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WORKSHOP ON ANTARCTIC GEOLOGY, 17-18 MAY 1979

ABSTRACTS

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Sponsored by the Bureau of Mineral Resources, Canberra and the School of Earth Sciences, University of Melbourne, and held at the University of Melbourne. The Workshop was organised by the Geology Sub Committee of the Australian National Committee for Antarctic Research.

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H. Brady
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Cores taken in sea-floor sediments below the Ross Ice Shelf indicate that open-water conditions existed in the Ross Sea embayment during the Middle Miocene. The Ross Sea received a steady input from glaciations on the Antarctic mainland on which there were still pockets of vegetation including angiosperms and gymnosperms. Evidence from Mount Feather, Southern Victoria Land indicates that Antarctic glacial drainage patterns changed in the early Tertiary due to the continued uplift of the Transantarctic Mountains.

MICROPALAEONTOLOGY IN THE DRY VALLEYS, SOUTHERN VICTORIA LAND.

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Diatom microfossils have been recovered from surface sections and drill holes in the Taylor and Wright Valleys, Southern Victoria Land. Wright Valley and Taylor Valley were fiords in the Miocene and Early Pliocene, and their subsequent terrestrial history is marked by glacial and lacustrine events. One drill hole in McMurdo Sound, 20 miles east of the dry valleys, has yielded evidence of related Pleistocene? glacial events in McMurdo Sound.

INDIAN OCEAN HOTSPOTS - AN ABSOLUTE FRAME OF REFERENCE FOR MOTION OF THE GONDWANA CONTINENTS

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The geometry and (incomplete) geochronology of Indian Ocean aseismic ridges and oceanic islands provide a good test of the proposition that hotspots remain fixed over long periods of time; that is, of an order of magnitude less than the relative motion between plate pairs. It is concluded that hotspot movement cannot be discerned, and that the widely distributed hotspots of the Indian Ocean provide a frame of reference for plate motions following the disintegration of Gondwanaland which is independent of paleomagnetism. This frame of reference is 'absolute', in that it gives the motion of the lithosphere with respect to the mantle. The absolute motion model indicates that Africa and Antarctica are now nearly stationary, that there must have been significant closure of East and West Antarctica before about 40 m.y., that Malagasy has been in its present position with respect to Africa for at least the last 100 m.y., and that the Kerguelen-Gaussberg Ridge is a complex lineament due to overlapping hotspot activity of different ages.

APPLICATIONS OF CATION PARTITION DATA TO DETERMINATION OF P,T HISTORY OF ENDERBY LAND GRANULITES, ANTARCTICA

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The Precambrian granulites of Enderby Land, Antarctica were metamorphosed at temperatures as high as 900°C, and underwent slow isobaric cooling at 10kb pressure. Mafic and pelitic granulites are characterised by retrograde reaction coronas, a variety of exsolution textures, and compositional zoning of minerals.

The pelitic rocks contain coexisting spinel-quartz, sapphirine-quartz, hypersthene-sillimanite-quartz and ozumilite on a regional scale. The mineral assemblages delimit the metamorphic maximum as $T > 900\text{-}920^{\circ}C$, $P \sim 10\text{-}11$ kb and also demonstrate that our present understanding of controls of Fe/Mg partitioning between coexisting garnet and cordierite is inadequate, at least for very magnesian cordierites and/or very high temperature/high pressure granulite conditions.

Studies of mafic rocks show development of garnet and exsolution textures during cooling of initial differentiated igneous rocks through the regional metamorphic conditions. The data from diverse rocks from a single locality suggest a marked compositional dependence (related to grossular content of garnet) to the garnet-clinopyroxene Fe-Mg exchange reaction. An experimental investigation of this effect has confirmed the compositional effect and reconciled previous inconsistencies in the temperature and pressure dependence of the Fe-Mg distribution coefficient for coexisting garnet-clinopyroxene in simple systems, eclogite, garnet peridotite and grospydite compositions. The experimentally determined geothermometer gives similar temperature estimates for garnet-clinopyroxene equilibration for neighbouring rocks of different composition and different K_D values.

The Enderby Land granulites provide a metamorphic terrane exceptionally suited to combination of experimental petrology and natural petrology in the establishment of valid methods of estimationof metamorphic conditions.

STRUCTURAL EVOLUTION OF ARCHAEAN SUPRACRUSTAL ROCKS AT AMUNDSEN BAY, EAST ANTARCTICA.

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A supracrustal sequence of granulite facies rocks exposed at Amundsen Bay, East Antarctica is dominated by metamorphosed arenites, pelites, iron-rich sediments, and rocks considered to have been of volcanogenic origin. Charnockitic magmas were developed and intruded into the sequence at the peak of prograde metamorphism which culminated with isoclinal folding during the D_1 deformational event. The folds show shallow east-west plunging axes and axial surfaces dipping steeply to the north, with poorly developed axial surface foliations. High metamorphic grades were maintained during the D_2 deformational event which is characterised by folds of similar geometry to D_1. The grade of metamorphism slowly decreased, with basic intrusions being injected into the sequences, still at granulite facies grades, at the commencement of D_3. By the completion of D_3 grades had probably dropped to amphibolite facies. The D_3 folds are asymmetric with long limbs dipping steeply to the north and short limbs shallowly to the north. The regional axial surface dips moderately to the north. F_3 folds control the regional orientations of rock strata and structural elements of the D_1 and D_2 events.

Post-deformational faulting was accompanied by further basic intrusions, most of which are unmetamorphosed. Some dykes have retrogressed to hornblende - biotite amphibolites where post-intrusive movement continued on the fault systems.

GEOLOGICAL STRUCTURE OF THE DONOVAN ISLANDS, CASEY AREA

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The rocks outcropping at the Donovan Islands are a sequence of biotite gneisses with strong foliation and localised intense disruption. Strike varies from northwesterly to west, with both northerly and southerly dips being recorded. Deformation can be divided into six geometrically distinct phases with at least the first four taking place during the main amphibolite-facies metamorphism. The major events are summarised as follows:

D_1 - first foliation development and boudinage associated with isoclinal folding.

D_2 - new foliation (most important regional foliation), folding, veining.

D_3 - crenulation cleavage developed and various types of lineation.

D_4 - recumbent isoclinal folds deform lineations and develop late crenulations.

D_5 - open folding of both limbs of F_4 folds.

D_6 - dome/basin interference patterns with F_5 folds.

MINERAL CHEMISTRY AND GEOTHERMOMETRY OF GRANULITES FROM ENDERBY LAND, ANTARCTICA

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Two-pyroxene granulites, garnet-orthopyroxene-quartz-feldspar granulites and two-pyroxene-garnet granulites from Enderby Land, Antarctica have been studied. The mineral chemistry of coexisting garnets and pyroxenes is described, and the equilibration temperatures of the rocks are estimated using two-pyroxene and garnet-clinopyroxene geothermometry.

Equilibration temperatures above 800°C are recorded in the two-pyroxene granulites. In the garnet-orthopyroxene-clinopyroxene granulites, garnet-clinopyroxene Fe-Mg partitioning indicates temperatures of 700°C. Two-pyroxene thermometry overestimates the temperatures of equilibration in comparison with other geothermometers used for these rocks.

Pressure estimeates, based on the Al_2O_3 content of orthopyroxene coexisting with garnet, for a range of garnet-orthopyroxene and garnet-orthopyroxene-clinopyroxene granulites are inconsistent with pressures indicated by other assemblages. In some cases negative pressures are obtained. Such results demonstrate the present limitations of this geobarometer for crustal assemblages. Some preliminary results of an experimental study of garnet-orthopyroxene equilibria being undertaken by the author are considered in the light of the natural rock data.

THE "PRE-BEACON" STRATIGRAPHY AND GEOLOGICAL DEVELOPMENT OF THE TRANSANTARCTIC MOUNTAINS

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The oldest known rocks of the Transantarctic Mountains are those of the Nimrod Group (Nimrod-Beardmore Glacier area), Wilson Group (North Victoria Land) and correlatives, which consist of gneiss, schist, marble, amphibolite, migmatite and quartzite. It has been suggested that the Nimrod Group meta-sediments, which may be as old as 2000 m.y., were deposited in shallow water colse to the eastern edge of the East Antarctic Craton. They were folded and metamorphosed during the Nimrod Orogeny at about 1000 m.y.

The Nimrod Group and correlatives are unconformably overlain by the Late Precambrian Beardmore Group and correlatives (Robertson Bay Group, Patuxent Formation, Goldie Formation, etc.) which consist of considerable thicknesses of greywacke, sandstone and mudstone. These sediments accumulated in a basin, or series of basins, along the present site of the Transantarctic Mountains. They were folded and metamorphosed during the 680-620 m.y. Beardmore Orogeny. In the Central Transantarctic Mountains there was an episode of granite emplacement and associated rhyolitic volcanism immediately following the Beardmore Orogeny.

Shallow-water, fossiliferous Early and Middle Cambrian sediments are known from the Pensacola Mountains (Nelson Limestone), and Nimrod Glacier area (Byrd Group), whereas in North Victoria Land (Bowers Group) Late Middle and Late Cambrian fossils are known. It is possible that Cambrian sedimentation occurred in two distinct belts, the Early and Middle Cambrian archaecyathid bearing one lying parallel to but well to the west of the late Middle-Late Cambrian belt, which included the Dundas Trough of Tasmania. All faunas show affinities with Australia, New Zealand, China and Siberia. The fossiliferous Cambrian sequences in North Victoria Land overly a clastic-mafic volcanic sequence and are overlain unconformably by a dominantly continental coarse quartzose sandstone of probable Late Cambrian age. In the Pensacola Mountains the Middle Cambrian Nelson Limestone is overlain by rhyolites, pyroclastics and associated sediments.

The Ross Orogeny (500-420 m.y.) folded and, in some places, metamorphosed the Precambrian and Cambrian rocks. During the orogeny the very widespread Granite Harbour Intrusives (granite, granodiorite, tonalite) were emplaced. Probable Late Ordovician to Silurian continental sediments (Neptune Group) were deposited in the Pensacola Mountains.

The Admiralty Intrusives (granite, granodiorite, of the Devonian - Late Carboniferous age (385-300 m.y.) intruded the Robertson Bay Group in North Victoria Land. The rhyolitic volcanics of the Gallipoli Porphyries may be extrusive equivalents of the Admiralty Intrusives.

APATITE FISSION-TRACK AGE PATTERNS IN ANTARCTICA: COMPARISON WITH SOUTHERN AUSTRALIA

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The blocking temperature for the retention of spontaneous fission tracks in apatites is known to be about 100°C, so that apatite fission - track ages are uniquely sensitive to mild thermal and tectonic events which have no effect on other dating systems. Previous work (Gleadow & Lowering 1978, Gleadow 1978) has shown a strong association of apatite fission-track ages with the early stages of continental rifting in basement rocks from a number of rifted continental margins. Apatite ages from King Island in Bass Strait range from 270 to 110 m.y. and the youngest of these are thought to be caused by increased heatflow, uplift and erosion during Lower Cretaceous rifting in this area, which eventually led to the breakup of Australia and Antarctica.

Apatite fission-track ages have now been determined on samples from George V Land in Antarctica, and other areas along the southern margin of Australia. These new data indicate apatite ages of 230 to 270 m.y. for coastal rocks in the Casey area and individual ages of 280 m.y. at Dumont d'Urville and 320 m.y. at Commonwealth Bay. Very similar ages have been obtained for areas of southern Australia which were adjacent to these on pre-drift reconstructions. Apatite ages of 250 to 300 m.y. were found in rocks from the Eyre Peninsula in South Australia and 230 to 290 m.y. from coastal samples in the Esperance area of Western Australia. The relatively low coastal apatite ages are in contrast to ages of around 500 m.y. found for apatites from inland occurrences in the Kalgoorlie area. A similar increase in apatite age away from the continental margin is implied in Antarctica by an age of 466 m.y. from an erratic boulder at Dumont d'Urville.

The area from Enderby Land to MacRobertson Land shows a more complex pattern of apatite ages, but these show no resemblence to much older values reported for apatites from Southern India (Nagpaul & Mehta 1975), usually reconstructed to lie adjacent to this part of Antarctica. On the eastern side of the Lambert Glacier and the Amery Ice Shelf, apatite ages are mostly between 240 and 360 m.y. Between Enderby Land and the northern Prince Charles Mountains, however, many Jurassic apatite ages occur reaching just below 160 m.y. and suggest that this area, like southeastern Australia, has been more severely affected than elsewhere by early events in the break-up history of Gondwanaland.

THE EVIDENCE FOR ~4000 m.y. CRUSTAL MATERIAL IN ARCHAEAN TERRAINS

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Ion microprobe measurement of $^{207}Pb/^{206}Pb$ ratios in 20 μm - diameter sites on individual zircon grains from Archaean terrains have shown that these sites preserve a range of apparent $^{207}Pb/^{206}Pb$ ages. The youngest ages, measured at the highest uranium sites, can normally be correlated with relatively major geological events affecting the rocks after their formation. The oldest ages are measured at the lowest uranium sites, and seem to refer to zircon grains inherited from pre-existing crustal rocks and incorporated in the present rocks when they formed (or perhaps re-formed) at a time presumably given by conventional total rock Rb/Sr isochron data.

In at least two Archaean terrains, the Amitsoq Gneisses of West Greenland and the Fyfe Hills Charnockites of Enderby Land (Antarctica), the oldest sites on zircon grains have $^{207}Pb/^{205}Pb$ ages of 4000 m.y. This would imply that zircon-bearing acidic rocks formed surface crustal rocks at least as long as 4000 m.y. ago in the source regions of both Archaean terrains as they now exist.

EVOLUTION OF THE GONDWANALAND ARCHAEAN SHIELD : ION MICROPROBE ZIRCON DATING AND SOUTHWESTERN AUSTRALIA/WILKES LAND, ANTARCTICA RELATIONSHIPS.

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The ion microprobe has been used to study $^{207}Pb/^{206}Pb$ ages on 20 μm-size sites on single zircon grains from coastal rocks on either side of the rift in the Gondwanaland Archaean Shield between southwestern Australia and Wilkes Land, Antarctica.

The rocks from southwestern Australia, collected from the islands of the Archipelago of the Recherche and the coastline around Esperance in southwestern Western Australia, form part of the Albany-Frazer Orogenic Domain, for which previous workers have reported geological events ranging from high-grade metamorphism around 1700-1600 m.y. and granitic intrusions at about 1100 m.y. The ion microprobe $^{207}Pb/^{205}Pb$ ages on individual 20 μm sites on zircon grains from a variety of rock types from the area shown a range from 1600 m.y. up to $\sim$3400 m.y. with an inverse dependence on the uranium abundance at each site. These results suggest that the zircons in the particular suite of rocks studied have a complex origin, with some representing material derived from pre-existing crustal rocks of granitic composition at least 3400 m.y. old, while others have either formed or been re-set during the previously recognised high-grade metamorphic event around 1600 m.y.

Gneisses and intrusive granitic rocks from the Windmill Islands and the Antarctic mainland in the vicinity of Casey Station, Wilkes Land, Antarctica have been studied by previous workers, who determined total-rock Rb/Sr isochrons of between 1400 and 1100 m.y. and biotite K/Ar ages of around 1100 m.y. Ion microprobe $^{207}Pb/^{206}Pb$ ages on zircons from a wide variety of rocks collected in the same area show a range from 1600 m.y. up

to 3100 m.y. again with an inverse relationship with the uranium content at each 20 um analysis site. The minimum zircon age of 1600 m.y. has not been recognised as a distinct event by previous workers, but it is identical with those from the Esperance area and probably relates to the same high-grade metamorphic event which affected both areas. The maximum zircon ages measured are at least 3100 m.y. and, although slightly younger than the oldest Esperance dates, would indicate that the Casey area rocks also contain zircons derived from pre-existing granitic country rocks at least 3100 m.y. old.

The similarity in the zircon data, taken along with the coincidence of a later 1100 m.y. old event in both regions, is strong evidence in support of conventional Gondwanaland reconstructions which place both areas in close association

STRUCTURAL HISTORY OF ENDERBY LAND, ANTARCTICA

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Enderby Land is part of the Precambrian East Antarctic Shield and makes up the western portion of the Australian Antarctic Territory. High-grade metamorphics of sedimentary, volcanic and plutonic origin are exposed, and have been subdivided into two metamorphic complexes - the Archaean Napier Complex and the Proterozoic Rayner Complex.

In the Napier Complex the earliest recognised deformation is characterised by mesoscopic intrafolial, irregular plastic, and isoclinal folds, as well as major, tight to isoclinal, overturned and recumbent folds. It was accompanied by granulite-facies metamorphism characterised by high temperatures and low P_{H_2O}. Later folding, which postdates the peak of that metamorphism, mainly controlled the regional strike in most of the Napier Complex and produced folds that are commonly upright, open and assymetric. A dolerite dyke suite - the Amundsen Dykes - postdates this later folding, but is itself older than near-vertical shear zones which are mostly confined to areas near the younger Rayner Complex.

The Rayner Complex probably incorporates reworked remnants of Napier Complex, and no Amundsen Dykes have been recognised. The earliest deformation preserved in the Rayner Complex is characterised by mesoscopic isoclinal and rare intrafolial folds with an axial-plaine foliation. Later open to tight folding with weak axial-plane fabric development was accompanied by granulite-facies metamorphism under conditions more hydrous than those prevailing in the formation of the Napier Complex.

THE BUTCHER RIDGE COMPLEX, DARWIN GLACIER, VICTORIA LAND, ANTARCTICA

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A banded sequence of felsic volcanic rocks is exposed at Butcher Ridge. These rocks crop out over an area of 30 sq. km and extend to 500 metres above the upper Darwin Glacier in Victoria Land, Antarctica. The banded rocks constitute a predominantly easterly dipping sequence, the layers or bands consisting of yellowish brown to black glassy porphyritic rocks of dacitic to rhyolitic composition. The colour zonation represents a transition from extensively altered to fresh glassy rocks and the bands are often persistently continuous at a relatively uniform thickness of several metres.

Abundant included xenoliths are predominantly siliceous in composition and exhibit extensive degrees of fusion. Coal-bearing xenoliths are also present and appear to have derived from the underlying Permian rocks of the Beacon Formation.

Numerous plug-like bodies of quartz dolerite are emplaced within the banded sequence. These dolerites do not exhibit chilled contact effects against the surrounding rocks, in contrast to a later sill of quartz dolerite, exposed in the southern part of the Ridge, which has developed a sharp chilled contact zone against both the dolerite and felsic lavas of the Butcher Ridge complex.

This later dolerite is similar in composition and mode of emplacement to the Jurassic Ferrar Dolerite occurring extensively throughout Victoria Land, and implies that the surrounding rocks of the Butcher Ridge complex are representative of an earlier stage of ?Ferrar igneous activity.

THE METAMORPHIC GEOLOGY OF ENDERBY LAND, ANTARCTICA

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The high-grade metamorphic rocks of Enderby Land, which form part of the East Antarctic Precambrian Shield, have been subdivided into two metamorphic complexes - the Archaean Napier Complex and the Proterozoic Rayner Complex. The Napier Complex consists predominantly of pyroxene-quartz-feldspar gneiss and garnet-quartz-feldspar gneiss, with subordinate mafic granulite, pyroxenite, and various siliceous, aluminous, and ferruginous metasediments. The gneisses are intruded by a suite of dolerite dykes - the Amundsen Dykes - and locally by granitic rocks and pegmatite.

Temperatures of at least 950°C at pressures of 8-10 kb, corresponding to intermediate-pressure granulite facies, were reached in parts of the Napier Complex, and the presence in metapelites of the rare parageneses sapphirine + quartz, orthopyroxene + sillimanite, and osumilite, as well as the common occurrence of calcic mesoperthite, is compatible with very low water pressures (less than 500 bars) during metamorphism. The metamorphic grade of the Rayner Complex is generally rather lower (upper amphibolite to granulite facies) than that of the Napier Complex, although high-pressure granulites occur locally, and water pressures were higher, as evidenced by the relative abundance of hydrous minerals (biotite and hornblende) and the absence of mesoperthite.

Much of the Rayner Complex probably represents reworked Napier Complex rocks, and Amundsen dykes occur only as metamorphosed relics. It is correlated with the Proterozoic metamorphics of the MacRobertson Land coast and northern Prince Charles Mountains on which Rb-Sr dates of 800-1100 m.y. have been obtained. The effects of the Rayner metamorphism on the Napier Complex are mostly confined to localised shear zones and areas of retrogression.

GEOCHEMISTRY OF MAFIC INTRUSIVE ROCKS OF EAST ANTARCTICA

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Tholeiitic dykes of probable Proterozoic age are widespread in Enderby Land, the southern Prince Charles Mountains, and the Vestfold Hills. Although only those of the Vestfold Hills have been dated (at about 1400 m.y.), field relations from the other areas indicate a generally similar age; these dykes may thus represent a related suite which extends for at least 1200 km.

Representatives of at least four distinct magma types have been recognised in Enderby Land. Quartz tholeiites of two types with generally similar major element compositions are present, one of which is characterised by relatively high TiO_2 and incompatible elements (K, P, Rb, Sr, Zr, Nb, Ba, La, and Ce). Rare olivine tholeiites show marked iron-enrichment and have high K_2O, Nb, and Ba. The remaining group consists of magnesian tholeiites, ranging from norite to hypersthene-bearing quartz tholeiites and relatively enriched in some incompatible elements (notably Pb, Th, U, and As), but depleted in P_2O_5 and Nb. The high MgO, Ni, and Cr contents of the norites suggest that they represent near-primary magmas, similar to liquids produced by hydrous melting of pyrolite at 10-20 kb. The more siliceous rocks of this group (about 8% normative quartz) may have been derived from a magma of similar composition to the norites by fractionation initially dominated by olivine, then by orthopyroxene and probably clinopyroxene.

Dykes from the Vestfold Hills include olivine tholeiites, quartz tholeiites, and Mg-rich hyperthene tholeiites, whereas those (mostly amphibolitised) from the southern Prince Charles Mountains comprise quartz tholeiites and subordinate olivine tholeiites. Rare mafic dykes which intrude Late Proterozoic (900-1100 m.y.) metamorphics of the northern Prince Charles Mountains and MacRobertson Land Coast are alkaline (alkali olivine basalt and tristanite) or have alkaline affinities. Those dated have given Phanerozoic ages.

Two isolated examples of K-rich mafic dykes from Enderby Land and the southern Prince Charles Mountains consist of K-richterite, phlogopite, K-feldspar, and apatite, with accessory anatase, rutile, sphene, barite, and zircon. Both belong to the rare ultrapotassic volcanic and sub-volcanic rock suite, and are characterised by extremely high K_2O, TiO_2, P_2O_5, Ba, Sr and Zr. That from Enderby Land is relatively magnesian, has higher Cr and Ni contents, and probably represents a near-primary magma, whereas the other, which has given a Silurian age, is more evolved (quartz-normative) and shows evidence of liquid immiscibility. The only other known occurrence of such rocks on the Antarctic continent are the leucitite lavas of Gaussberg, Wilhelm II Land.

EAST ANTARCTICA - THE KEY PIECE OF GONDWANALAND

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Geological evidence provides a constraint on the reassembly of continents into such groupings as Gondwanaland. East Antarctica has featured in many such reassemblies since du Toit identified it as the 'key piece' of Gondwanaland and predicted certain of its geological features on the basis of the continental drift hypothesis he espoused. However its roughly circular outline provides poor geometric control for the repositioning of supposed former continental neighbours against it, and the poorly exposed, and until recently poorly known geology provides few constraints. Other difficulties include the dearth of geological observations by the same workers on the supposedly once-conjugate coastlines, the scarcity of marine geophysical data around the East Antarctic coast, the poorly defined bathymetry in the same area, and failure to take into account the thickness of post break-up sediments off Antarctica and the effect of the ice load on the Antarctic continent.

Our knowledge has advanced in the past decade as a result of regional investigations, associated geochronological studies, and more detailed research. This is especially true of the western part of Australian Antarctic Territory, between 45°E and 80°E, where Archaean rocks in Enderby Land and the Vestfold Hills are separated from rocks of similar age in the southern Prince Charles Mountains by a 500 km-wide zone of high-grade metamorphic rocks which give Rb-Sr whole rock ages of about 1000 m.y. This zone is thought to extend west through the Rayner Complex in southern Enderby Land to Dronning Maud Land.

However, comparison of the Vestfold Hills - Prince Charles Mountains - Enderby Land area with that part of India most commonly placed against it in Gondwanaland reassemblies ramains unconvincing, despite the neat fit of the Enderby Land peninsula into the Bay of Bengal. In particular there are few indications in India of a major metamorphism at about 1000 m.y. Late Palaeozoic sediments, which occur inland in both India and East

Antarctica in down-faulted troughs surrounded by basement, are not helpful in controlling reconstructions. The broad geochronological patterns in the western sector of Australian Antarctic Territory are reminiscent of patterns in southern Africa, where the widespread Kibaran orogeny occurred at about 1000 $\pm$ 200 m.y., but such comparisons do not significantly constrain continental reassemblies.

EARLY CAINOZOIC GLACIAL HISTORY OF ANTARCTICA

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The Cainozoic era was one in which climatic changes occurred that were as drastic as any in earth history. Climatic extremes range from an ice-free globe at the beginning of the era, in which a meridional system of heat-transfer was dominant, and circulatory systems were sluggish, to the present situation of polar ice-caps, a strong latitudinal temperature gradient, and intense atmospheric and oceanic circulation. Events in Antarctica have been a major causal factor in this change, particularly with respect to changing circulation patterns. The isolation of Antarctica by the migration of Australia away to the north and the opening of the Drake Passage enabled the setting up of a circum-polar circulation which terminated the old meridional system and steepened the temperature gradient between equator and pole.

Evidence for the deterioration of Antarctica climates in the interval through the Palaeocene to the end of the Miocene comes from a variety of sources, e.g., oxygen isotopic ratios in sea water, ice-rafted debris in marine sediments, spatial and temporal distribution of siliceous and calcareous bioperic sediment, subglacial vulcanism, the composition of marine microbiota, and the evidence for continental vegetation.

Use of data from these sources suggests that the Palaeocene was an ice-free epoch, in which Antarctica was vegetated, and the surrounding high-latitude seas were warm enough for the deposition of carbonate oozes. The Eocene was comparably warm in its early phases, but the oxygen-isotope curvey for surface-water temperatures shows a steady decline through the epoch. Evidence for Eocene glaciation remains unconvincing. At the end of the epoch cool temperate forests covered at least the coastal regions of East Antarctica. There is good isotopic evidence for major cooling at the Eocene/Oligocene boundary, but it is less clear how this cooling was reflected in terms of Antarctic ice cover. There is no evidence yet of ice-rafting of glacially-eroded debris before the late Oligocene; the suggestion that there was extensive sea-ice development through much of the Oligocene is hard to reconcile with palynological evidence showing that vegetation persisted in the Ross Sea region until at least the latest Miocene.

The build up of the East Antarctic ice sheet to something approaching its modern dimensions occurred relatively quickly in the middle and early late Miocene. There is a time-lag between this event and the initiation of complete circum-polar circulation following the opening of Drake Passage in the earliest Miocene. At the end of the Miocene or the beginning of the Pliocene there was a major cooling event, shown in the sudden northward movement of a cold water front and in ice-shelf expansion. The timing of this event remains confused, but it seems possible that the buildup of the West Antarctic ice-sheet was associated with it; whether the association was cause or result remains uncertain.

ANTARCTIC AEROMAGNETIC AND PALAEOMAGNETIC WORK

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During 1977 and 1978, using the Pilatus Porter aircraft, simultaneous aeromagnetic and ice radar recordings were obtained along some long traverses. The measured total force magnetic field consists of a very long wavelength regional component, the terrain effect caused by rapid variation in ice thickness, and normal magnetic anomalies due to small areas of abnormally magnetic rock. I am analysing the records obtained so far to map the variations in apparent suceptibility of the rock under the ice. It is hoped that the map will show areas of sediments, metamorphic grade boundaries, and areas of iron-rich rock or basic intrusives.

Samples of late intrusives collected for palaeomagnetic work in 1977 are now being measured (by M. Idnurm). The samples include seven sites of pegmatites from Casey Bay in Enderby Land, fourty-four sites of Enderby Land basic dykes of a wide range of ages, and three sites of the major basic dyke suite in the Bunger Hills.

EASTERN ANTARCTIC GRAVITY SURVEYS IN THE SECTOR 30° TO 80°D

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Bureau of Mineral Resources, Canberra

Reconnaissance gravity surveys now cover a large part of this sector, from the coastline to 75°S. The surveys were carried out by Australia during 1969-77, by USSR during 1972-75, and by Japan during 1968-75. Observations were made on rock outcrops, and on ice - either along detailed glaciological ground-traverses or on a irregular grid using helicopter transport. Ice thickness has been measured using radar and seismic reflection; the ice thickness information allows Bouguer and isostatic maps to be drawn.

Most of the variation on the Bouguer anomaly map is explained by a correlation between these anomalies and the mass of rock and ice above sea-level in the surrounding 100 km^2 areas. This correlation proves that the rock and ice above sea-level is isostatically compensated, the compensation probably reflecting variation in crustal thickness. The amplitudes and wavelengths of isostatic anomalies are consistent with the area having higher than average variations in mean crustal density and greater than average lithospheric strength.

Most isostatic anomaly gradients overlie geologically mapped metamorphic grade or rock composition boundaries, but the cause of some gradients is unknown. The most prominent gravity gradient overlies the western margin of a major crustal rift underlying the Amery Ice Shelf. Structural variation across this rift is defined by a Soviet seismic profile.