or steeply dipping joints, others are pipe-like bodies, and some are controlled by more than one structural feature (Joklik, 1955).

The economic pegmatites are coarse grained (>10 cm) zoned bodies, with relatively fine grained border zones, a coarse wall zone of quartz-muscovite, an intermediate zone of feldspar (perthitic microcline and albite) and accessory minerals, and quartz-rich cores, in some pegmatites containing large microcline crystals.

Joklik, G.F., 1955. The geolgy and mica fields of the Harts Range, central Australia. Bureau of Mineral Resources, Australia. Bulletin 26.

HARTS RANGE AREA

by

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Structural development of the Harts Range, central Australia.

Metamorphic rocks from part of the Harts Range Area of the eastern Arunta Inlier, central Australia, have been divided into four main units; the Entia gneiss complex, the Bruna granitic gneiss, the Irindina supracrustal assemblage and the Brady supracrustal assemblage. Ding & James (1985) proposed that the Entia gneiss complex was part of basement to the supracrustal cover. They also proposed that the basement and cover were juxtaposed during the first Harts Range Remobilization thrusting event (HRT_1) and that the Bruna granitic gneiss was tectonically emplaced during HRT_2 and HRT_3. .

The Entia gneiss complex, along the western margin of the Entia Dome, is composed mainly of felsic gneisses. The complex has been locally subdivided into three units with different abundances of interlayered mafic amphibolites and various metasediments. A major isoclinal fold of this sequence and the sequence itself are both sheared towards parallelism with the lower margin of the Bruna granitic gneiss, indicating that the overlying sequence has moved in a southeasterly direction. The complex is affected by the open folding responsible for the Entia Dome.

The Bruna granitic gneiss occurs as a layer at the base of the Irindina supracrustal assemblage. It consists of three varieties of differing deformation intensity. Large lense shaped bodies of almost undeformed granite occur within more typical granitic gneiss. Schistose mylonites with alkali feldspar megacrysts occur at the upper margin. The deformed rocks have strong lineations trending in northerly directions.

The Irindina supracrustal assemblage consists predominantly of biotite schists and mafic amphibolites, with lesser horizons of marble and calc-silicates. Three units of amphibolite have been distinguished throughout much of the area. Two of these units are separated by the Entia gneiss complex, which was used as a marker horizon during mapping. Five generations of folding have occurred in the Ruby Mine Area. A strong S_1 foliation is ubiquitous, although major F_1 folds are rare. A major flexure in the trend of the weak L_1 mineral lineations occurs along the eastern margin of the Entia Dome from 325° in the north, through 360°, to 015° in the south. Major F_2 isoclinal folds have a very wide distribution and fold HRT_1 further to the west. F_2 folds are tighter approaching the Bruna granitic gneiss. F_3 folding is tight and restricted to the Ruby Mine Area. F_2 and F_3 folds are both coaxial with L_1. Upright F_4 folding trends E-W and is most strongly developed at the contact between the mylonites of the Bruna granitic gneiss and the Irindina supracrustals. F_5 folding is open and trends N-S.

The Brady supracrustal assemblage consists of a monotonous sequence of biotite gneisses which have been divided into two units, the lower of which thins around the north of the Entia Dome. Tight and isoclinal folds occur and the assemblage is also folded by F_5.

The ruby deposits in the Entire anorthosite provide information on the timing of metamorphism in relation to folding in the Irindina supracrustal assemblage. Extra silica was required in order to produce S_1 hornblende in ultramafics, which previously consisted of pyroxenes, olivine and spinel. Silica was supplied through metasomatic exchange between anorthosite and ultramafic. Loss of silica caused a relative concentration of alumina in anorthosite resulting in ruby formation. Retrograde chlorite caused ultramafic to be less competent than anorthosite during F_3 folding.

EXCURSION STOPS, RUBY MINE AREA.

A Bruna Gap

At the western end of Bruna Gap there is an exposure of well layered and folded gneisses of the Entia gneiss complex. Within the Bruna Gap itself, strain variation within the Bruna granitic gneiss is well represented. At the upper (western) margin are schistose mylonites which were classified into the Irindina Gneiss by Shaw et al (1982). However, Ding and James (1985) have included them within their Bruna granitic gneiss because of the obvious granitic protolith of these mylonites.

B Ruby excavation

Metamorphic differentiation has occurred in anorthosite adjacent to ultramafic. Some small ruby corundum crystals, rimmed by sericite, occur in the layered and metasomatically altered anorthosite. This exposure demonstrates that metasomatism has occurred during S_1 development and ruby has formed in altered anorthosite adjacent to ultramafic. The complex shape of the ultramafic is due to F_3 folding, which can be examined at the next locality.

C The Knoll ruby excavation

The southern faces of the Knoll ruby excavation are the main exposures from which the origin of the ruby deposits has been deduced. The geology is represented in Fig. 2, although the Knoll has since been mined down to the ruby-bearing ultramafic layer. Layers of ruby bearing gneisses within ultramafic are continuous with and grade into anorthosite outside of the ultramafic. These layers are therefore considered to be isoclinal F_1 folds as they are continuous with and parallel to the S_1 foliation within the ultramafics defined by hornblende. The ruby-bearing layers also have an S_1 fabric and the rubies are considered to have grown during the S_1 development.

The present mineralogy of the ultramafics is dominated by hornblende and chlorite. This chlorite has formed from a retrograde reaction between hornblende, olivine and spinel. The margins of the ultramafic are particularly rich in chlorite. The addition of chlorite would have caused ultramafic to be more ductile and the shapes of F_3 folds indicates that this retrograde (although still amphibolite facies) reaction had commenced prior to F_3 folding.

Large scale F_3 folds can be observed in the hills to the south of the Knoll. Non-cylindrical E-W open F_4 folds occur in mafic amphibolites north of the Knoll.

D Trenched Area

Much excavation has been carried out in the Trenched Area since earlier mapping (Fig. 3). In this area there are two distinct layers of ultramafic, the upper of which is ruby bearing. Thickness changes due to boudinage can be observed in the existing exposures, as well as open F_5 folding plunging in a northerly direction. Of particular interest is a boudin of altered anorthosite with a thin rim of ultramafic ("C" on Fig. 3a). This ultramafic is considered to have been attenuated after the metasomatism that altered this boudin.

E Dating locality

Muscovite and zircon have been analysed from acid pegmatites within folded mafic amphibolites. The pegmatites appear to have an S_3 fabric (Fig. 4)

F SE corner of Ruby Mine Area

Of particular interest is the more intense F_4 upright folding in this area compared with near the Knoll. Steep dips are particularly obvious in the biotite gneisses immediately south of the large E-W pegmatite dyke. The mylonites at the upper margin of the Bruna granitic gneiss and the mylonitized "unit 1" mafic amphibolite are more strongly folded than the underlying less deformed Bruna gneiss.

Another feature in this area is a small boudin of norite deformed and metamorphosed during F_1, but still retaining a subophitic texture.

A prominant group of hills 15 km due south contains the same F_2 closure of the top of the "unit 2" amphibolite which is exposed in the hill 400 m to the west of this locality.

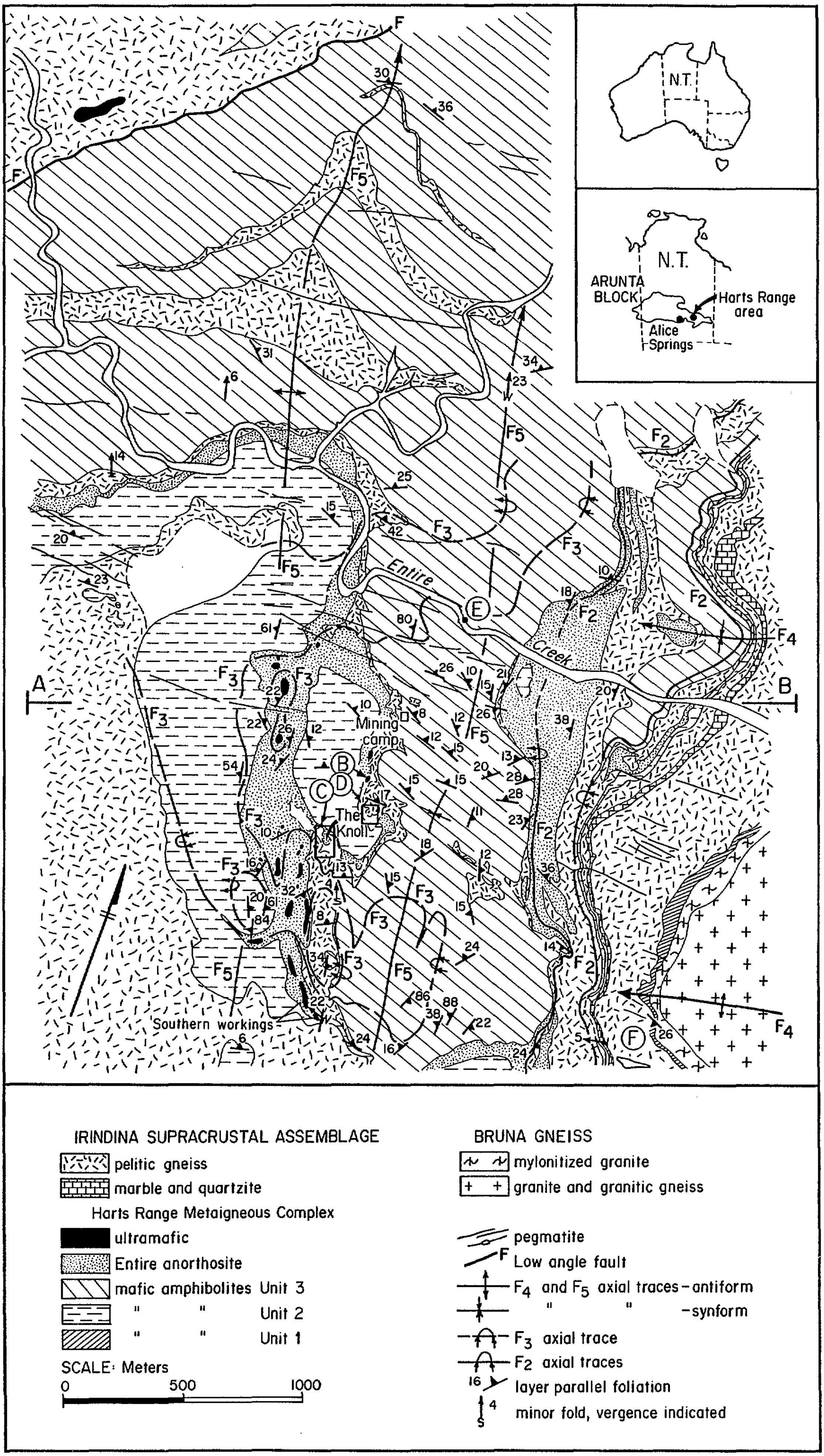

Fig. 5.1a Geology of the Ruby Mine area

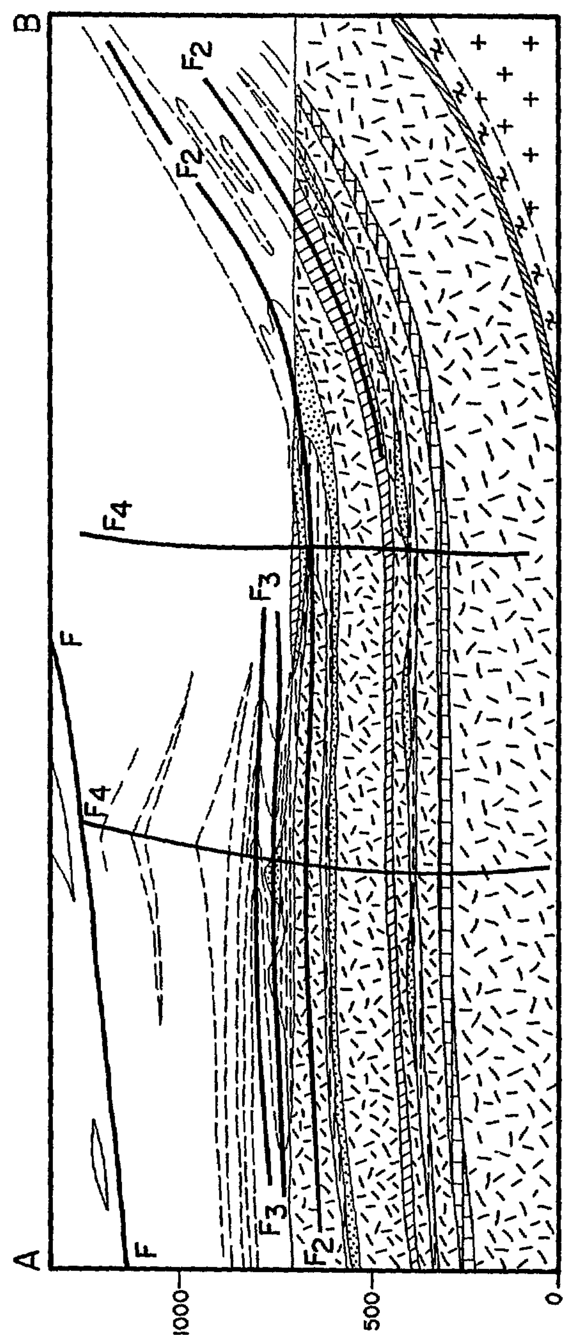

Fig. 5.1b Fold relations in the Ruby Mine area

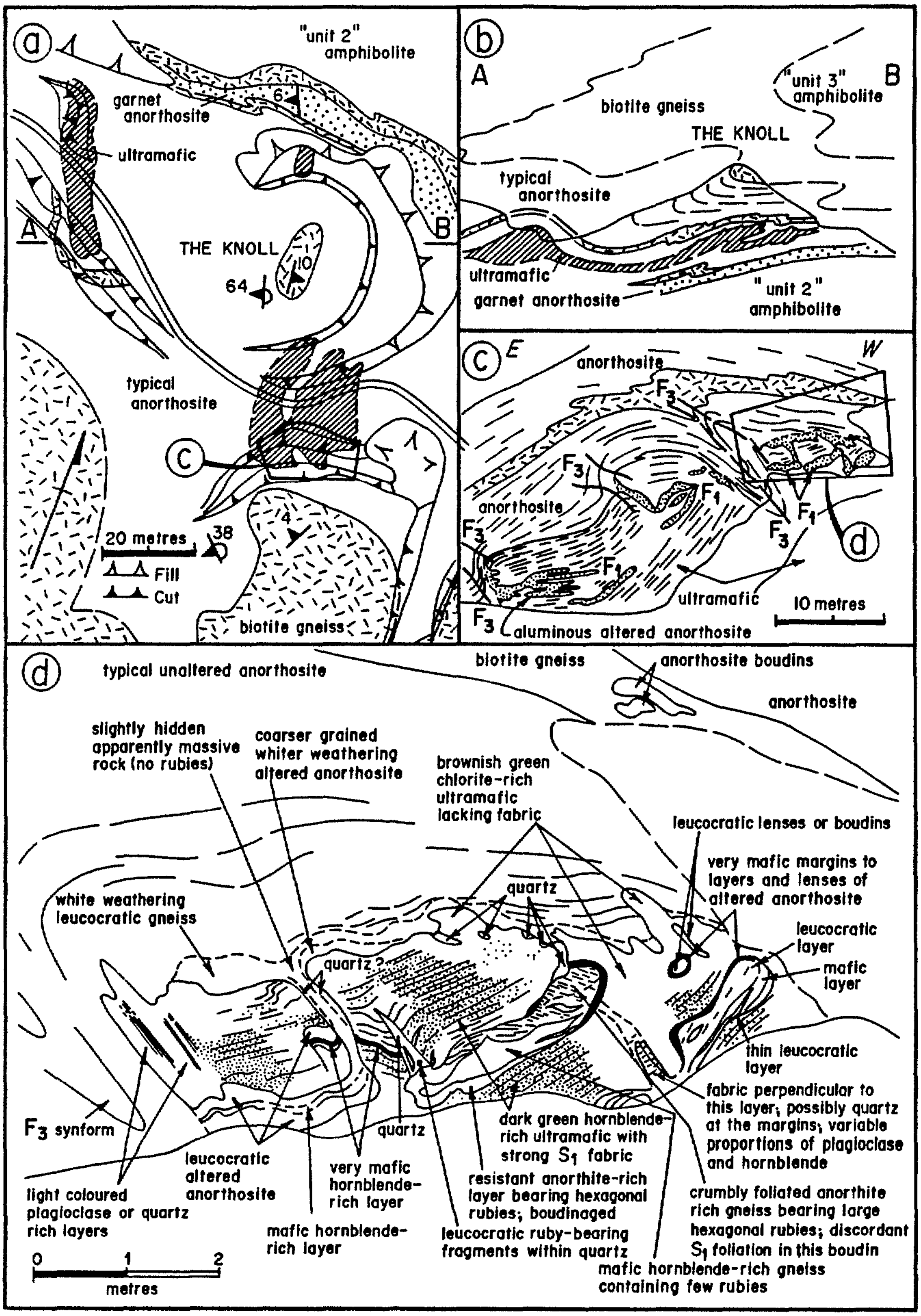

Fig. 5.2 Geology of the Knoll ruby excavation

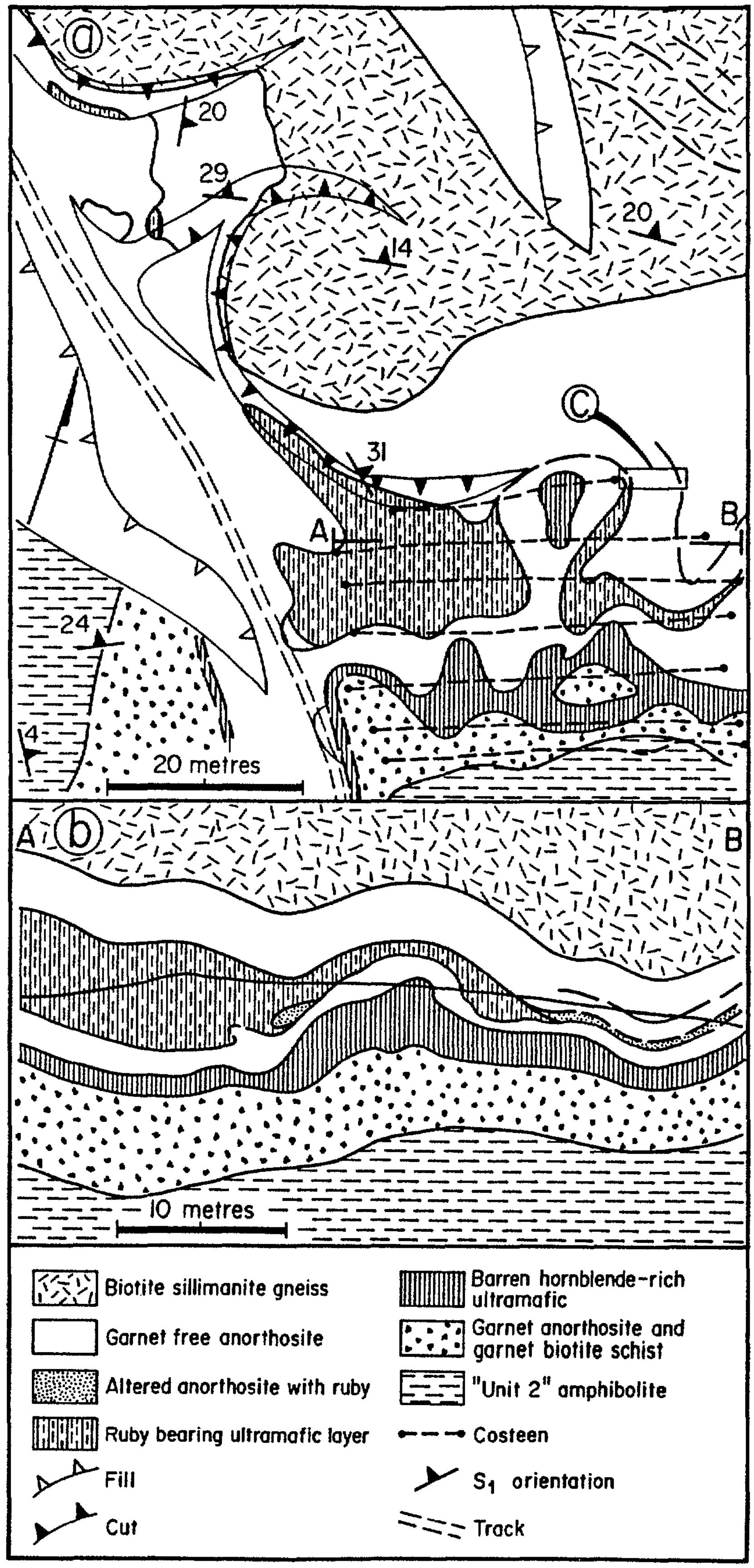

Fig. 5.3 Geology of the Trench Area, Ruby Mine

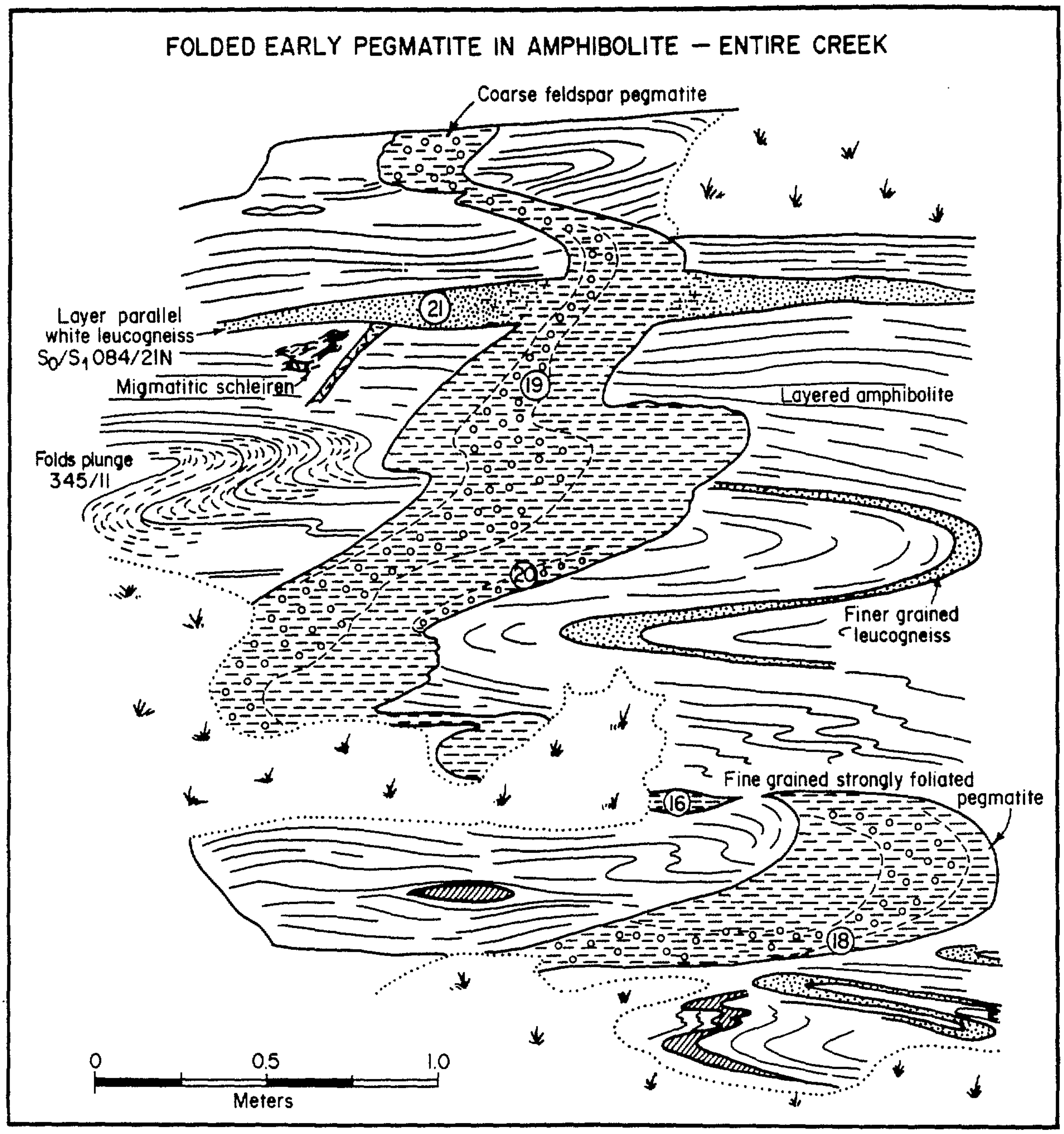
FOLDED EARLY PEGMATITE IN AMPHIBOLITE — ENTIRE CREEK
Coarse feldspar pegmatite
Layer parallel
white leucogneiss
S_0/S_1 084/21N
Migmatitic schleiren
Layered amphibolite
Folds plunge
345/11
21
19
20
Finer grained
leucogneiss
Fine grained strongly foliated
pegmatite
16
18
0
0.5
1.0
Meters

Fig.5.4

THE GEOLOGY OF THE ENTIA DOMAL STRUCTURE, EASTERN HARTS RANGES, N.T.

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The Entia Domal Structure(EDS) is at the eastern end of the Harts Range in the eastern Arunta Block as defined by Plumb et al ,(1981).Here rocks are regionally of amphibolite or granulite facies and have yielded maximum radiometric ages of about 1800 Ma.(Black et al ,1983).This is thought to represent the oldest metamorphism,refered to as the Strangways Event.

Subsequent to the work of Joklik (1955),investigation of the regional geology of the Harts Range area has been carried out by the B.M.R. (Shaw and Stewart,1975;Shaw et al. 1979,1982).These investigations resulted in the establishment of a three-fold approximately chronological division of the rocks of the Arunta Block.This division (after Shaw et al. ,1982) is as follows:

Division 3 : quartz-rich metasediments (youngest)
Division 2 : basal quartzofeldspathic gneiss,overlain by pelitic gneisses and amphibolite units
Division 1 :interlayered basic and acid granulites with minor amphibolite grade gneisses (oldest).

Shaw et al. (1979,1982) considered that rocks of division 1 were overlain by those of division 2 at a faulted or discordant contact which may have been an original unconformity disrupted by thrust faulting.The rocks of the Harts Range Area are mainly assigned to division 2.Shaw et al. (1982) refer to these as the Harts Range Group.

The rocks of the Entia Domal Structure were referred to as the Entia Gneiss and were regarded as the basal unit of the group.The Entia Gneiss is overlain by the Bruna Gneiss, the Irindina Gneiss and the Brady Gneiss.They considered that the Entia Gneiss overlay the division 1 rocks of the Strangways Metamorphic Complex.

More recently Ding and James (1984) have undertaken detailed structural studies in the Harts Range area and have suggested on the basis of structural style that the Entia Gneiss (refering to all the rocks of the Entia Domal Structure) be included in division 1.In recognition of the diversity of lithologies and ages of rocks previously defined as the Entia Gneiss,Ding and James (1985) rededefined this as the Entia gneiss complex. They regard the Brady and Irindina Gneisses (Shaw et al. 1982) as supracrustal ,cover associations which were juxtaposed with the division 1 "basement"(including the Entia gneiss complex) as a result of thrusting. Both cover and basement were multiply deformed before they were thrust together and the mylonite zone defining this thrust became the site of intrusion of the Bruna Gneiss whilst this event was in progress.

The area of outcrop of the Entia gneiss complex is confined to the Entia Domal Structure.This is an area about 20-30 km. in diameter (figure 1) where the gneisses dip circumferentially outwards beneath the Bruna Gneiss and the cover sequence rocks.This domal form of the Entia Gneiss is due to late stage upright open folding and is not due to diapirism of any of the granitic bodies presently exposed (ie the Huckitta or Inkamulla granite-gneisses).The doming of the Entia postdates the juxtaposition of cover and basement whereas the important granites are components of the gneiss complex and show complex deformation predating the doming events.

Rocks of the EDS can be subdivided into a supracrustal association whose most distinctive component is amphibolite and an intrusive component represented by sheet-like units of orthogneiss of mainly intermediate to acid composition.These rocks have been collectively referred to as the Entia gneiss complex by Ding and James (1985) and have suffered complex multiphase deformation.It can be shown that prior to the introduction of the major granite sheets at least two important isoclinal deformations of the supracrustal association took place and that after intrusion there were two more large-scale tight to isoclinal recumbent events.

It is likly that the metamorphic thermal peak was reached in the EDS during the time of the first of these large-scale recumbent folding events and migmatite development is widespread as a result.Pegmatite intrusions took place over a very lengthy period of the geological history of the dome. Some pegmatites clearly predate the granite intrusions, some are coeval and some very prominant and widespread pegmatites clearly crosscut the latest dome-forming structures.

Rock Types.

The rocks of the Entia Domal Structure (EDS) can be subdivided into two broad groups;1. The supracrustal association and 2. The intrusive association.All rock types have experienced a lengthy and complex deformational and metamorphic history and most rock types are now deformed and recrystallised gneisses.

Supracrustal Association.

These are the oldest rocks of the EDS and comprise both ortho- and para -amphibolite ,thin carbonate units and calc-silicate rocks together with thin meta pelite-psammite sequences .The pelitic components of the latter association have suffered extensive partial fusion yielding migmatite with restite/melanosome composed of biotite-phlogopite and often an aluminous phase ,either kyanite,garnet or cordierite. Rocks of this supracrustal association are seen at stops 1,2,3 and 5 and analyses of typical orthoamphibolites and a knotted phlogopite-kyanite schist are given in table 1.The amphibolites are the most distinctive lithology of the supracrustal association and their outcrop patterns provide the most easily mapped definition of the post-intrusive structures.

Least distinctive of the pre-intrusive lithologies is the finely layered Grey Biotite Gneiss.This unit is perhaps the major pre-intrusive component, but it forms highly weathered outcrops and its origin is uncertain.It may represent an early felsic meta-intrusive , a meta-arkose or a meta-volcanic sequence .

Intrusive Orthogneisses.

The EDS is dominated by metaigneous rocks of largely intermediate to felsic composition which have intruded the above supracrustal rocks as flat-lying ,conformable sheets (sills).Towards their margins these sheets are interleaved with the supracrustal rocks forming complex zones of xenoliths and thin sills.These contact features are well illustrated at localities 4 and 5 where the contact of the Inkamulla Granite Gneiss is well exposed.

Four main intrusive units are distinguished ;1. the Huckitta Granodiorite Gneiss,2.the Inkamulla Granite Gneiss,3.the Huckitta Tonalite Gneiss and 4. the Entia Leucogranite Gneiss.Typical analyses of these orthogneises are given in table 1.The Huckitta granodiorite (Buick,1983) is a mesocratic gneiss of granodioritic compostion composed of plagioclase, quartz,hornblende and biotite.It is a heterogeneous phase cut by thin dykes or sills of aplite,pegmatite and "spotty" hornblende-bearing leuco-granodiorite.The Inkamulla granite is a leucocratic true granite composed of quartz,potassium feldspar, plagioclase and biotite.It outcrops as a distinctive massive,homogeneous, sill-like body.

The Huckitta tonalite gneiss is a much more mafic unit than the other orthogneisses and ranges from gabbro to granodiorite in composition.The largest exposed volumes are of tonalitic or dioritic compostion.It is a quartz-poor,plagioclase-hornblende-rich lithology and like the Huckitta Granodiorite contains numerous xenoliths of amphibolite or diorite composition.

The Entia Leucogranite gneiss is very widespread orthogneiss phase .It occurs throughout the Entia Dome as sheet-like intrusions usually conformably interleaved with components of the supracrustal association.Locally however (eg stop 8) it cross-cuts this association.It is a pale orange coloured rock-type in outcrop forming pavemnents or slabby tors.Petrographically it is a quartz-plagioclase-microcline granite gneiss, with minor biotite, and is of fine-medium grainsize.

Throughout the EDS the pelitic gneiss and the grey biotite gneiss are pervasively migmatised and it is very possible that the Entia Leucogranite gneiss is a locally formed magma resulting from nearly in-situ partial melting. Pegmatite is also a very common component of the EDS and there are clearly many generations.Some pegmatites pre-date the intrusion of the orthogneisses while there are also several clearly younger generations. The latest are probably Palaeozoic and have E-W orientations .

Structure

The structural development of the area can be subdivided into three phases: 1. Pre-intrusive structures .These are indentified in the supracrustal association and can be placed as pre-intrusive by their occurence in xenolithic blocks within orthogneiss.There are at least three phases of folds which appear to be tight to isoclinal and at least in part recumbant.2. Early post-intrusive folds.There are at least two early post -intrusive deformations which produced recumbant, isoclinal folds (F1 and F2).The first of these produced a pervasive regional schistosity (S1)in all the orthogneiss units described above.Folds attributable to this phase are difficult to recognise, but can be seen as closures in xenolith sheets in some granites (eg Inkamulla Granite, stop 4).The second post-intrusive phase (F2) has produced large scale meso to macro -folds in the EDS.These are also recumbant and tight .They refold S1 and locally can be seen to develop a new axial planar schistosity (S2) (eg stop 6), though this weak by comparison with S1.The "steep zone "in the centre of the EDS is the hinge of a very large F2 fold.

3. The late-stage folds .These are upright and open folds and are not clearly associated with fabric development or metamorphism (the metamorphic peak was probably syn-F1-F2).There are probably three distinguishable phases of these (F3,F4 and F5).The domal character of the EDS is due to interference between F4 and F5.Late pegmatite intrusion and possible retrograde metamorphism (greenschist facies) may accompany these latest deformations.

Excursion Stops.

The Entia Domal Structure is approached from the Ruby Mine area to the west and its physiography is dominated by prominent strike-line ridges and resistant granite-gneiss units.The most prominent schistosity and the lithological layers are parallel and these dip outwards right around the perimeter of the dome.Also prominent is a zone of steep to vertical dips running approximately north-south through the centre of the dome .This zone represents the hinge line of a very large-scale recumbent F2 fold with axial surfaces approximately horizontal.

Also quite distinctive are the outcrops of the Huckitta granodioritic gneiss in the east of the dome .These form striking bald, rounded hills which give the superficial appearance of diapiric intrusions though on closer examination they are in fact remnants of dipping gneissic sheets.

Stop 1.

Between Spriggs Bore and Valley Bore:Knotted phlogopite-kyanite schist.

This is typical of many such knotted kyanite schist' occurences throughout the EDS.It is part of the supracrustal association and occurs with migmatite An origin as a partial melting residue is suggested. The co-existance of granitic minimum melt and kyanite suggest minimum pressures of about 8kb. and temperatures of 700 C.

Stop 2.

Near the Valley Bore intersection to the west of Inkamulla Bore .Amphibolite

This is a very mafic amphibolite composed of hornblende ,clinopyroxene and minor plagioclase.This is one of the ortho-amphibolites of the supracrustal association.

Stop 3.

On the eastern flank of the hill with prominent cairn, 300 meters to the south east of stop 2.

The para-amphibolite -quartzose metasediment sequence of the supracrustal suite.Here the amphibolites are finely banded with quartz-rich layers and prominent flattened garnets.

Stop 4.

At the base of the low ridge directly to the east of stop 3 (about 200 meters).Here the contact of the Inkamulla Granite Gneiss can be seen .It intrudes the older gneiss sequence, including lithologies observed at stop 3.In the hillside to the south some thin sills of the granite can be seen and in the western face of the low ridge projecting back towards the road, a number of folded sheets of amphibolite are included in the granite as xenoliths.

The host Inkamulla granite has been folded together with these xenoliths in what appears to be two distinct generations.In the first of these , the xenolith closures have the pervasive granitic schistosity (S1) as an axial planar fabric .These closures are therefore equated with the F1 folds which must have produced the regional foliation in the orthogneisses . These F1 closures have horizontal axial planes and hinges striking E-W. Refolding this early set of folds together with the schistosity is a second generation again with horizontal axial planes but with hinge lines striking NNW-SSE.This generation of folds (F2) has only developed a weak axial planar fabric which is best seen at stop 6.

Stop 5.

The supracrustal meta-pelite association and amphibolite in contact with the Inkamulla Granite Gneiss.This locality is situated about 400 meters due south from Inkamulla Bore (turn south and leave the road at the bore and drive parallel to the creek bed untill the first line of low hills and outcrops are reached).

At this locality the marginal apophyses of the Inkamulla granite can be seen intruded the older gneisses as thin sills.Towards the highest crest of the hill, about 150 meters east of the creek bed , a thin succesion of interbedded meta - pelite and quartzite of the supracrustal association are exposed.Here the pelitic units are now composed of garnet-biotite-kyanite -feldspar gneiss; while the quartz-rich units are pale, slabby quartzite.

Stop 6

On the eastern flank of the prominent hill just to the north of Inkamulla Bore.The prominent orange cliff on the south side of this hill ,facing the road is Inkamulla Granite Gneiss.This cliff exposes a broad open syncline with vertical axial plane (F3 or F4) .Stop 6 is located around the eastern side of this hill (procede eastwards about 1km along the Huckitta road past the next creek and turn north along a recent bulldozer scrape).

The eastern flank of the hill exposes Inkamulla granite and represents the core of a major F2 fold.Leaving the vehicals at the helicopter pad and crossing the fence-line into Riddock station, the base of the cliffs about 100 meters to the NW expose well developed zones of M-vergence minor folds in the granite gneiss with hinges striking about 330 and plunging about 5 degrees.Locally well developed S2 schistosity is parallel to near-horizontal axial planes.

Stop 7

At stop 7 an outcrop of Huckitta Granodioritic Gneiss is observed on the eastern side of the road about 1km after this road has swung to a more southerly average direction.The Huckitta granodiorite here is a complex gneiss with several components.These include an early mesocratic-melanocratic granodiorite which is cut by thin veins of later spotty-leucocratic ,hornblende granodiorite.

Stop 8

This stop starts at the "Huckitta Camp" and involves a short walk to the west through the saddle in the low amphibolite ridge-top to the west.Here pavement outcrops of the Entia Leucogranite Gneiss can be seen intruding the amphibolite.These intrusions are generally conformable, but below the saddle , about 100 meters to the west, amphibolite can be seen with cross-cutting leucogranite intrusion.

Continuing westwards beyond the first creek the last major orthogneiss unit is exposed.This is the Huckitta Tonalite Gneiss, a meso-melanocratic ,plagioclase-hornblende rock which forms low ,brown tors.It may have several internal phases including cross-cutting networks of more leucocratic veins.

References.

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Table 1.

Analyses of representative lithologies from the Entia Domal Structure.

Sample No.	H2	H19	H14	H27	H28	I	IB132
SiO_2	67.80	75.07	49.84	59.04	61.03	74.75	72.45
Al_2O_3	17.19	13.75	7.00	16.66	16.70	13.54	15.10
Fe_2O_3	3.06	0.74	13.32	5.79	4.57	0.73	1.69
MnO	0.08	0.03	0.28	0.09	0.08	0.03	0.03
MgO	1.07	0.21	14.28	4.90	3.94	0.18	0.51
CaO	4.17	1.94	12.31	7.18	7.01	0.81	3.14
Na_2O	4.36	2.87	0.72	3.35	3.13	4.07	4.53
K_2O	1.44	4.77	0.62	1.80	2.64	4.96	2.31
TiO_2	0.26	0.07	0.72	0.49	0.20	0.07	0.14
P_2O_5	0.11	0.05	0.11	0.13	0.13	0.01	0.05
L.O.I.	0.37	0.20	0.88	0.54	0.42	0.21	0.30
TOTAL	99.52	99.48	99.79	99.43	99.44	99.32	100.14
Sr	553	440	34	530	622	47	489
Rb	47.9	92	3	45	50	127	57
Y	7	4	28	13	13	5	2
Zr	111	79	77	89	79	58	101
Nb	3.2	0.2	3.3	4	3	3	3.3
Ba	849	2668	36	1064	1671	202	1759
Sc	7	1	72	19	18	2	3
Ni	4	4	81	68	53	5	4
V	33	3	223	115	73	5	9
Ce	53	51	39	57	69	19	19
Nd	20	9	28	19	21	3	11

H2 Huckitta Granodioritic Gneiss
H19 Huckitta Granodioritic Gneiss (leuco vein)
H14 Amphibolite
H27,H28 Huckitta Tonalitic Gneiss
I Inkamulla Granite Gneiss (analysis from I.Buick MSc thesis under examination)
IB132 Entia Leucgranite Gneiss (Buick,1983)

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