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Geology and Tectonic Evolution of Strangways and Harts Range Region of Eastern Arunta Inlier, Central Australia – a Post-conference Geotraverse of "Orogenesis in the Outback" (Alice Springs, July 1999)

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Abstract

The field trip attached to the meeting "Orogenesis in the Outback" held in Alice Springs, July 1999 was carried out by 32 scientists from different countries in the eastern Arunta Inlier, central Australia. During this trip a traverse through the major units of three metamorphic complexes namely, the Strangways Metamorphic Complex, Harts Range Metamorphic Complex and the Entia Gneiss Complex was undertaken. The imprints of several magmatic and metamorphic events and the associated tectonic build-up of this area were examined from the recently accumulated data of petrology and geochronology. In this paper, the outline of the geology and tectonic evolution of the Arunta Inlier has been reviewed as a result of the preliminary investigations during the above-mentioned field trip and the information supplied in the field guide and on-field discussions.

Key words : Arunta Inlier, Strangways Metamorphic Complex, Harts Range Metamorphic Complex

Introduction

An international symposium on "Orogenesis in the Outback, a look at the cyclicity and reactivation in orogenic belts" with pre- and post-conference field trips were organized from 12 th—18 th July, 1999 by Specialist Group in Geochemistry, Mineralogy and Petrology, Geological Society of Australia in association with the Tectonic Study Group, UK, IGCP 368, the Northern Territory Geological Survey, Australia and the Northern Territory Division of the Geological Society of Australia. The post-conference fieldtrip attached to the meeting, in the eastern Arunta Inlier from 18 th to 22 nd July 1999 focussed on the three major metamorphic complexes in this region e.g. the Strangways Metamorphic Complex, the Harts Range Metamorphic Complex and the Entia Gneiss Complex. The first part of the field trip to the Strangways Metamorphic Complex was led by Bas Hensen (University of New South Wales, Australia) and Andreas Möller (University of Mainz, Germany). The later part of the trip in Harts Range Metamorphic Complex and the Entia Gneiss Complex was led by Martin Hand and Jo Mawby of Adelaide University ; Jodie Miller of Monash University and Ian Buick of La Trobe University. A total of 32 delegates from 10 countries attended this 5 days post-conference field trip.

Broad Geological Outline and Tectonic History

The Strangways Metamorphic Complex, the Harts Range Metamorphic Complex and the Entia Gneiss Complex comprise the eastern part of the Arunta Inlier (a 200,000 km 2 large metamorphic complex in total) in central Australia. A minimum history of 1600 Ma, ranging from >2000 Ma to 300-400 Ma, is preserved in these complexes. Three major tectonothermal events explain the evolution of the eastern Arunta Inlier in the broader sense (Hand et al, 1999 b). The first, the Strangways Orogeny, occurred in the Paleoproterozoic to Mesoproterozoic (ca. ~ 1780 – 1715 Ma). This was the period of major deformation, metamorphism and voluminous magmatic emplacement. The second important event, the Larapinta Event is early Paleozoic in age (ca. 480 – 460 Ma). This event has been recently identified from the Harts Range Metamorphic Complex. The Alice Springs Orogeny of the late Paleozoic (ca. 450-300 Ma) marks the end of tectonic activity in the Arunta Inlier and is thought to be a compressional intraplate orogeny that exhumed the Arunta Inlier from beneath the continuous Neoproterozoic to late Palaeozoic intracratonic Centralian Superbasin (Shaw 1991). The remnants of this superbasin are now represented the Amadeus, Georgina, Ngalia and Wiso basins.

The Strangways Metamorphic Complex (SMC) in the eastern part of Arunta Inlier consists of the granulite-facies middle to lower crustal rocks. The SMC comprises mafic and felsic granulites, that are inferred to have been derived from a bimodal volcanic association (Warren, 1979), metapelites, some marbles and calcsilicates. Granitic plutons such as the Anamarra granite (Norman and Clarke, 1990) and the Wuluma granite (Collins et al., 1989) are thought to represent syn-tectonic partial melts formed during the Stranways Orogeny. These granulite grade rocks are disected by multiple amphibolite to green-schist facies shear zones. The early granulite assemblages imply an isobaric cooling history along a counterclockwise path in response to the Strangways Orogeny at ca. 1720-1730 Ma (Warren, 1983 ; Ballèvre et al, 1997). Peak assemblages yield higher P-T estimates (give P-T estimates across the SMC) in the eastern part than the western part of the SMC. These differences may reflect greater depth of burial of the eastern SMC. The amphibolite grade shear zones, which over in multiple generations with overprinting relationships show the sequential development of kyanite-stuarolite, sillimanite - and orthopyroxene - andalusite - bearing assemblages (Warren, 1983 ; Ballèvre et al, 1997) that imply a clockwise P-T path during Alice Springs Orogeny.

In the Harts Range region, the lithological assemblages can be divided broadly into two complexes, the structurally higher Harts Range Metamorphic Complex (HRMC) and the structurally lower Entia Gniess Complex (EGC). These two complexes are separated by high-grade, low-angle shear zone (Harts Range Detachment Zone, or HRDZ) that contains a sheet-like body of granitic gneiss called the Bruna Granitic Gneiss. The main lithostratigraphic packages within the HRMC are the Irindina Supracrustals (metapelites, quartzite, marble and calcsilicate rocks) and the Harts Range Metaigneous Complex (metabasic, meta-anorthositic and meta-ultrabasic rocks). The structurally underlying EGC is exposed in the core of a domal structure called Entia Dome and is dominated by mafic to felsic orthogneiss. The precursors of these orthogneisses intruded a supracrustal assemblage of calcsilicates, quartzite, aluminous metapelites and amphibolites. The Bruna Granitic Gneiss forms sheets of megacrystic metagranite that have been heterogeneously deformed to form augen gneisses. Kinematic indicators in the HRDZ are generally consistent with the HRMC being thrust to the south over the EGC (James and Ding, 1988, Collins and Teyssier, 1989). However, earlier northwards displacement associated with extension is also recorded in the HRDZ. In the HRMC the layering represented by variable amounts of coarse grained clinopyroxene, hornblende and plagioclase in the migmatitic mafic gneiss forms the S 1 layering. As calculated by Mawby et al. (1999) the peak assemblage of HRMC migmatitic metabasites yields a temperature around 820℃ and pressure of 10 Kbar. This syn-D 1 peak assemblage is overprinted by a regional-scale gently dipping fabric. The garnet-hornblende-plagioclase-quartz assemblage related to D 2 gives a pressure estimate of nearly 6.5 Kbar at 700℃ (Mawby et al., 1999). This suggests a decompressional path for this assemblage in the HRMC. In the EGC, the peak assemblage in the garnet-hornblende bearing rock yields 700℃ and 8.5 Kbar (Mawby et al., 1999). The mid-amphibolite facies shear zone assemblage from deformed Bruna Granitic Gneiss in the HRDZ gives 650℃ at 6 Kbar for this shearing event i.e. D 3 (Mawby et al., 1999). The earlier geochronologic data of this region suggested that the high grade metamorphism and D 2 occurred between ca. 1767 to 1730 Ma obtained by U-Pb zircon dating from the Bruna Gneiss and granitic orthogneisses in the EGC (Mortimer et al., 1987, Cooper et al., 1988). These ages fall within the range of the Strangways Orogeny that affected the Strangways Metamorphic Complex to the west, as mentioned earlier. However, recent Sm-Nd dating (Mawby et al., 1999) and SHRIMP U-Pb dating of zircon and monazite (Miller et al., 1998 ; Hand et al., 1999) suggests an early Ordovician age (480-460 Ma) for high-grade metamorphism in the HRMC whereas in the EGC upper amphibolite facies condition prevailed at the same time. The age data of early metamorphism in HRMC imply that the deposition must have started after the close of the Strangways Orogeny. The Larapinta Event in the early Ordovician represents an important event that is characterized by a similar style of P-T evolution in an wide area including the central Harts Range (Mawby et al., 1999), and the Mallee Bore area further to the north (Miller et al., 1998). It should be mentioned here that Goscombe (1992) reported a similar P-T evolution from the western Strangways Metamorphic Complex, although he suggested

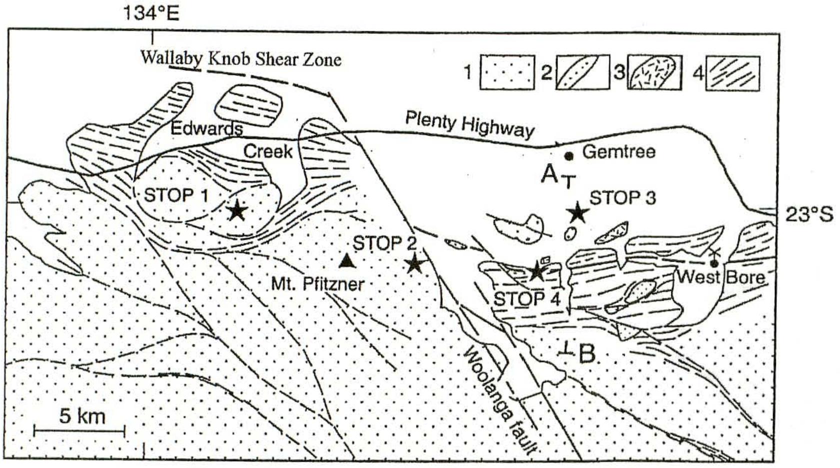

Fig. 1. A simplified geological map of the part of the Strangways Metamorphic Complex with the first 4 localities during the field trip. This map is reproduced and modified from Hand et al., 1999 b and Ballèvre et al., 1999 after the author's permission.
1 : Granulites from Strangways Metamorphic Complex, 2 : Heavitree Quartzite, 3 : Mud Tank Carbonatite, 4 : Main amphibolite to greenschist facies shear zones.

that this event was mid-Proterozoic in age. In the later Alice Springs Orogeny (ca. 400-300 Ma), the Harts Range were affected by major compressional deformation that may have been near-pervasive in the EGC. In contrast, the development of Alice Springs -age assemblages in the SMC was restricted to amphibolite grade shear zones that developed along a clockwise path.

Detailed Description of the Study Locations

Strangways Metamorphic Complex

The first exposure (Stop 1 of Fig. 1) that had been examined was at Edward Creek Prospect on the southern side of the Plenty Highway. Fig. 1 represents the general geology of this part of the Strangways Metamorphic Complex (SMC). Here the granulite facies metapelite shows tight to isoclinally folded gneissic layering (Plate 1 A), which is correlated with D 2 Strangways-age deformation. The dominant foliation, S 2, in this locality is axial-planar to this fold. This foliation plane is sub-vertical and trends north-south. The form surface of these folds i.e. S 1 is characterized by the high-grade gneissic layering containing the peak metamorphic assemblage (M 1) of coarse grained garnet, cordierite, orthopyroxene, K-feldspar in the metapelites. The layer parallel, orthopyroxene-bearing leucosomes are caused by the partial melting of the rock during the M 1 metamorphic event. There is a later set of leucosomes that cut across the earlier folded one and are almost axial planar to the D 2 folds. M 2 assemblages synkinematic to D 2 show formation of biotite and sillimanite in expense of cordierite, which implies an early near-isobaric cooling. The early granulite grade assemblage of garnet, cordierite, orthopyroxene + biotite is cut by several late amphibolite facies to greenschist facies shear zones which acted as fluid pathways. A coarse grained gedrite-kyanite bearing assemblage formed early in this shear zone whereas the later assemblage contains andalusite. Apart from that, some pseudotachylites are found which deformed even the andalusite bearing assemblage. SHIRMP data of the new zircon growth in the orthopyroxene bearing leucosomes of different generations indicate a continuum of metamorphism and deformation history for M 1-D 1 and M 2-D 2 ranging from ca. 1717 to 1727 Ma (Ballèvre et al., 1999 a). The late shear zone was also dated from new zircon growth at ca. 443 Ma. This age doesn't match with any major Paleozoic orogenic event (cf. Alice Springs Orogeny) (Möller et al, 1999), whereas monazite from the same shear zone rocks yielded an age of about 385 Ma by laser-ablation ICP-MS (Ballèvre et al., 1999 a). Nearly similar age of ca. 440 Ma has been obtained from the low angle shear zone in the Harts Range Metamorphic Complex (Mawby et al., 1999). Interestingly enough, these late shear zone zircons show magmatic looking core that formed at 1800 Ma but it failed to record the two major events e.g. 1720 Ma of partial melting and 380 Ma of Alice Springs-age thrusting.

The next exposure (Stop 3, Fig. 1) was of two-pyroxene mafic granulite with interlayered felsic gneisses. These units are cut across by a narrow subvertical shear zone along which the earlier garnet and sillimanite-bearing assemblage are transformed into biotite and kyanite-bearing assemblages. Anastomosing shear zones with high strain gradient are thought to be an effect of the Alice Springs Orogeny. The next stop (Stop 4, Fig. 1) was at a ridge on the highly deformed Heavitree Quartzite. This quartzite unit is believed to be of Neoproterozoic age and lies unconformably over the earlier porphyritic granite with a conglomerate bed in between. All of these units were strongly deformed to produce a subvertical foliation and a near-horizontal stretching lineation. Although the deformation in the muscovite-rich quartzite layers and the stretching lineations are conspicuous, deformation of the

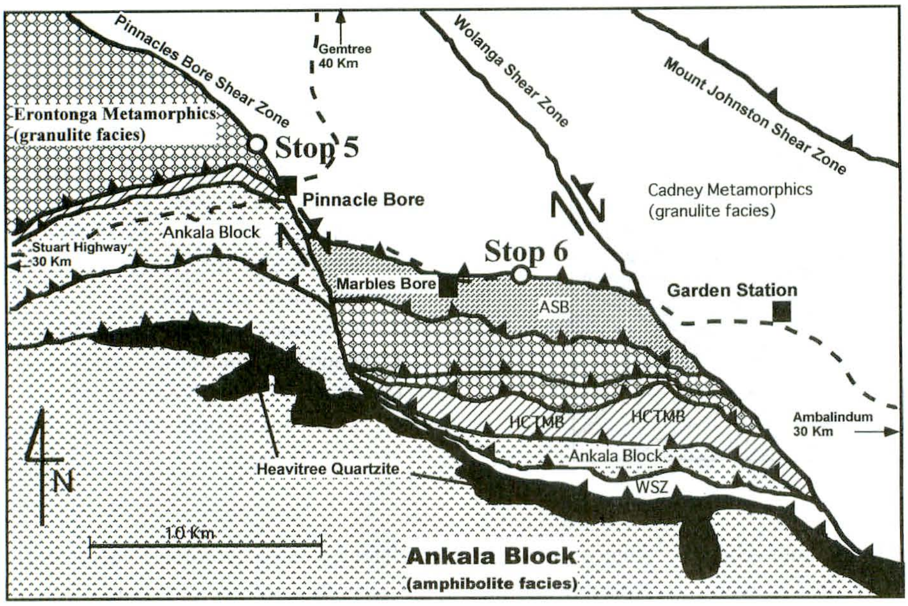

Fig. 2. General geological map of the part of southern Stangways Metamorphic Complex showing the important Alice Springs Orogeny shear zones and the visited spots. ABS : Anuma Schist Belt, WSZ : Winnecke Shear Zone. This map is reproduced and modified after Hand et al., 1999 and Ballèvre et al., 1999 with the author's permission.

conglomerate layer is not very clear. However, on the foliation perpendicular plane some elongated lenticular quartz grains (pebbles?) are observed.

The anastomosing amphibolite facies shear zones that cut across the earlier granulite assemblage have also been found in the southern part of the Strangways Metamorphic Complex. One of such shear zones, the Pinnacles Bore Shear Zone was visited on the field trip (Stop 5, Fig. 2). The Sm-Nd data of garnet from this shear zone implies an age of ca. 320 Ma (Bendall et al., 1998) which is distinctly younger than the shear zones in the northern Strangways Range (ca. 440 Ma and 385 Ma as reported by Ballèvre et al., 1999 a). Here kyanite-two mica-quartz schist contains garnet and staurolite in places. Nearly 9 km southeast of Pinnacles Bore, a small hill composed of late Proterozoic Heavitree Quartzite was found from the hillock by the side of Arltunga Tourist Drive (Stop 6, Fig. 2). This forms the southern boundary of the Strangways metamorphic complex. The lower grade metamorphic rocks comprise the southern part of this quartzite, which is quite distinct from the granulite grade rocks of SMC north of it. A highly deformed section of Heavitree Quartzite was also examined in the northern Strangways Metamorphic Complex (SMC). As the east-west trending thrust system separates the northern SMC and the associated quartzite from the southern lower grade rocks with the same quartzite unit, the depth of burial in north and south are considered to be different. This may be caused by differential crustal thickening during the Alice Springs Orogeny or by the presence of another pre-orogenic history linked to the development of the adjacent Amadeus Basin (Shaw et al., 1991). The situation here is somewhat similar to a transpressional type system.

Contact between Strangways Metamorphic Complex and Harts Range Metamorphic Complex

After a long drive of nearly ninety kilometers towards the east, we reached (Stop 7, Fig. 3) Florence Creek, which is the boundary between the Harts Range Metamorphic Complex (HRMC) and Strangways Metamorphic Complex. This boundary is also highly sheared. Mylonitized upper amphibolite grade rocks in this shear zone show a strong shear foliation that dips nearly 50° towards north. In the shear zone, two lithounits predominate. Both the dark colored mafic metabasites and light colored metapelites show a strong porphyroclastic shear fabric. In the metapelites, garnets are enveloped by a fabric that is defined by fine-grained biotite-sillimanite-K-feldspar-quartz-plagioclase-rich assemblages (Plate 1 B). In the metabasites, the fabric is defined by orthopyroxene, clinopyroxene, hornblende and plagioclase. Kinematic indicators in these fabrics locally show southward movement. In the southwest of this shear zone, the lithounit consists of granulite grade rocks of the SMC and in the northeast it is the supracrustals of the HRMC. Ten km further to the east, in the Lizzie Creek area (Stop 8, Fig. 3), the same sense of movement is conspicuous from the highly deformed similar intercalation of HRMC mebasites and metapelites (Plate 1 C). Large euhedral garnets (early generation) are seen to be enveloped by the later foliation of the fine-grained assemblages (with hornblende, plagioclase and quartz in metabasites and with biotite, sillimanite, plagioclase and quartz in metapelites). At some places, the pegmatites and tonalitic leucosomes cut this

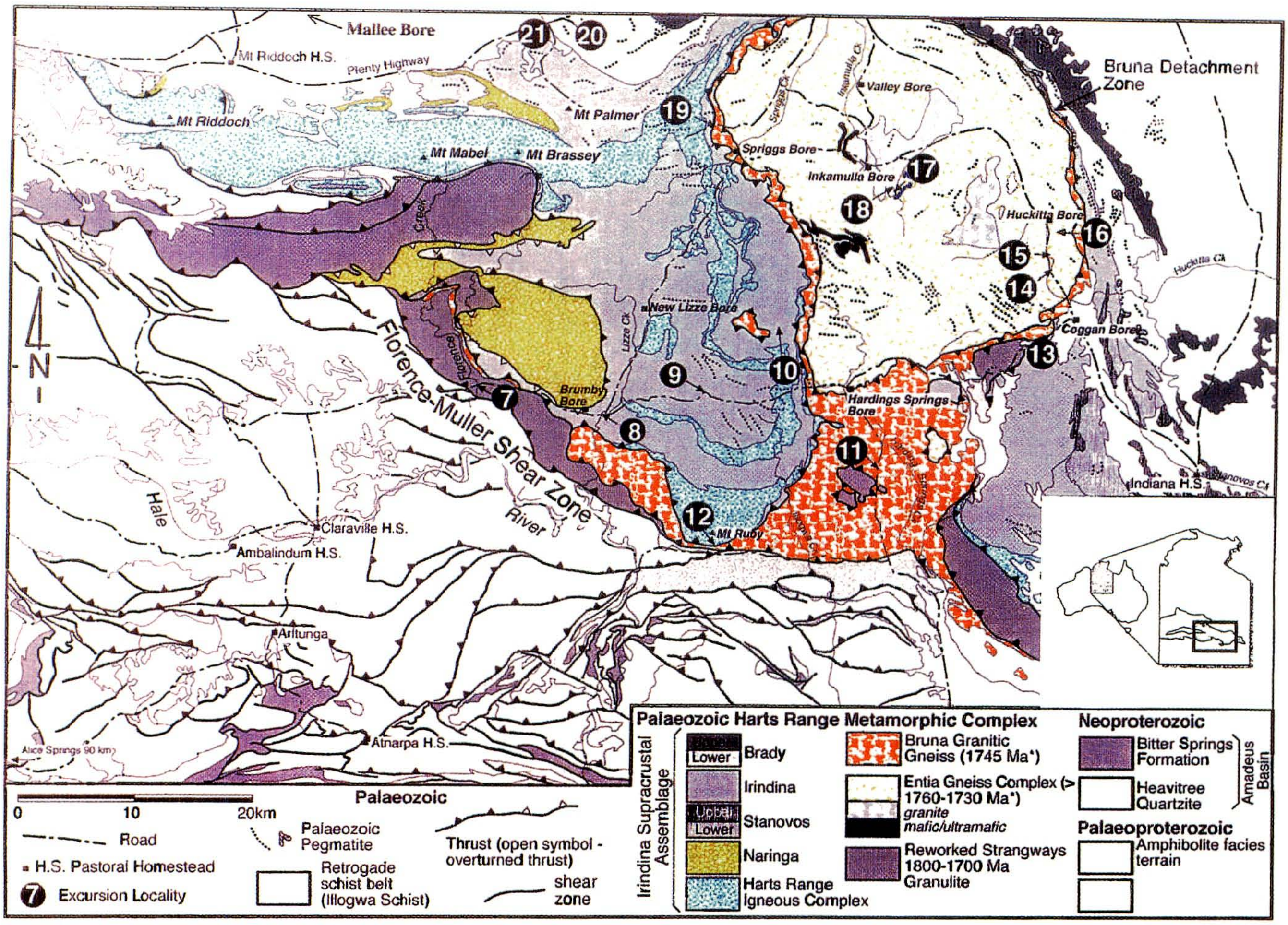

Fig. 3. Geological map of Harts Range region.The stop numbers are shown.This is reproduced and modified from Hand et al., 1999 b after the author's permission.

fabric. Pinch- and swell structure and beautifully formed boudins in the metabasites have garnet bearing high-grade assemblages. Fig. 3 depicts the general geological assembly in the HRMC.

Harts Range Metamorphic Complex

In the HRMC, the Irindina Supracrustals comprise a meta-sedimentary package. The migmatitic metapelite forms a part of the Irindina Gneiss in the Eastern Belle Mine (Stop 10, Fig. 3) and contains garnet, biotite and sillimanite-bearing metapelite. This is locally associated with granite containing sillimanite and retrograde muscovite, which is supposed to be the partial melt product from the metapelite. Some pegmatite bodies were mined for muscovite and garnet. On the top of the abandoned mine, some boudinaged mafic bodies are also found (Plate 2 A). In this area, locally occurring megacrystic granite is also present which looks like the megacrystic Bruna Granitic Gneiss, but the former contains muscovite. There is a controversy in the age relationship between Bruna Gneiss and the Irindina Supracrustals. The highly deformed contact relation, absence of intrusive contact and absence of a pre-Ordovician metamorphic event in Irindina Supracrustals (Mawby et al., 1998 ; Miller et al., 1999) hint to an earlier age for the Bruna Gneiss. This gneissic body has an interesting regional disposition as a thin to thick sheet of megacrystic metagranite that is now mostly represented as augen gneiss. Bruna Gneiss is so thought to be a syntectonic granite (igneous characters are preserved at some low strain zones) that structurally lies between the younger Irindina Supracrustals and the older Entia Gneiss Complex. At some places, the sub-horizontal foliation in the Bruna Gneiss is cut by massive-looking north-south trending mafic dykes (Stop 11, Fig. 3). Along their length, these dykes are show dextral offset. Though the dyke is very massive and looks undeformed mostly, at some portions near the contact of the dyke, they look like crudely foliated in nature. Hand et al. (1999 b) reported a week foliation defined by the metamorphic assemblage of garnet, clinopyroxene, orthopyroxene, hornblende and plagioclase in this dyke. This implies a syn-kinematic mafic magmatism during early Paleozoic, considering the age data of ca. 450 Ma for the foliation in the Bruna Gneiss (Mawby et al., 1999).

One of the important members of the HRMC is the meta-igneous complex, which is well exposed at Mt. Ruby (Stop 12, Fig. 3). This is dominantly a coarse-grained migmatitic amphibolite. The foliation dips gently towards north. The fluid-absent melting of hornblende might produce garnet and clinopyroxene-bearing tonalitic melt as suggested from the experimentally studied reaction hornblende + plagioclase + quartz ⇒garnet±clinopyroxene + melt (Wolf and Wyllie, 1994). Some coarse- grained garnet and hornblende-bearing segregations were found to cut across the host foliation at a moderate angle. Big garnet (single grain or cluster) is rimmed by felsic materials (Plate 2 B). It is reported that in some places this early formed garnet are replaced by hornblende and plagioclase involving the non-segregated melt by the back reaction of the above-mentioned fluid-absent hornblende melting (Hand et al, 1999 b). The complete replacement of hornblende in some portions and textural evidence of such back-reaction in some other portions indicate a differential migration of the melt volume produced during the fluid-absent melting. Such garnet breakdown reaction indicates decompression across the experimentally deduced positively sloping hornblende melting reaction (Wolf and Wyllie, 1994) i.e.. A second generation of small sized garnet and clinopyroxene-bearing intergrowth is formed at the boundary of secondary hornblende and hence a two-stage decompression path with an intermediate cooling is suggested from this assemblage (Hand et al., 1999 b).

The intensely mylonitized Bruna Granitic Gneiss separates this meta-igneous complex at Mt. Ruby in the south from the felsic rocks of older Entia Gneissic Complex in a kilometer scale detachment zone (HRDZ). Further towards the northeast from this area, highly folded calcsilicate rocks of the HRMC are exposed in the Coggan Bore region (Stop 13, Fig. 3). Wollastonite-bearing calcsilicate rock is interlayered within the metapelitic and metapsammitic units. The quartz-rich layer contains calcite and diopsidic pyroxene. These calcsilicates contain large garnets and some sphenes and have yielded an isochron age of ~470 Ma (Mawby et al., 1999). Hence, Paleozoic fluid flow (Lavery and Buick, unpublished data) is considered to have affected both the units in this terrain. They observed that garnet and wollastonite in these rocks were formed by reactions involving calcite, quartz and plagioclase. But in interlayered calcsilicates locally contain garnet, wollastonite-rich assemblages that lack one or more reactants suggesting that the reaction had been driven to completion. On the other hand in some places low variance assemblages such as wollastonite, calcite and quartz still buffer the fluid composition in these layers. This indicates that the fluid flow was highly channelled within the calcsilicate layers.

Entia Gneissic Complex

To the north of Stop 13, lithounits that are grouped together as Entia Gneiss Complex occur within a regional-scale domal structure, the Entia Dome. At Huckitta Creek (Stop 14, Fig. 3), intercalated layers of amphibolite grade leucogneiss, garnet- and biotite-bearing gneiss, muscovite-bearing leucogneiss and amphibolite were found. The dominant gneissic layering dips 40-45(to the northeast. There is a faint mineral lineation that is parallel to the axis of the recumbent isoclinal folds. The age data from these gneisses show two major ages that represent possible emplacement at Paleoproterozoic (between 1767±2 to 1730±1 Ma) and metamorphism at Paleozoic (between 360±5 to 325±1 Ma) (Cooper et al, 1988). A beautifully boudinaged pegmatite was found in this creek section (Stop 15, Fig. 3) (Plate 2 C). This is parallel to the axial plane of a meter scale asymmetric fold. Some thinner pegmatitic veins occurring at high angle to the host rock fabric have a cross cutting relation with the earlier one, and are folded. These two generations of pegmatites were supposed to be emplaced at different times during the deformation but are not yet dated. The main body of the pegmatite is apparently undeformed.

Along the waterfall section at Huckitta Bore Boudin (Stop 16, Fig. 3), the lower portion of the cliff shows a highly deformed zone with tightly folded and sometimes stretched out limbs of mafic bands in a felsic and foliated host (Plate 3 A). The garnet-bearing mafic rocks and felsic layers are cut across by pegmatitic veins. Towards the higher reaches of the cliff, a relatively less deformed area is identified as a boudin with predominantly mafic assemblages. Partially recrystallized metagabbro and charnockites are intimately layered and a dolerite dyke crosscuts the charnockites. The age of all these mafic and felsic magmatism is suggested to be Paleoproterozoic (ca. 1760 – 1780 Ma) in age (Foden et al., 1995). These magmatic rocks are elsewhere much more strongly deformed to form the sub-horizontal layering that charactertises the EGC.

In the Entia Gneiss Complex, fluid-present melting is evident from the migmatised felsic gneiss at Inkamulla Creek (Stop 17, Fig. 3). The felsic gneiss contain leucosomes of granitic composition separated from paleosome by thick biotite-rich melanosomes. The layer parallel leucosomes are boudinaged and intrafolially folded. This suggests that melting predated at least some deformation. This felsic migmatised gneiss occurs adjacent to the metabasites of upper amphibolite facies. Further southwest (Stop 18, Fig. 3), an interesting schistose rock was examined which contained a characteristic assemblage of kyanite, garnet and mica. This rock is overall coarse grained and big kyanite crystals sometimes include garnet suggesting formation of kyanite from an earlier garnet-bearing assemblage along a decompressional path (Hand et al., 1999).

Further to the NW from Stop 18 the upper surface of the HRDZ was examined towards the in Bruna Gorge (Stop 19, Fig. 3) the. In the downstream section, the Irindina Supracrustals are composed of intensely foliated metapelites and metabasic rocks. The mylonite layers with porphyroclastic garnet in the metasupracrustals are considered to be the member of the Bruna Gneiss, but the contact relation with the Irindina Supracrustals is not clear. The strongly deformed metapelitic units contain porphyroclasts of garnet. Foliation parallel torn-out lenses (also lenses with pinch- and swell structure) of metabasic lithologies are found on a cliff face. The adjacent rock unit is the megacrystic Bruna gneiss with porphyroclasts of K-feldspar (Plate 3 B).

Structurally the highest unit of the Irindina metasupracrustals is the Brady Gneiss (Stop 20, Fig. 3). The metapelitic gneiss has strong foliation defined by biotite and muscovite. This foliation dips toward north. In some places big euhedral garnet crystals are enclosed by the foliation. This metapelitic gneiss contains leucosomes and garnet-bearing pegmatites that are mostly discordant. Here the fluid-present melting of two micas is suggested and though the age is not well constrained, the metamorphism is considered to be of Ordovician age (Hand et al., 1999 a). The micaceous pegmatite is also an important component of the Harts Range Group as visited at Stop 21, Fig. 3. In most places this is associated with the metapelites.

Northern Harts Range Metamorphic Complex

In the exposures at the northernmost part of the HRMC around Mallee Bore, the lithounits are mostly comprised of metapelites and metabasic rocks with minor calcsilicates. The mafic granulites are migmatitic in nature. Along the margin of quartzofeldspathic leucosomes concentration of garnet and clinopyroxene were found. Garnetiferous metabasites and metapelites are interlayered in some places. The foliations in the metapelites show a steep dip.to the south. Stretching lineations on the foliation surface plunge towards east. The granulite grade metamorphism and the partial melting along a clockwise P-T-t path for this terrain followed by a high temperature shearing event was suggested by Miller et al., 1997. This high grade metamorphism was correlated with the Strangways Orogeny (ca. 1730-1745 Ma) from the similarity of the type of metamorphism in this region and the other regions of the SMC. The stable isotope studies indicate early infiltration of the low O 18-meteoric water before the peak granulite grade regional metamorphism, may be Paleoproterozoic as suggested by Miller and Cartwright, (1997). However, recent geochronological data of Miller et al, (1998) suggest that the protolith was deposited younger than ca. 700 Ma and that the granulite grade metamorphism occurred at 480-460 Ma. This indicate that the fluid/rock interaction should be a much later event than previously thought and should be in between ca. 700-460 Ma. Hence the regional granulite grade metamorphism may be of the same age as of the mid-Ordovician high grade metamorphic event of Harts Range Metamorphic Complex (Mawby et al., 1999). Moreover, the P-T-t path of the Mallee Bore Region (Miller et al., 1997) is very similar to that of the HRMC as determined by Mawby et al. (1999). This early Ordovician granulite grade metamorphism and the deformation in Harts Range is identified as the Larapinta Event. At the last stop of this field trip, we examined a biotite rich granite body, which intrudes the Irindina Supracrustals.

Conclusion

Summarizing, the Strangways Metamorphic Complex preserves an early (ca.1720-1730 Ma) isobaric cooling along an anticlockwise history that encompasses two metamorphic events, M 1, M 2 and two simultaneous deformation events, D 1 and D 2. In addition, this complex also records a later (ca. 380 Ma) history of exhumation along a clockwise path (Ballevre et al, 1999). The first major metamorphism corresponds to the Strangways Orogeny, which brought materials to the lower crustal depth and subsequently cooled down at that depth. While the later Devonian to Carbonifereous Alice Springs Orogeny brought back the lower to middle crustal material and the associated erosion of the relief can be accounted by the presence of depositions at the Amadeus Basin (Jones, 1991). In the Strangways Metamorphic Complex, the imprint of the Ordovician event is not ubiquitous except for one shear zone where the zircon growth associated with some amphibolite facies deformation indicates an age of 440 Ma (Möller at al, 1999). On the other hand, in the Harts Range there has been considerable debate regarding the age relationship of metamorphism and deformation events (Ding and James, 1989, Collins and Teyssier, 1989). The recent data pinpoints the early Ordovician (ca. 480 - 450 Ma) metamorphic event both in the lower Entia Gneiss Complex and structurally upper Harts Range Metamorphic

Complex (Mawby et al, 1999). However, the granulite facies metamorphism in the Irindina Supracrustals and amphibolite facies metamorphism in the Entia Gneiss imply that they are of two different crustal blocks separated by structurally important sheet of Bruna Granitic Gneiss in between. Miller et al (1997) inferred a decompression path from nearly 10 kbar to 6.5 kbar at 700 - 800℃ from Irindina Supracrustals during this period of the Larapinta Event. This high temperature decompression event coupled with the development of sub-horizontal regional fabric suggests extensional tectonics (Mawby et al., 1999 ; Hand et al., 1999). Some parts of the Entia Gneiss Complex underwent mid-amphibolite facies metamorphism during the Carboniferous Alice Springs Orogeny, as suggested from U-Pb monazite and zircon data (Hand et al, 1999 a). Overall, during the Alice Springs Orogeny, the southwards-directed convergent deformation (continuous or in pulses) was accommodated along several shear zones. This convergence started ca. 450 Ma and continued till ca. 300 Ma (Mawby et al., 1999).

The five days of field trip were very informative and exciting. On-site explanations by all the leaders with posters were complete, very easy to understand and enthusiastic, and greatly encouraged the participants in fruitful discussions, logistics and academic arrangements. The new data and understanding on the so far unknown Ordovician events in this part of the continental crust developed a lot of interests among the academic world as well as amongst industry personnel. The unresolved questions and problems for future researchers have been delineated.

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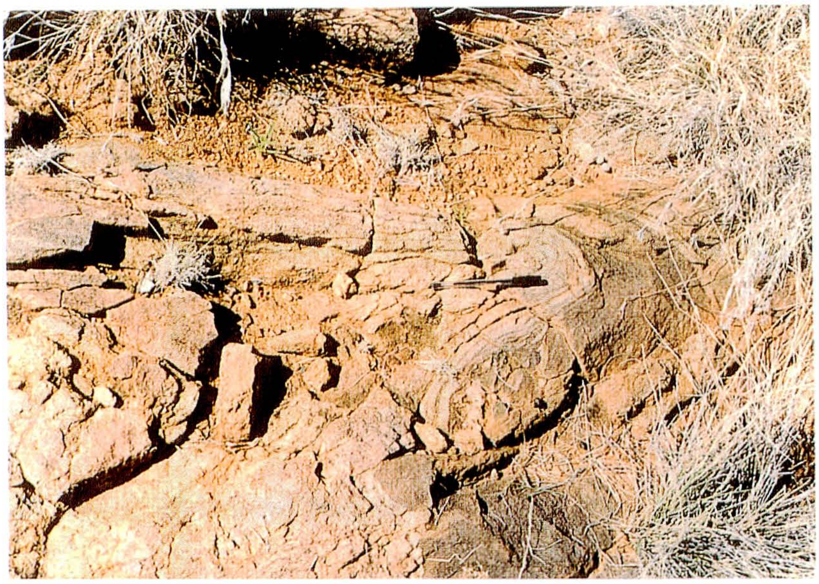
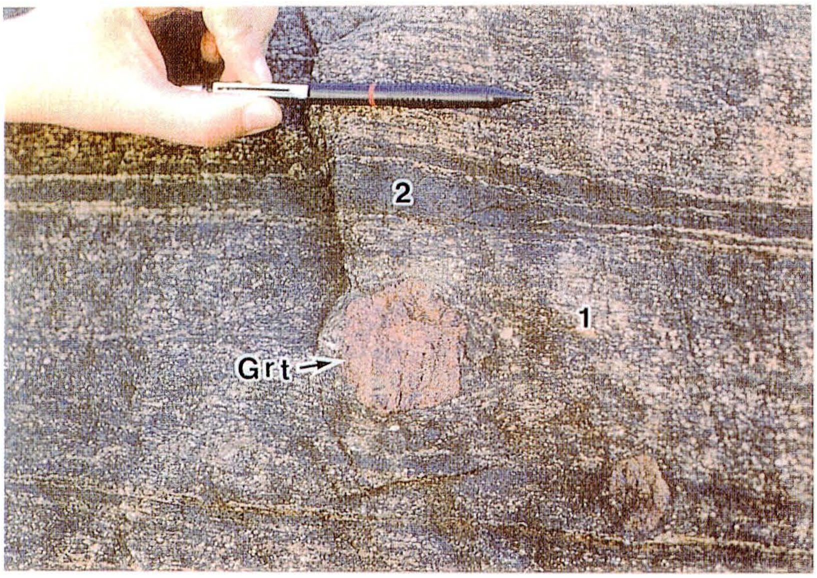
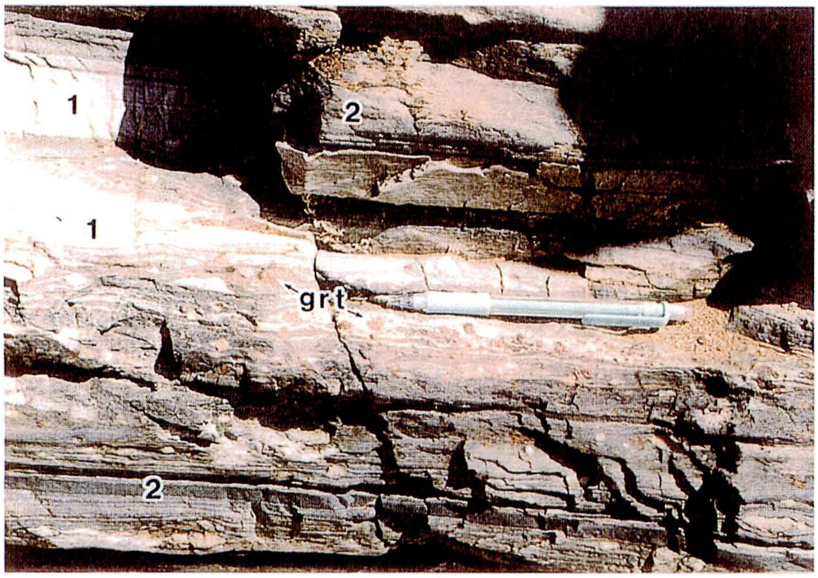
Plate 1



A : Tightly folded gneissic layerings in metapelites of Edward Creek Prospect in the Strangways Metamorphic Complex that is correlated to the D 2 deformation in this area. The pen is lying in the N-S direction and points towards north.

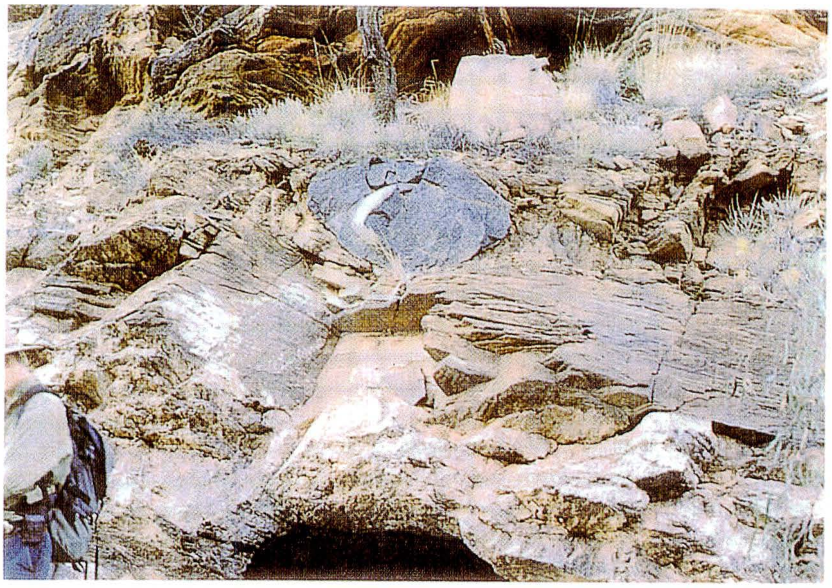


B : In the metapelites, garnets are enveloped by fine-grained biotite-sillimanite-rich assemblages in the intercalations of metapelites (1) and metabasites (2) at Florence Creek region. The pen points towards south.



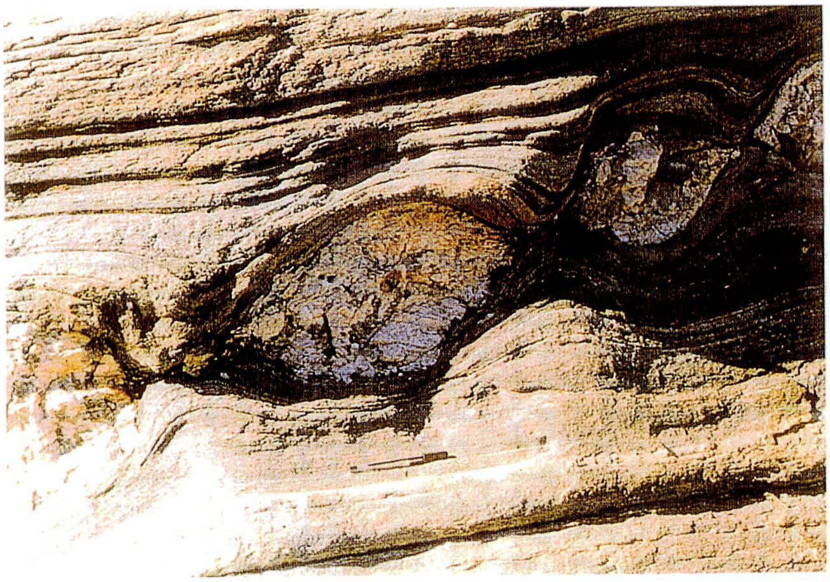
C : The intensely layered recumbent garnet-bearing metapelites (1) and metabasites (2) at the outcrop of Lizzie Creek bed. The regional sub-horizontal foliation S 2 is seen on the vertical section. The pen points towards south. This deformation event is dated ca. 475 Ma from a rock not from this exposure that is similar to the garnet-hornblende Sm-Nd age as dated by Foden et al., 1995. These D 2 fabrics formed at around 6-7 Kbar and 7000℃.

Plate 2



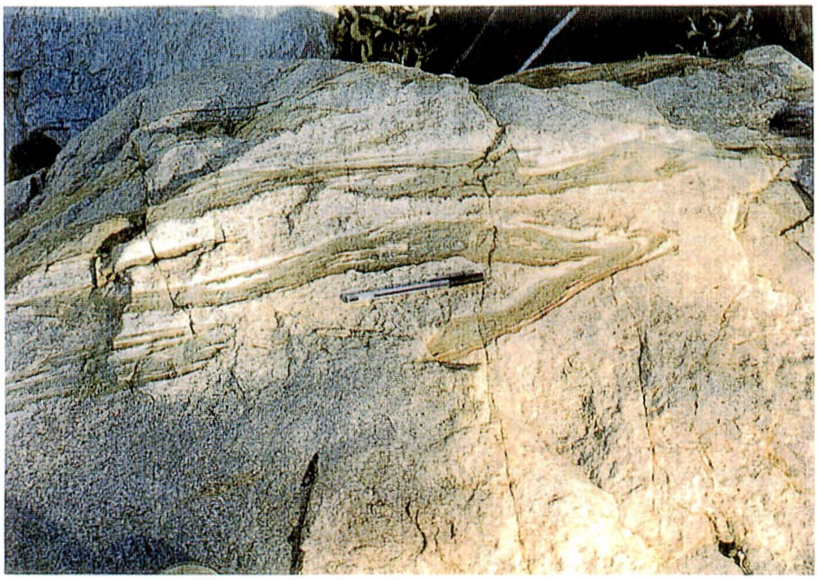
A : The migmatitic metapelites and associated muscovite-sillimanite bearing microgranite belonging to Irindina Supracrustal Assemblage at Eastern Belle Mines was mined for mica. On the face of the abandoned mine boudinaged mafic body is seen. This body is of 1 meter along the longer direction.

B : The fluid-absent melting of hornblende has been thought to have produced the garnet-bearing tonalitic melt which shows heterogeneity in terms of effective melt migration. Big garnet (single grain or cluster) is found to be rimmed by felsic materials at Mount Ruby.



C : Deformed pegmatites are the major component of Entia Gneiss Complex at Huckitta Creek. Beautifully boudinaged pegmatites are seen that has been emplaced in the biotite-bearing felsic gneiss at a low angle to the dominant foliation in this creek section.

Plate 3



A : Near the base of the low-strain zone at Huckitta Bore Boudin, intensely folded mafic layers with torn-off limbs are seen. The pen points towards south (bearing of 170°).

B : Typical look of the megacrystic Bruna gneiss with the big crystals of K-feldspar at the Bruna Gorge. Some places the K-feldspars are aligned and elongated along the foliation of this augen gneiss.