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Prince Charles Mountains Workshop, Abstracts

Compiled by G.T. Nichols

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PRINCE CHARLES MOUNTAINS WORKSHOP, ABSTRACTS

compiled by

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PREFACE

The abstracts compiled here are the result of the Prince Charles Mountains workshop held at the University of Tasmania on 26 June 1991. The workshop was part of the Eighth International Symposium on Gondwana. This volume provides an introduction to the ideas and research topics currently the subject of investigation in this area of Antarctica, by geoscientists mainly from Australian universities, but also those from the Bureau of Mineral Resources, the Australian Antarctic Division, and from Russian institutions.

The research themes covered by the abstracts range from a historical perspective of Australian geoscientists in the Prince Charles Mountains by Betts, to a geophysical appraisal of the East Antarctic region by Wellman. The results of geochemical and geochronological investigations of Proterozoic granulites are presented by Hensen et al. Whilst the structural and tectonic evolution of Proterozoic gneisses in the northern Prince Charles Mountains is the main research area, and is covered by Hand, Kamenev, Nichols, Scrimgeour, Stüwe, and Thost and Hensen. The geochemical evolution, age and tectonic environment of granitoids from the southern Prince Charles Mountains is described by Kovach and Belyatsky, and mafic igneous suites and their relationship to the Lambert-Amery rift are investigated by Mikhalsky. The magnitude and relative timing of Cretaceous exhumation of the Proterozoic granulites is evaluated with apatite fission track analysis, by Arne. The youngest rocks covered by current research in the region, are the Late Permian - Early Triassic sediments which comprise the Amery Group, and are the sedimentological interest of Fielding and Webb; these results are combined with sedimentary stratigraphy and basin analysis by Webb and Fielding, to establish the basin evolution of the Lambert Graben during Permo-Triassic times.

Kurt Stüwe is thanked for enthusiastically organising the PCM workshop, and in arranging Dr Kamenev's visit to Australia.

1. EVIDENCE FROM APATITE FISSION TRACK ANALYSIS FOR EARLY CRETACEOUS UPLIFT AND EROSION OF THE NORTHERN PRINCE CHARLES MOUNTAINS, ANTARCTICA

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Thirty-three samples of Precambrian basement, Upper Permian to Lower Triassic Amery Group sandstone, and post-Amery Group intrusive rocks from the northern Prince Charles Mountains have been evaluated by apatite fission track analysis to investigate their low temperature thermal history (i.e. $< \approx 110°C$) during the Phanerozoic. The results of this study place important new constraints on the thermotectonic evolution of the Prince Charles Mountains and suggest that uplift of the range was associated with Gondwana breakup.

Apatite fission track data in samples of Precambrian basement show consistent evidence of cooling from palaeotemperatures greater than ≈110°C in the Late Palaeozoic and in the Early Cretaceous. The fission track age of Precambrian basement apatites increases from 90.7±6.0 Ma near sea level to 306.7±12.6 Ma at an elevation of ≈2000 m. Samples with the oldest fission track ages preserve evidence of cooling below ≈110°C in the Late Palaeozoic, beginning in the Carboniferous and continuing through to the Permian, while samples with the youngest fission track ages (Radok Lake section) cooled below ≈110°C in the Early Cretaceous. Fission tracks in samples that were not totally annealed prior to cooling in the Early Cretaceous either show evidence of partial annealing at palaeotemperatures in the range 60-80°C (Mt Seaton section), or had already cooled below ≈60°C (Mt Kirkby section).

Detrital apatite grains in samples of Amery Group sandstone give fission track ages that increase from 81.5±9.0 Ma near the base of the preserved sequence to 314.2±24.4 Ma at the top. These data record various degrees of fission track annealing at palaeotemperatures greater than ≈110°C to ≈80°C respectively, during burial before exhumation in the Early Cretaceous. Palaeotemperatures in this range are also indicated by previous vitrinite reflectance determinations from coal seams in the Amery Group. Fission track data in detrital grains from the Amery Group are also consistent with the derivation of sediment from Precambrian basement similar to that preserved in the Mt Kirkby area.

Evaluation of apatite fission track data from adjacent three post-Amery Group intrusives indicates that they were emplaced in the mid-Cretaceous after regional cooling to palaeotemperatures below ≈50°C. Fission track data from these intrusions not only place important constraints on the thermal history of the region, but indicate that apatite fission track analysis may be used successfully to determine the ages of some post-Amery Group intrusives which are unsuited to other geochronological techniques.

These apatite fission track data not only indicate the magnitude of cooling since the Early Cretaceous, but also allow an estimation of the palaeogeothermal gradient before cooling. This suggests that cooling beginning in the Early Cretaceous may largely be attributed to exhumation involving the removal of several kilometres of material. As the relationship between exhumation and uplift of rocks in the region is not known, the amount of surface uplift since the Early Cretaceous cannot be constrained. However, it seems likely that rapid cooling in the Beaver Lake area during the Early Cretaceous resulted from uplift and erosion of the northern Prince Charles Mountains

during aborted rifting and asymmetric extension centred in the Lambert Graben. The timing of uplift and erosion suggests an association with the separation of east Antarctica and India during Gondwana breakup.

2. AUSTRALIANS IN THE PRINCE CHARLES MOUNTAINS

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Human activity on the Antarctic Continent began less than 100 years ago; however knowledge of the presence of the huge mountain range now known as the Prince Charles Mountains (PCMs) is even shorter, its extent only being significantly revealed for the first time in April 1954.

The sheer size and location of the PCMs makes operations in the region difficult. From the coast of Mac.Robertson Land to the southern outcrops of the mountains is almost 1000 km. This is equivalent to the distance between Melbourne and Newcastle in Australia, from Lenningrad [now St. Petersburg] to Kiev, the north-south length of England and Scotland, or Chicago to Washington DC. The mountains can be divided into two broad areas, the northern PCMs (nPCM) and the southern PCMs (sPCM). In size each has approximately the same area as Tasmania.

Australian expeditions were the first to open up the PCMs, and to date have conducted operations in three distinct phases, from 1954-61, 1968-74, and 1988 to the present time. Current plans are for the present program to continue up until around 1998, although operations will not be conducted in every season.

The Soviet Antarctic Expeditions were the only other group to have worked in the PCMs region, their first visit there being in 1966, with summer programs being conducted throughout the 1970s and 1980s, and continuing to this time.

The first phase of Australian operations in the 1950s was very much exploratory, and in terms of earth science a total of five geologists spent a total of around eight person seasons work there, six of those eight being the the nPCM and two in the sPCM. In the second phase from 1968-74 more work was possible because of the different nature of the logistics approach taken, and thirteen earth scientists worked for a total of twenty person seasons, activity being evenly divided between nPCM and sPCM. In the current phase, which began in 1988-89, and has concentrated on the nPCM alone, a total of twenty-two earth scientists have worked a total of twenty-eight person seasons.

All told forty-one Australian earth scientists have spent a total of around five person years of field time in the PCMs over the past 37 years. There has been little co-ordinated scientific activity between the Australian and Soviet programs, although both groups get on very well when working in the region, and there is a need to improve links with the Soviet program there in order to maximise the use of the total human resources that are being applied to the study of this important region.

Name	Affiliation	Season(s)
'Winter' phase — 3 earth scientists, total of 6 person 'seasons'		
B.H. Stinear	BMR (Geologist)	54-55, 57-58, 59-60
P.W. Crohn	BMR (Geologist)	55-56, 56-57
L.R. McLeod	BMR (Geologist)	58-59, 68-69, 69-70
First 'summer' phase — 7 earth scientists, total of 10 person 'seasons'		
J. Bain	BMR (Geologist)	68-69, 69-70
R. Dodson	BMR (Geologist)	70-71
D. Grainger	BMR (Geologist)	68-69, 69-70
R. Hill	BMR (Geologist)	70-71
A. Medveckey (Mond)	BMR (Geologist)	68-69
M.J. Robertson	BMR (Geophysicist)	70-71
R.J.Tingey	BMR (Geologist)	69-70, 70-71
Second 'summer' phase — 22 earth scientists, total of 28 person 'seasons'		
D. Adamson	Macquarie University (Geomorph.)	88-89
D. Arne	University of Melbourne (Geologist)	89-90
R. Brown	University of Melbourne (Geologist)	90-91
N. Cook	University of New England (Geologist)	89-90
P. Crosthwaite	BMR (Geophysicist)	89-90
W. Crowe	ANU (Geologist)	90-91
A. Darragh	Macquarie University (Geomorph.)	88-89
K. Docking	University of Melbourne (Geologist)	90-91
C. Fielding	University of Queensland (Geologist)	89-90
I. Fitzsimons	Edinburgh University (Geologist)	88-89
R. Flint	SA Department of Mines (Geologist)	87-88, 88-89
M. Hand	University of Melbourne (Geologist)	89-90
P. Kinny	ANU (Geologist)	90-91
B. McKelvey	University of New England (Geologist)	87-88, 89-90
M. Mabin	James Cook University (Geomorph.)	89-90
N. Munksgaard	Macquarie University (Geologist)	88-89
G. Nichols	University of Tasmanian (Geologist)	87-88, 88-89, 89-90
I. Scrimgeour	University of Adelaide (Geologist)	89-90, 90-91
N. Stephenson	University of New England (Geologist)	87-88, 89-90
K. Stuwe	University of Adelaide (Geologist)	89-90
D. Thost	University of NSW (Geologist)	88-89
J. Webb	La Trobe University (Geologist)	89-90

ANARE earth scientists in the sPCM: Total of 8 earth scientists over a total of 11 person seasons

'Winter' phase — 2 earth scientists for a total of 2 person 'seasons'		
R. Ruker	BMR (Geologist)	60-61
D.S. Trail	BMR (Geologist)	60-61
First 'summer' phase — 7 earth scientists for a total of 10 person 'seasons'		
R.J. Tingey	BMR (Geologist)	70-71, 72-73
R.N. England	BMR (Geologist)	70-71, 72-73, 73-74
J. Petkovic	BMR (Geophysicist)	70-71
J. Sheraton	BMR (Geologist)	72-73
P. Arriens	ANU (Geologist)	72-73
A. Langworthy	BMR (Geologist)	73-74
R.A. Almond	BMR (Geophysicist)	73-74

3. SEDIMENTOLOGY OF THE PERMO-TRIASSIC AMERY GROUP IN THE NORTHERN PRINCE CHARLES MOUNTAINS

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The Permo-Triassic Amery Group comprises three formations, the basal Radok Conglomerate and overlying Bainmedart Coal Measures of Late Permian age, and the uppermost Flagstone Bench Formation (Late Permian to Triassic). All three units represent sediment accumulation in continental environments within a western extension of the north-south elongate Lambert Graben.

The Radok Conglomerate comprises over 400 m of interbedded coarse clastic sedimentary rocks, with significant mudrock and thin coals in the uppermost part of the unit. The base of the formation is not exposed. Conglomerate is in many cases matrix-supported and shows a mud-rich matrix; coarse clasts range up to 1.5 m in diameter, are poorly sorted and rounded, and dominantly composed of felsic granulite. Sandstone typically lacks an internal structure, and beds are often disrupted by soft-sediment deformation. Mudrock ranges from thin siltstone partings between coarse-grained beds to thick intervals of claystone and siltstone at the top of the unit (Panorama Point Beds). The facies assemblage, lateral facies variations and palaeocurrent distributions suggest that the Radok Conglomerate accumulated on alluvial fans with subaqueous fans issuing eastward and westward from active fault scarps into semi-permanent lakes and wetlands.

The overlying Bainmedart Coal Measures comprise about 1100 m of interbedded sandstones, siltstones, claystones and coals. Sandstones are the dominant lithology forming sheet-like bodies up to 30 m thick. Interbedded and fine-grained facies may also form thick and persistent units, and laterally extensive coal seams range up to 8 m in thickness. This unit was deposited in well established alluvial systems in which deep, probably braided rivers flowed axially (northward) down the dominant structural grain. In between active channels were floodbasin lakes and wetlands where peat was able to accumulate.

The Flagstone Bench Formation is sandstone-dominated, with quartzo-feldspathic sandstones similar in many respects to the underlying coal measures. In contrast to the latter, however, mudrock intervals show evidence of deposition in oxidising (i.e. well-drained) environments. Facies and palaeocurrent relationships suggest continuation of the axially-flowing fluvial systems established earlier, but with exposed floodplains flanking channels. A succession of more mudrock-dominated facies within the formation (Soyuz Member) shows evidence of derivation from the west, indicating interruption of the axial drainage net perhaps due to further movements along the western boundary fault.

The Amery Group represents a superbly-exposed example of continental rift-valley fill, illustrating the interplay between axial and transverse sediment dispersal systems in such basins.

4. THE GEOLOGY OF ELSE PLATFORM, NORTHERN PRINCE CHARLES MOUNTAINS, EAST ANTARCTICA

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Late Proterozoic metamorphic rocks on Else Platform on the eastern margin of the northern Prince Charles Mountains, East Antarctica consist of granulite, metasedimentary gneisses and granitoids that were metamorphosed and deformed approximately 1000 Ma. Peak metamorphic assemblages define the earliest penetrative foliation in this area and indicate conditions in the order of 700-750°C at 5-6 kbar. A second deformation, D_2 was preceded by the intrusion of numerous granites and caused strong north-south crustal compression, producing upright isoclinal folds culminating with the development of large ductile thrust faults. Synchronous with this, decompression textures overprinted the peak assemblages. What is not clear, is whether the textures actually record true decompression during crustal thickening, thereby implying a certain style of tectonic process, or simply reflect net decompression caused by the overprinting of an unrelated metamorphic event at lower pressure and similar temperature. This overprinting of higher pressure assemblages by lower pressure assemblages associated with north-south compression occurs throughout the northern Prince Charles Mountains.

During a later period of probable Phanerozoic deformation, small ductile shear zones were overprinted by basaltic dykes and associated brittle faults. The brittle faults are numerous and parallel the Lambert Graben and may be related to opening of that structure.

5. GEOCHEMISTRY AND GEOCHRONOLOGY OF PROTEROZOIC GRANULITES FROM THE NORTHERN PRINCE CHARLES MOUNTAINS, EAST ANTARCTICA

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The Late Proterozoic basement of the Porthos Range in the northern Prince Charles Mountains, east Antarctica, is dominated by a suite of felsic to mafic granulites derived from igneous and, less importantly, sedimentary protoliths. Compositionally, they are broadly similar to granulites occurring along the Mac.Robertson Land coast and in the southern Prince Charles Mountains. Ultramafic to mafic orthopyroxene-clinopyroxene granulites with relic igneous layering occur as lenses within the felsic to mafic granulites, and show compositional evidence of a cumulate origin.

The large charnockite bodies have similarities to the Mawson Charnockite, and may have formed via a two-stage partial melting process. The charnockite and host granulites are chemically very similar, and both may have been derived from a common middle to lower crustal source region. Undepleted K/Rb ratios suggest retention of original chemistry, with variations being due to igneous fractionation processes. Normalised trace-element patterns resembling modern-day arc settings suggest that the Porthos Range granulites were possibly generated in a subduction zone environment.

Nd model ages of granulites, charnockites and pelitic gneisses point to a minimum mantle derivation age of 1793±346 Ma for the nPCM crust. Rb/Sr whole rock ages for the same samples range from 882-1170 Ma with a most likely age of charnockite formation and late high grade metamorphism at 882±140 Ma. This age is supported by a Sm/Nd mineral isochron of 889±37 Ma on a nearby pelitic gneiss. A K/Ar age of 755±6 Ma on a metamorphosed but essentially undeformed basic dyke may date the waning stage of high grade metamorphism.

Combined Nd, Sr and O isotope information is consistent with a model of mixed mantle-metasedimentary derivation of the granulites and charnockites.

6. MAJOR TECTONIC PROVINCES AND EVOLUTION OF THE PRINCE CHARLES MOUNTAINS IN THE PRECAMBRIAN

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Some fragments of Early Archaean protocratons, Late Archaean granite-greenstone terrain, Proterozoic granulite-gneissic terrain and Late Proterozoic greenstone belt are recognised in the Prince Charles Mountains (PCM) area.

The largest fragment of the Early Archaean protocraton is the Vestfold Block. The granulites of the Vestfold Block were formed 3000-2800 Ma ago from the initial volcanic and sedimentary rocks older than 3100 Ma (Collerson *et al.* 1983). A minor fragment of the protocraton is found inside the Late Archaean granite-greenstone Ruker Terrain at Mawson Escarpment. It consists of a 3300 Ma old hypersthene tonalite converted about 2800-2700 Ma ago to biotite-homblende granite gneisses.

The Ruker Terrain occupies the southern PCM. It includes several greenstone belts intermingled with different kinds of granites including protocratonic fragments. Mafic, ultramafic and felsic volcanics, volcanoclastic, some sedimentary rocks, and banded iron formations. Metamorphism at greenschist and low grade amphibolite facies are specific features of greenstone belts. Isotopic data indicate that the Ruker Terrain (volcanism, sedimentation, granite extrusion and intrusion, deformation and metamorphism of greenschist facies) developed over a time interval between 3100 and 2700 Ma. Initial volcanic-sedimentary troughs developed upon and laterally to, an older protocraton that existed here since about 3300 Ma.

The Proterozoic granulite-gneissic terrain which occupies the northern part of the PCM and is subdivided into the northern charnockite-granulite Beaver Belt and a southern granite-gneiss schist, Lambert Province. Most rocks of the Beaver Belt are domes, sheets and tectonic slabs; some supracrustal sequences (mainly biotite-garnet gneisses) and mafic-ultramafic lenses occur. The Beaver Belt is intruded by large plutons of porphyroblastic subalkaline granitoids.

The Lambert Province is composed of a tectonic mixture of retrogressively metamorphosed Beaver Belt granulites and progressively metamorphosed supracrustals and granitoids of the Ruker Terrain. Distinctive features of the Lambert Province are mineral assemblages of high grade amphibolite facies, widespread banded gneisses and schists, calcareous rocks, abundant undeformed veins of leucogranites and pegmatites. Structural analysis and isotopic data show that the granu lite-gneissic terrain developed over a broad time interval between 2500 and 500 Ma and apparently through polycyclic evolution. The cycles of tectonic activity recognised culminated at approximately 2400, 2100, 1800, 1300, 1000 and 500±100 Ma (Tingey 1982, Ravich *et al.* 1978; Sheraton 1984; new data). The geologic events of the same ages are manifested by repeated metamorphism, basic dykes and granite vein intrusions in the protocratonic blocks and Ruker Terrain.

The Late Proterozoic greenstone Fisher Belt is located in the central PCM where it is entirely thrust bounded against the Lambert Province. The rocks of the Fisher Belt are mostly volcanics and intrusives of mafic, intermediate and felsic composition metamorphosed into epidote-amphibolite facies assemblages. No age determinations are available for metavolcanic sequences of the Fisher Belt. Isotopic data from plutonic rocks support the intrusion over a time interval between 1300 and 800 Ma. It is likely that metavolcanic sequences are also of a Late Proterozoic age. The Fisher Belt is thought to have originated as the first manifestation of a major tectonic cycle that produced most granulite and amphibolite facies rocks in the PCM and completed the formation of regional metamorphic zonality: a north-south change in metamorphic grade is apparent.

The structure of the PCM is dominated by multiple tight folding, thrusting and shearing. The majority of the large geologic bodies are tectonic slabs, nappes, fold-nappes and domes with intense internal folding, shearing and cleavage. Tectonic breccias, conglomerates, melange sequences and mylonite zones are very common. Syntectonic movement is represented mainly by overthrusting, underthrusting and strike-slipping. The normal faults are the latest.

Geochronologic and geologic data from the PCM demonstrate that this area has had a long and complex geological history and tectonic structure created by accretion and collision of Archaean protocratonics in the Proterozoic time.

7. STRUCTURE AND EVOLUTION OF THE ANTARCTIC SHIELD IN THE PRECAMBRIAN

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The following major structural types exist in the Precambrian Antarctic Shield: (1) Early Archaean protocratonic blocks; (2) Late Archaean-Proterozoic Wegener-Mawson mobile belt; (3) Proterozoic sedimentary-volcanogenic proto-aulacogens. Each type reflects successive stages of evolution of the Antarctic Shield in the Precambrian.

Protocratonic blocks (Napier, Vestfold, Bunger, West Ritscher, inferred South Lambert and Read) were formed between 3900 and 2400 Ma ago. They are dominated by ultrametamorphic plutonic domes built up of enderbitic, charnockitic and garnetiferous granite gneisses or tonalitic and trondhjemitic granite gneisses. Relics of the oldest greenstone belts, ultramafic bodies and mafic plutons occur between these domes and as xenoliths.

The Wegener-Mawson mobile belt (WMMB) strikes throughout the whole shield from east to west. It was formed between 3000 and 500 Ma ago and is characterised by a polycyclic evolution. The WMMB consists of granulite-gneissic terrains and granite-greenstone terrains. Metamorphic prograde and retrograde zoning in the WMMB is best explained by its nappe-block structure caused by collision and accretion of protocratons. Six cycles of tectonic activity in the WMMB culminating at approximately (±200 Ma) 2900, 2400, 1700, 1100 and 600 Ma are recognised. Initial stages of the first and fourth cycles are the most prominent (greenstone troughs, ultrabasites, low-gradient metamorphism). Final stages of the cycles (high gradient metamorphism, granites) are most evident in the second, fourth and fifth cycles. The cycles of tectonic activity are separated by epochs of partial or complete cratonization, marked by mafic dyke swarms, subalkaline and alkaline plutons,as well as plutons of stratified basic rocks. Cratonizations subsequent to 2400, 1100 and 600 Ma events were most extensive.

Proterozoic proto-aulacogens (Ritscher, Sandow-Amundsen possibly Tumpike) were formed 1800 to 600 Ma ago. Various volcanic and volcanoclastic rocks of the contrasted series and differentiated intrusive traps dominate in the fill of the proto-aulacogens. Formation of proto-aulacogens marked transition to the rift stage evolution of the Antarctic shield.

This kind of structural interpretation of Antarctic shield permits more accurate definition of the position of Antarctica within Gondwana. In particular, the WMMB and the Albany-Fraser province of Australia are branches of a single huge Precambrian mobile Belt.

8. GEOCHEMISTRY, AGE AND TECTONIC ENVIRONMENTS OF GRANITOIDS OF THE RUKER GRANITE-GREENSTONE TERRAIN (SOUTHERN PRINCE CHARLES MOUNTAINS, EAST ANTARCTICA)

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Reconnaissance results of investigations of U-Pb zircon systems, Sm-Nd whole-rock systematics, REE and other trace elements geochemistry of granitoids from the southern Mawson Escarpment (SME) and the Ruker Massif (RM) of the Ruker granite-greenstone terrain (GGT) are presented.

The Ruker GGT defined by Kamenev (1990) in southern Prince Charles Mountains consists of volcanogenic-sedimentary suites of different greenstone belts that formed along with granitic rock systems and piles of tectonic slabs, nappes and domes with complex inner folded structure.

Granitoid rocks in the SME are represented by:
a) 3.2 Ga old (T Nd (CHUR)) high-Al_2O_3 am-bt tonalite-trondhjemite gneisses with relics of granulite facies metamorphism assemblages. They have geochemical characteristics close to tonalite-trondhjemite grey gneiss terrains elsewhere and high-Al_2O_3 siliceous gneisses of the bi-modal suite of the Ancient Gneiss Complex (AGC), Kaapvaal Shield: fractionated REE patterns with steep L- and HREE sloping and with no or positive Eu anomaly, high Sr and low Rb, Ba, Zr, Nb and Hf concentrations. Derivation of high-Al_2O_3 tonalite-trondjhemites of the SME by partial melting of long term depleted in LREE mafic source ($\varepsilon Nd(T)=+1.3$) with grt±hbl in residue are proposed.

b) low-Al_2O_3 bt- and hbl-bt-qtz-fsp uniform and banded gneisses with prominent lineation, and their migmatites, have major-element and Zr/TiO_2 and Nb/Y characteristics similar to the low-Al_2O_3 rhyodacite and rhyolite. They are characterised by weakly fractionated REE patterns with gently sloping L- and HREE with small positive and prominent negative Eu anomaly; Sr and Rb contents are relatively low, whereas Ba, Zr, Nb and Hf concentrations are high. These rocks are similar to undepleted felsic volcanics of greenstone belts, low-Al_2O_3 siliceous gneisses of the Mkhondo metamorphite suite and bimodal suite of AGC. Origin of protoliths of low-Al_2O_3 gneisses yield T Nd(CHUR)=2.5 Ga and $\varepsilon Nd=+2.2\pm0.2$. Low-$Al_2O_3$ am-bt trondhjemite gneisses without lineation from a lens in meta-rhyolites have the same age (Pb-Pb from zircon). They are close to type B gneisses on geochemical affinities and probably formed in a similar manner.

3.0 Ga old coarse-grained cataclased porphyritic subalkaline bt-fsp granites and leucogranites of the RM have strongly fractionated REE patterns with steep L- and HREE sloping and prominent negative Eu anomaly; relatively high Rb and Ba and low Sr and Zr contents. There features are comparable with syn- and post-tectonic granites of the Eastern Kaapvaal shield. Granites of the RM may be derived by partial melting of pre-existing sialic crust similar to SME tonalite-trondhjemites ($\varepsilon Nd(T)=-1.75\pm0.4$) leaving pl+px±hb in residue with followed crystal fractionation of pl+hbl+bt±all.

The Nb-Y and Ta-Yb diagrams of high-Al_2O_3 tonalite-trondhjemitic rocks of the SME are compared with modern volcanic arc granites, whereas low-Al_2O_3 meta-rhyolites are close to those from plate granites. Subalkaline granites of the RM are similar to modern syn-collision granites.

The derivation of granitoid rocks of the Ruker granite-greenstone terrain is connected with an evolving geodynamic environment. At the same time these granitoids are comparable with Archaean granitoids of the Kaapvaal Shield.

9. PROTEROZOIC AND PALAEOZOIC MAFIC IGENOUS SUITES IN THE LAMBERT-AMERY RIFT ZONE

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The geologic setting and petrogenetic characteristics of basic igneous rocks are important indicators of lithosphere extension and rifting. In this report the dyke swarms in Vestfold Hills (VH), Mawson Escarpment (ME), Mt Collins (MC), Beaver Lake area and in the plutons at Mt Willing (MW) and MC, are considered to be manifestations of deep-seated processes preceding and accompanying Gondwana breakup.

Data presented in the paper suggest recurrent tectono-thermal events in the Lambert-Amery rift zone that were manifested in several igneous episodes. The earliest record of extensional igneous activity in brittle sialic crust is represented by Early Proterozoic (2400-1800 Ma) tholeiites in VH (Collerson and Sheraton 1986) and ME. The first rift-related magmatism is believed to have occurred at c.1400 Ma when the oldest alkaline mafic dyke rocks of K-Na character were formed (VH alkaline lamprophyres). The latter contain deep-seated nodules represented by dunites, Pl-bearing lherzolites, spinel lherzolites and other rock types. Some nodules may originate from depths as great as 80 km. A Late Proterozoic igneous event is believed to be represented in the central Prince Charles Mountains by a MC metasyenite-monzonite intrusion cut by numerous mafic dykes (partly of alkaline character) and by a MW layered gabbroid pluton. Metasyenites of MC are considered to have crystallised at 1400±80 Ma (U-Pb zircon data) and undergone subsequent thermal events at 1200, 870-900 and 500 Ma. The MW layered pluton might have originated during the same Late Proterozoic (c.1400 Ma) extensional event. Nine gabbro and gabbro-norite MW samples define a Sm-Nd whole-rock isochron of 1187±145 Ma corresponding probably to a recrystallisation event. Relatively high values of εNd=1.5-3.5 are thought to indicate a low degree of crustal contamination.

As subsequent accumulation in a depleted mantle source region of K-rich mineral phases (phlogopite) was not released until Middle Palaeozoic time marked by intrusion of lamproitic dykes (at Mt Bayliss and Mt Rubin). Ancient regional fracture zones marked by linear dyke swarms (Early Proterozoic predominantly W-E trending and Late Proterozoic N-S trending) were revived, and a new ENE direction was developed in Phanerozoic time. In the late Palaeozoic, renewed K-Na magmatic activity (dykes of alkaline dolerites and alkaline lamprophyres at 320 Ma) began in relation to initial pre-breakup rifting; it lasted until the major breakup event at c. 145-120 Ma.

10. DEFORMATIONAL HISTORY OF THE NORTHERN PRINCE CHARLES MOUNTAINS, EAST ANTARCTICA

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Granulite to upper amphibolite facies gneisses which experienced pervasive deformation in the Proterozoic, are exposed in the northern Prince Charles Mountains that constitute a well exposed fragment of an extensive belt of similar rocks recognised elsewhere in east Antarctica, extending as far west as the margin of Enderby Land and include the Reinbolt Hills and the Rauer Islands to the east.

Important to the understanding and conceptualisation of the deformational history of the high grade rocks of the northern Prince Charles Mountains, is the recognition of an early very high strain episode evidenced by a pervasive stretching mineral lineation composed of orthopyroxene, sillimanite and aggregates of amphiboles or garnet, the formation of quartz ribbons, the boudinage of competent mafic layers, the development of intrafolial sheath folds ('F_1'?) over a large areal area,the identification of early, recrystallized thrust zones, and continued high strain throughout the early stages of deformation producing transposition of fabrics.

The early high strain event is considered to have transposed all earlier layering, producing a layer parallel gneissosity ('S_1') which is refolded by isoclinal steeply plunging folds ('F_2') that are themselves refolded by tight, moderately plunging folds ('F_3') which are responsible for the approximately east-west strike of the gneissosity in the northern Prince Charles Mountains. The colinearity of stretching mineral lineations, intrafolial sheath folds and '$F_{2\text{-}3}$' fold axes, strongly suggests that this period of early deformation was rotational and progressive. A relatively minor fourth folding event is postulated on the basis of data collected at Mt Meredith which display a change in the orientation of mineral lineations about upright north-south striking axial planes.

Felsic gneisses with granitoid appearances such as K-feldspar phenocrysts and mafic xenoliths, are interpreted as having been emplaced after D_1, but prior to the $D_{2\text{-}3}$ episode, as their 'foliation' defined by the planar alignment of the K-feldspars is parallel to $S_{2\text{-}3}$. It is suggested that charnockites, exemplified by the Loewe Massif outcrops, were emplaced very late in $D_{2\text{-}3}$ to post D_3, as they generally have a massive appearance with only a weak alignment of K-feldspars. Fine grained 'aplitic' dykes and veins are occasionally folded by 'F_3' folds; however some veins also cross-cut these folds, indicating a protracted period of magmatic activity.

Sub-vertical to steeply dipping mylonitic sheer zones truncate the early high grade gneisses, granitoids and charnockites indicating the continuation of considerable crustal strain, but possibly related to the early part of the exhumation path, with deformation occurring in the brittle to ductile stress regime. Numerous pegmatite swarms post-date the mylonite zones and were emplaced in many cases along sub-horizontal shear zones, and are frequently encapsulated by biotite and amphibole rich zones implying relatively high, but localised, fluid (particularly water) infiltration.

Cretaceous(?) basaltic dykes intrude the gneisses in most regions of the northern Prince Charles Mountains, and are off-set by north-south striking faults. An Eocene (K/Ar) basaltic lava flow on the subdued topography of Manning Massif is the last recorded evidence of magmatic activity in the region.

11. BASEMENT GEOLOGY OF THE ELSE PLATFORM/JETTY PENINSULA REGION, NORTHERN PRINCE CHARLES MOUNTAINS

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The Else Platform/Jetty Peninsula region of the northern Prince Charles Mountains contains approximately 150 km^2 of granulite facies metamorphics of probable Proterozoic age which are separated from the rest of the Precambrian exposure of the northern PCMs by the Permo-Triassic sediments of the Beaver Lake Graben. This granulite facies terrain includes pelitic, semi-pelitic and calc-silicate metasediments, with numerous syn- and post-tectonic intrusions, preserving perhaps the most complete geological history, from Proterozoic sedimentation and metamorphism through to the Lambert Graben development of any region in the Prince Charles Mountains.

Peak metamorphism in the Jetty Peninsula region of around 750-800°C at 5-6 kbar was accompanied by intense deformation including at least two phases of isoclinal folding, and resulted in the development of sillimanite-biotite-garnet-cordierite-spinel assemblages in pelitic gneisses. As in much of the PCMs, isoclinally folded partial melts indicate that peak metamorphic conditions appear to have occurred early in this event. This was followed by E-W trending open to tight upright folding of the sequence (F_3), with the development of a weak to moderate S_3 foliation and lower pressure metamorphic assemblages. A broad east-west trending shear zone with a near vertical sense of movement then developed under amphibolite facies conditions. The final deformation was a NNE-SSW trending tight syncline (F_4) on Else Platform, which was apparently synchronous with the intrusion of fine grained biotite granite dykes, which are highly discordant to the regional gneissic foliation and which developed folded leucosomal segregations. These granites, as well as associated pegmatites and late mylonites which are common on northern Else Platform may be associated with the 500 Ma event.

N-S and NE-SW trending faulting associated with the development of the Lambert Graben was synchronous with the intrusion of Carboniferous to Permian dolerite dykes, and was followed by deposition of Permo-Triassic sandstone within the graben. Cretaceous alkaline stocks containing lherzolite nodules intruded the Permian sediments which are exposed in the vicinity of Soyuz, and hydrothermal activity along the faults resulted in extensive quartz veining with associated epidote and chlorite alteration.

12. A REVIEW OF THE BASEMENT GEOLOGY AND OUR CURRENT KNOWLEDGE THEREOF IN THE NORTHERN PRINCE CHARLES MOUNTAINS

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With the first sighting of the summits of the northern Prince Charles Mountains in 1949, the PCMs were the last major mountain range discovered on the face of the Earth. Consequently, our knowledge of their geology is as yet poor. Nevertheless, some important work has been done and it is the purpose of this talk to give an overview of what we know about the PCM and discuss where future research may be directed.

The 1950s and 1970s ANARE programs in the PCM have given us considerable detail of the outcrop distribution, knowledge about the location and distribution of Phanerozoic rocks, knowledge of the Archaean ages in predominantly the Southern PCM and the Mid-Proterozoic ages (approximately the same time as metamorphism in the Rayner Complex) of the northern PCM. We also have learnt from these programs about the important transition from greenschist facies metamorphism in the south, to low pressure granulite facies metamorphism in the north. In the Mawson Escarpment this transition is continuously exposed and the Prince Charles Mountains may therefore become in the future one of the classic localities for this much looked-for metamorphic geological feature. The early programs have provided us as well with map-, and aerial photography- coverage of most of the Prince Charles Mountains.

However, the modern PCM program of ANARE (1988 – 1991) has brought the first modern tectonic interpretations and detailed geological maps, and this talk and the whole workshop, are aimed at increasing our know1edge of the state of research. Modern studies exist of Else Platform (Hand et al. 1991); the Depot peak area (Stüwe and Hand 1991), Porthos Range (Thost and Fitzsimons 1991) and there are also some detailed calc silicate studies (Buick et al. 1990) which — together with the work of the adjacent areas in Ingrid Christensen coast (Stüwe and Powell 1989, Stüwe et al. 1989, Nichols and Berry 1991, Harley 1987, Harley 1988, Thost and Hensen 1990) and Mac.Robertson Land (e.g. Clarke et al. 1989) — give us our first insights into details of their geological evolution. Full time research on the basement geology of the PCM is currently being conducted by at least six scientists and much of their work from three field seasons is in the process of being published.

The work of these authors on the distribution of lithologies and classification of structures has given us a framework in which we may be able to continue to discuss the geological evolution. Thost and Fitzsimons have suggested a classification of the lithologies of the northern PCM based on work in the Athos and Porthos ranges. Their study identifies 1) Basement gneiss lithologies constituting the majority of outcrop with felsic gneisses (70% of outcrop), mafic granulite, ultramafic gneisses, metapelitic gneisses, banded amphibolites and calcsilicates; 2) deformed intrusive rocks made up of leucogneisses, charnockite (10% of outcrop) and metamorphosed mafic dykes and 3) undeformed intrusive rocks made up of felsic dykes, pegmatites, late planar veins and mafic dykes. This classification holds for most of the northern PCM.

Studies of the structural history differ in their classification between those of Thost and Fitzsimons, and Nichols but the histories are compatible in the field with Thost and Fitzsimons identifying a total of six deformation phases and Nichols identifying three related events with his D1 being equivalent to D3 of Thost and Fitzsimons.

Studies of the metamorphic history of the PCM are still practically absent (partly due to the lack of suitable lithologies) but preliminary work has identified peak metamorphic conditions of 5 kbar/ 730°C at Depot Peak (Stüwe); 5.8 kbar/700-800°C at Else Platform (Stüwe et al.); 6 kbar/700-800°C at Carter Peak (Thost); 6 kbar/700-800°C in the Nemesis Glacier area (Nichols) and 6 kbar/700°C at Fox Ridge (Hand).

The preliminary nature of the work on the metamorphic evolution of the area does not allow derivation of any detailed tectonic history. However, the work and the controversies outlined above pose a number of questions for the northern PCM. Some of these important questions include: (1) What is the origin of similar peak condition estimates for such a large geographic area as the northern PCM? (equal metamorphic peak conditions over large aerial extent versus equilibration conditions for rocks from different origin) (-> metamorphic work needed); (2) what was the event producing enormous volumes of intrusive rocks (orthogneisses) intruding only remnant quantities of metasediments? (-> modelling and interpretation work needed); (3) what is the structural picture governing the distribution of rock types and structures over the PCM as a whole? -> PCM map and regional structural work needed).

In concluding this talk it should be said that much of the data needed for some of the questions posed do exist from the detailed geoscience programs of the Soviet Union which have been continuously conducted in the PCM for almost 20 years. I would like to encourage the reader to cooperate with our Soviet colleagues.

13. STRUCTURE AND PETROLOGY OF GRANULITE FACIES GNEISSES OF THE PORTHOS RANGE, NORTHERN PRINCE CHARLES MOUNTAINS, ANTARCTICA

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The Porthos Range in the northern Prince Charles Mountains, Mac.Robertson Land, is composed of upper amphibolite to granulite facies metamorphic rocks. The most common rock type is felsic orthogneiss, which hosts lenses and layers of ultramafic and mafic granulite, pelitic gneiss and calcsilicate gneiss. These rocks are cross-cut by at least two generations of mafic dykes, and have undergone at least two partial-melting events resulting in the formation of leucogneiss bodies. Large intrusive bodies of charnockite are common, and pre-date the mafic dyke intrusion. To varying degrees, these rock types have all been affected by a number of deformational events. D_1 is expressed as a moderate to strong foliation, only preserved in the ultra-mafic and mafic gneiss pods and boudinaged layers. D_2 is recognised as a series of low amplitude, disharmonic folds (F_2), with wavelengths generally less than 50 cm, again preserved only within ultra-mafic and mafic gneiss bodies. D_3 has produced the dominant gneissic foliation in the area (S_3) in both the felsic and pelitic gneisses. D_1-D_3 may represent a deformational progression during a single tectonic event. D_4 folds S_3, with steep easterly plunging fold hinges. F_4 folds are tight to isoclinal, with wavelengths less than 5 m. During D_4, calc-silicates were mobilized, and cross-cut S_3, generally axial planar to F_4 folds. This was followed by charnockite and later mafic dyke intrusion. D_5 is a heterogeneous deformation, coaxial with D_4. In zones of high strain, it is manifest as a strong sub-vertical foliation (S_5) and/or easterly plunging lineation (L_5). These zones may be hundreds of metres wide. Separating these high strain zones are areas of large scale F_5 folds, which refold S_3, with wavelengths of 1-2 km. The high strain zones anastomose between outcrops, resulting in the tightening of F_5 hinge zones or transposition of limbs. D_1-D_5 occurred under granulite facies conditions, as evidenced by the widespread occurrence of orthopyroxene in the felsic gneisses and mafic dykes. In D_5 high strain zones, orthopyroxene remains stable.

D_6 produced small scale gently dipping shear zones and minor flexures. These shears are locally intruded by planar pegmatite dykes. A series of mylonites, which locally offset pegmatites, and pseudotachylites are assigned to D_7. The interval D_6-D_7 reflects a decrease in grade, with late planar quartz and epidote-bearing veins being associated with a greenschist facies overprint. Rare, basaltic dykes cross-cut all the other rock types.

Geothermobarometry indicates maximum pressure-temperature conditions (D_1-D_5) of 700±50°C and 0.6±0.1 GPa using garnet+orthopyroxene+quartz+plagioclase assemblages in semipelitic rocks and garnet-bearing charnockites, and garnet+cordierite+sillimanite+plagioclase+quartz+biotite+Kfeldspar assemblages in the metapelites. Somewhat higher peak temperatures are indicated by the stability of scapolite+quartz and scapolite+wollastonite+calcite in calcsilicates from the adjacent Aramis Range. Coarse grained garnets in metapelites contain inclusions of cordierite, and less commonly sillimanite. Rare mafic rocks from the western end of Mt McCarthy exhibit orthopyroxene rimmed by garnet where it is in contact with plagioclase. Overall, this suggests a counter-clockwise prograde evolution for this terrane, followed by near isobaric decompression.

14. LATE PERMIAN – EARLY TRIASSIC STRATIGRAPHY AND BASIN EVOLUTION OF THE LAMBERT GRABEN, NORTHERN PRINCE CHARLES MOUNTAINS, ANTARCTICA

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The Lambert Glacier, which drains northwards through the Prince Charles Mountains, occupies a major crustal structure known as the Lambert Graben. Before the Cretaceous break-up between Antarctica and India, the Lambert Graben was probably continuous with the Son-Mahanadi Graben in northeastern India. The only outcrops of Phanerozoic sediments within the Antarctic part of the graben are on the western side, around Beaver Lake. In this area there is a thick sequence of fluviatile Late Permian – Early Triassic sediments, named the Amery Group. Geophysical work and debris within moraines indicate that these sediments probably extend along the graben under the ice for at least 1000 km.

Fission track data show that the Lambert Graben was probably initiated in the Late Carboniferous by a period of faulting that uplifted the Precambrian metamorphics along the western, and probably also the eastern, margins. The earliest sediments to be deposited in the graben may have been Late Carboniferous or Early Permian glacigene strata, as boulders of probable Palaeozoic diamictite are common in moraines in the Beaver Lake area. Outcrops of this material are unknown, however.

In the Late Permian, the western margin of the graben was bounded by an uplifted range of Precambrian, metamorphics, largely felsic gneisses and granulites. Streams flowing eastwards from these mountains deposited a series of alluvial fan deltas, which prograded into a shallow lake within the graben. These sediments, called the Radok Conglomerate, outcrop to the west of Beaver Lake, and consist of interbedded greenish-grey matrix-rich feldspathic sandstones and conglomerates, over 400 m thick.

On the eastern side of Beaver Lake there is another small outcrop of Radok Conglomerate. Southwesterly palaeocurrents measured at this locality indicate that the Precambrian basement rocks along this side of Beaver Lake probably formed an uplifted area within the Lambert Graben. To the west was the Beaver Lake Sub-graben, 25-30 km wide, separated from the main basin which was over 80 km in width.

Overlying the Radok Conglomerate is the Bainmedart Coal Measures, over 1400 m of coarse-grained, buff-coloured quartzose and feldspathic sandstone, with minor interbedded siltstones and numerous, mostly thin coal seams. These sediments were deposited on a broad alluvial plain by a north-northeasterly flowing braided river system. This system drained axially down the Lambert Graben, and probably flowed northwards into the Son-Mahanadi Graben, which has similar sediments of the same age. The coal seams of the Bainmedart Coal Measures are almost invariably directly overlain by coarse sandstone perhaps as the result of sudden switching of the course of the braided river system either side of the basement high within the graben.

About 300 m above the base of the coal measures is the Dragon's Teeth Member, a thin lensoidal unit of carbonaceous claystone containing upwards-coarsening sandstone cycles. The lowermost bed within this member is a silicified peat with abundant petrified wood. The Dragon's Teeth Member formed in a shallow lake, perhaps dammed by minor earth movements.

The top of the Bainmedart Coal Measures is not exposed; this unit is faulted against the Early Triassic Flagstone Bench Formation, which is underlain to the east by the Soyuz Formation.

The Soyuz Formation is at least 150 m thick, and consists of interbedded sandstone and siltstone with colour-mottled red-brown and green alluvial palaeosols showing large-scale mud-cracking. The lack of coal seams and the abundance of mud cracks suggest that the climate was more arid than during the deposition of the Bainmedart Coal Measures. Similar sediments accumulated elsewhere in Gondwana at this time, e.g. eastern Australia. Palaeocurrent directions in the Soyuz Formation are from the west, so it seems likely that renewed uplift of the western margin had diverted the rivers in this area towards the east. By this time the basement high within the Lambert Graben had been buried by accumulating sediment.

The overlying Flagstone Bench Formation is over 200 m thick, and consists almost entirely of quartzose and feldspathic sandstone. An Early Triassic flora *(Dicroidium zuberi* and *Voltziopsis* cf. *angusta)* was collected from a siltstone bed near the base of the formation. This unit represents the re-establishment of the north-flowing braided river system, axial to the graben.

Fission track data indicate that the Flagstone Bench Formation was overlain by as much as 2-3 km of section prior to exhumation. The age of these strata is unknown, but may be Triassic or younger; the youngest sediments in the Son-Mahanadi Graben are Middle Triassic.

15. COMPILATION AND INTERPRETATION OF SOVIET AND AUSTRALIAN MAGNETIC, ICE THICKNESS AND GRAVITY DATA IN ENDERBY – MAC.ROBERTSON – PRINCESS ELIZABETH LAND REGION

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BMR and Sevmorgeologia have a cooperative program to digitally compile, integrate and interpret all aeromagnetic, ice thickness and gravity data for the Antarctic sector between Molodezhnaya and Mirny. By early 1991 most of the information was digital, and survey integration had started. Australian airborne data are derived from surveys in Enderby Land and ice thickness surveys in the southern Prince Charles Mountains. Soviet airborne surveys cover much of the area; they extend south to 74.5°S, but they do not provide ice thickness over the southern Prince Charles Mountains.

In the Enderby – Mac.Robertson – Elizabeth Lands region the upper crust consists mainly of Late Proterozoic rocks, but there are three areas of Archaean rock. In most of the exposed area the mapped geology is complex. However, aeromagnetic surveys show that throughout most of the region the dominant lithological variation of the Proterozoic rocks is east-striking, with long wavelength lithological features extending over 100 km. At the margins of the Archaean blocks there are gravity and magnetic anomalies caused by the processes at the block margins. These anomalies can be used to map the extent of the Archaean blocks under the ice cap and continental shelf, and to map the extent of the reworked zones around the Archaean blocks. The Palaeozoic graben may be restricted to the Amery Ice Shelf – Lower Lambert Glacier area.