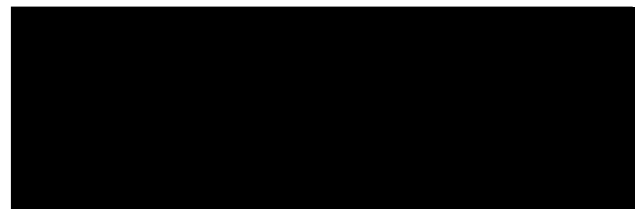


I declare that this dissertation is between  
10-20,000 words in length.



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"The tectonic evolution of Antarctica"

by

Richard Daniel Hamer

Diploma in Polar Studies dissertation,  
Scott Polar Research Institute,  
May 1977.



'Here at the focal point of past and future,  
The world is livid ice and lucid pain;  
The ways of light and darkness intersect,  
And the decisive spark goes out into the future.'

- Michael Roberts, 1936 -

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### Abstract

Five tectonic provinces; three volcanic provinces (each characteristic of a particular set of tectonic conditions) and a Precambrian shield, are outlined and described, in an attempt to illustrate the tectonic evolution of Antarctica. Evidence is presented for at least three structural stages in the development of the Precambrian shield, though it is not as yet possible to delineate individual tectonic provinces within the shield area.

From the late Proterozoic until the early Mesozoic, a series of tectonic provinces were successively stabilised and accreted onto the Pacific margin of the Precambrian shield. In the Mesozoic however, this unstable margin broke up into a number of blocks, as a result of differential movements between East and West Antarctica, associated with the fragmentation of Gondwanaland. Block tectonics, rifting and the development of fault-bounded marginal basins, were accompanied by alkali volcanism in the late Cenozoic. This activity continues at the present.

The proposed scheme is also viewed in the wider context of Gondwanaland and plate tectonics. Although the justification for long distance correlation of individual tectonic regions is called into question, four stages are illustrated in the evolution of the present Southern Hemisphere.

## Introduction

Antarctica is a roughly circular continent, centred approximately on the South Geographical Pole, 4500 km in diameter and covering an area of 14,000,000 km<sup>2</sup> (see fig. 1). It is the most isolated of all the continents, lying some 1000 km from Tierra del Fuego, 4000 km from South Africa and 3000 km from Australia and was the last continent to be systematically explored. Over 95% of Antarctica is covered by ice, up to 4.7 km thick, which spreads out over the shallow waters of the surrounding coastal regions to form extensive ice shelves. The coastal outline is broken by the narrow, sinuous Antarctic Peninsula and by two large embayments, known as the Ross and Weddell Seas. The existence of these embayments led to the division of the continent into two regions, Greater and Lesser Antarctica.\*

East Antarctica, that part of the continent lying mainly east of the Greenwich meridian, comprises a high ice plateau, deeply dissected on the sector adjacent the southern Indian Ocean, by the Lambert Glacier, which extends nearly 1000 km inland. Along the Ross-Weddell margin, a mountain chain, the Transantarctic Mountains, traverses the continent from western Queen Maud Land, to North Victoria Land. Airborne geophysical traverses across the East Antarctic ice sheet, have revealed the existence

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\* In geological literature, Greater Antarctica is known as East Antarctica and Lesser Antarctica as West Antarctica. Henceforth in this piece of work, the system of East and West Antarctica is adopted.



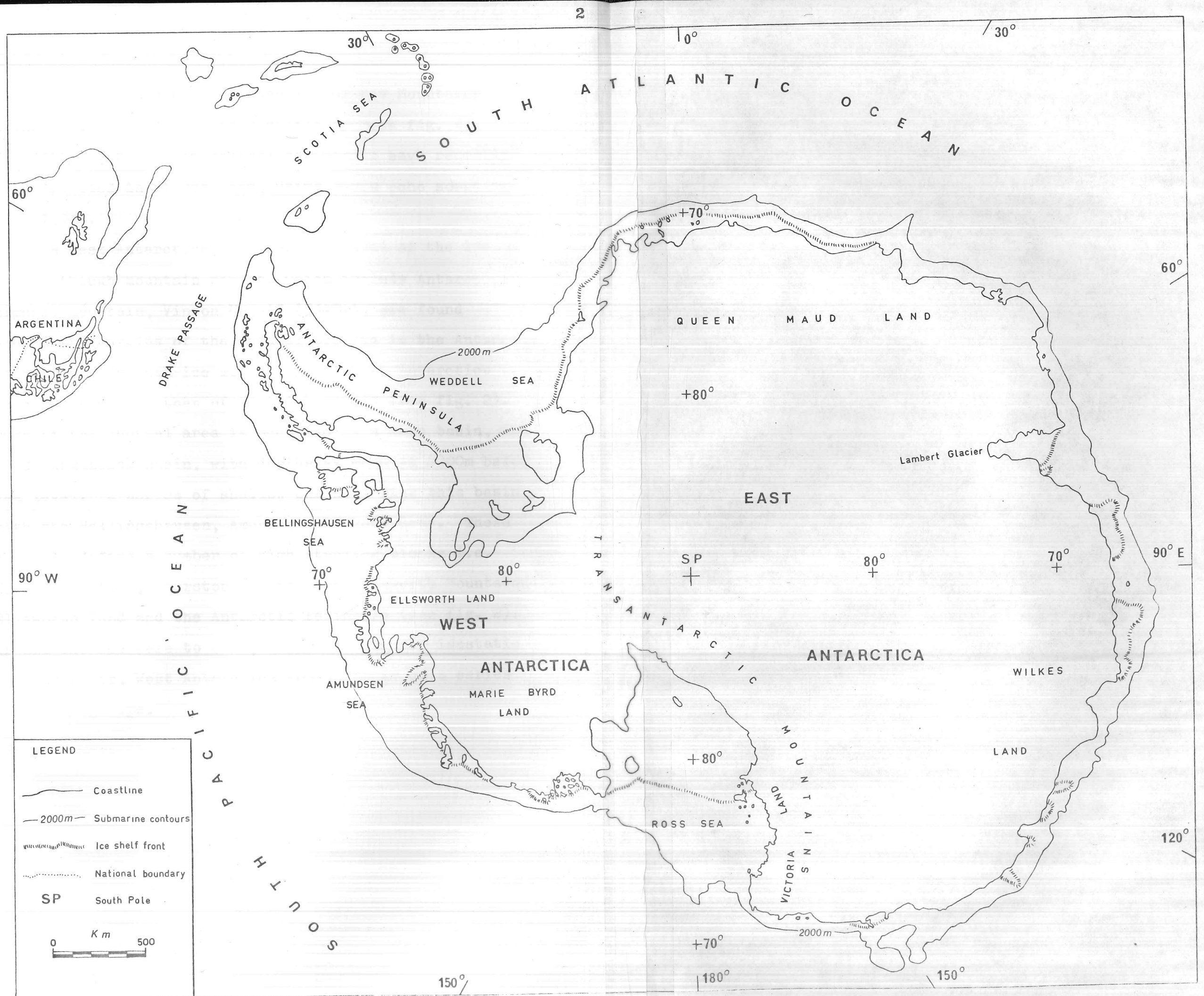


Fig.1 General location map - Polar stereographic projection



of a buried mountain range, the Gamburtsev Mountains lying near the Pole of Inaccessibility (see fig. 2). In addition, two major basinal structures have recently been detected in Wilkes Land, using radio echo sounding techniques.

In West Antarctica, the general level of the ice is lower, though mountain ranges, which include Antarctica's highest mountain, Vinson Massif (5140m), are found around the margins of the Weddell Sea and in the Antarctic Peninsula. The sub-ice morphology of West Antarctica is less uniform than that of East Antarctica (see fig. 2). Much of the central area is occupied by a deep basin, the Byrd Subglacial Basin, with depths as much as 2000m below sea level. A series of shallow channels link this basin with the Bellingshausen, Amundsen and Ross Seas. These channels define a number of high standing blocks i.e. Marie Byrd Land, Thurston Island, the Ellsworth Mountains, Ellsworth Land and the Antarctic Peninsula (see fig. 2). If all the ice were to melt, even allowing for isostatic readjustments, West Antarctica would appear as a series of island groups.

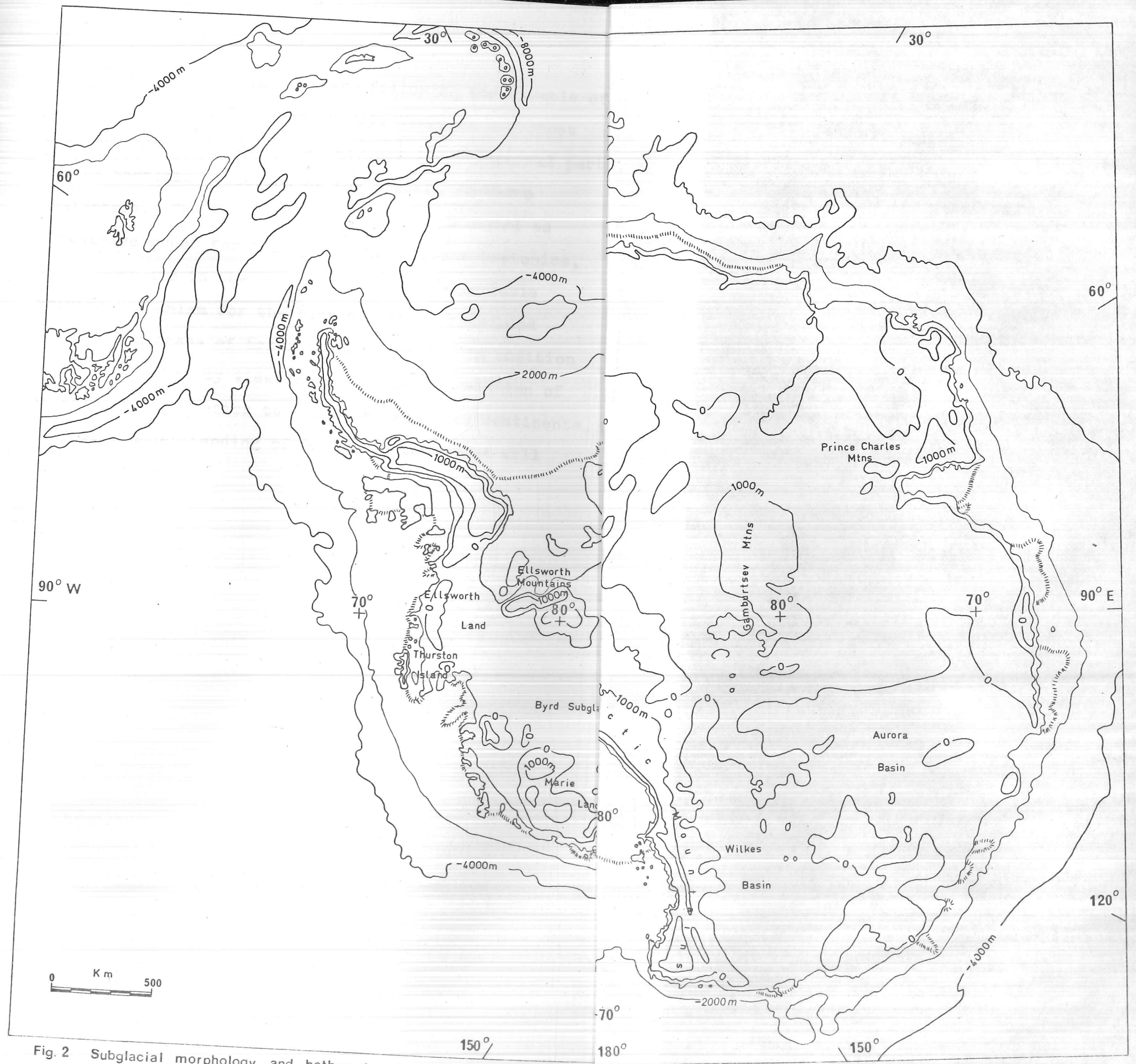


Fig. 2 Subglacial morphology and bathymetry

In this study, the writer, following the example of Ravich (1966) and Craddock (1970), seeks to interpret the tectonic evolution of Antarctica as an integral part of the tectonic evolution of the present Southern Hemisphere. The scheme outlined is not intended as conclusive proof for the operation of plate tectonics, which must lie in the elucidation of an acceptable driving mechanism for the plates. It is forwarded merely as a means of testing the concept. In addition it is hoped that by viewing the tectonic evolution of Antarctica in relation to the other southern continents, a greater understanding of Antarctic tectonics will be achieved.

## Chapter 1

## The history of research

Previous analyses of the geological structure of Antarctica have proposed a variety of tectonic patterns. Early in the twentieth century, Nordenskjöld (1913) suggested that Antarctica could be divided into two major regions, one (East Antarctica) comprising an ancient crystalline shield, overlain by younger undeformed sediments and the other (West Antarctica), displaying similarities to the Western Cordillera of the Americas.

In his review of Antarctic tectonics, Elliot (1975) noted that all the major geological units, with the exception of the Trinity Peninsula Series, were identified by the Swedish South-Polar Expedition 1901-3. Nordenskjöld's (1905) description of two structural zones in the Antarctic Peninsula region, demonstrating the geological similarities between the Peninsula and South America, supported the comparison already proposed by Arctowski (1895), and implied that the South American Andes and the Antarctic Peninsula had once formed part of a single, continuous mountain chain. The discovery of folded metasediments intruded by granitic plutons, in Marie Byrd Land, led Wade (1937) to suggest that structures similar to those of the Antarctic Peninsula, appeared elsewhere in West Antarctica.

The basic structure in the Transantarctic Mountains, of a crystalline basement overlain by Devonian-Permian sediments and intruded by doleritic sills of Jurassic age, was elucidated by geologists of the Scott and Shackleton expeditions (Ferrar, 1905; Priestley and David, 1912;



Taylor, 1913; Debenham, 1913). Gould (1935) sought to explain the present physiography of the Transantarctic Mountains in terms of block tectonics in the Cretaceous and early Cenozoic. He considered the recent volcanics of Ross Island and Victoria Land to be an expression of continued instability of these blocks.

In 1937, Du Toit with meritorious foresight, emphasised the unique importance of Antarctica in the understanding of the geological evolution of the Southern Hemisphere. Applying Wegener's hypothesis of continental drift to explain the similarity of geological history exhibited by the southern continents, he concluded that, "the role of the Antarctic is a vital one. As will be observed... the shield of East Antarctica constitutes the key-piece - shaped surprisingly like Australia, only larger - around which, with wonderful correspondence in outline, the remaining 'puzzle-pieces' of Gondwanaland, can with remarkable precision be fitted". Geological investigations in Antarctica since that time have, with a few minor adjustments, substantiated many of Du Toit's pioneering ideas.

The marked contrast in the geology of East and West Antarctica together with the existence of the two large embayments on the Pacific side of the Transantarctic Mountains, have long been cited as evidence for a major structural discontinuity across the continent. Despite the extensive study and rigorous debates which the topic has received and been the subject of respectively, the precise nature of the structural relations between

East and West Antarctica remains the major problem to be resolved in the understanding of Antarctic tectonics (Hamilton, 1967; Elliot, 1975).

The initiation of systematic geological mapping, in the Antarctic Peninsula, with the formation of the Falkland Islands Dependency Survey (now British Antarctic Survey) and in East Antarctica following the International Geophysical Year 1957-8, has considerably advanced the understanding of Antarctic tectonics. In 1952, Fairbridge summarised the knowledge of Antarctic tectonics with a map, which depicted the East Antarctic shield separated from the West Antarctic Mesozoic-Cenozoic folded zone, by a graben linking the Ross and Weddell Seas. Voronov (1958) showed an ancient shield with a Cenozoic block-faulted rim, bordered by an 'Alpine downwarp' and a folded zone in West Antarctica. More recently (1964), he portrayed an older 'Caledonian' folded zone in the Transantarctic Mountains, tectogenesis around much of the East Antarctic coast and forwarded the idea of a 'Hercynian' fold belt in Marie Byrd Land. Adie (1962, 1964) divided the continent into a Gondwana province (East Antarctica) and an Andean province (West Antarctica).

In 1963, Hamilton first proposed the idea of an East Antarctic shield bordered on one side by a series of orogenic belts younging towards the Pacific margin. These included a Cambro-Ordovician orogen; a Siluro-Permian orogen, and a Cretaceous orogen. Later (1964, 1967) he presented a scheme with a Precambrian shield in East Antarctica; a late Precambrian - early Palaeozoic orogen,

and a Palaeozoic orogen in the Transantarctic Mountains; a Mesozoic orogen and a Cenozoic volcanic province.

Klimov (1964, 1967), defined three structural stages in East Antarctica and extended Adie's Gondwana province to include parts of Ellsworth and Marie Byrd Lands.

Angino and Turner (1964) summarised the radiometric ages and illustrated distinct groupings of dates particularly around 500 Ma. In this fashion they presented evidence for seven recognisable orogenies in Antarctica. Ravich (1966) analysed the major tectonic features of Antarctica in relation to the other southern continents. In Antarctica these included pre-Riphean folding; Baikalian (Caledonian) folding; Palaeozoic folding; Mesozoic-Cenozoic folding and a Cenozoic volcanic province. In 1968, he outlined three tectonic regions - the East Antarctic platform; a late 'Hercynian' fold belt and a Mesozoic fold belt, for which he introduced the term *Antarctandes*.

Grindley and McDougall (1969) cited evidence for two orogenic episodes in the Transantarctic Mountains, one of late Precambrian age - the Beardmore orogen and the other of early Palaeozoic age - the Ross orogen. The following year, Ravich and Grikurov recognised a crystalline basement ranging from Archean-middle Proterozoic in age; a Riphean-early Palaeozoic complex; a middle Palaeozoic-Mesozoic complex; two platform sequences, one Riphean and the other Devonian-Jurassic and a Neogene-Quaternary volcanogenic belt.

Craddock (1970, 1975) outlined an ancient Precambrian

shield, four Phanerozoic orogens and a Cenozoic volcanic province. The contrasts in tectonic setting of the late Mesozoic-Cenozoic orogenic activity, between the Andes and the Antarctic Peninsula, were first emphasised by Katz (1973), who concluded that the use of such terms as Antarctandes was invalid and should be discontinued.

In reviewing the previous attempts to elucidate Antarctic tectonics, Elliot (1975) described an East Antarctic shield with associated platform sediments; a late Precambrian Beardmore, and an early Palaeozoic Ross orogenic episode in the Transantarctic Mountains; a Borchgrevink orogen; an Andean orogen and three distinct Cenozoic volcanic provinces.

Most recently, Tingey (personal communication December 1976) has isolated radiometric dates within the 2800-2600 Ma range from MacRobertson Land in East Antarctica. These provide the first evidence from the Antarctic Precambrian record of a tectonic episode of that age, well known in the Precambrian stratigraphy of the other southern continents.



## Chapter 2 Criteria for the selection of tectonic units

There are basically four criteria which can be adopted for the selection of units in the compilation of a tectonic scheme:

- a) The distinction between flat-lying and deformed strata.
- b) The age of the units.
- c) The origin e.g. volcanic.
- d) The tectonic environment e.g. compressive.

The effectiveness of tectonic schemes is controlled by the current state of knowledge of the regional geology in the area under study. In a favourable situation, where such knowledge is reasonably complete, all four criteria may be incorporated into the scheme. Elsewhere, the limitations imposed by the level of knowledge of the regional geology, diminish the effectiveness of proposed tectonic interpretations.

In Antarctica the tectonic geologist is confronted by a number of problems, some common to all regions and others that are exclusively Antarctic. First, more than 95% of the continent is covered by ice, up to 4.7km thick. The knowledge of the area beneath the ice is confined to a few geophysical surveys, whereas the scattered rock outcrops around the perimeter of the continent and throughout the Transantarctic Mountains have been mapped only on a reconnaissance basis. Considering the fact that Antarctica has been subjected to systematic investigation for less than a quarter of a century, the knowledge of the regional geology is still in a preliminary state.

Secondly, the interpretation of many rock units is

based solely upon radiometric dating, which may be inaccurate, or correlation with similar rocks of known age, which may be invalid. The writer considers that in the absence of more conclusive evidence, such methods are worthy of mention and may prove to be justified, but stresses that general agreement upon these interpretations is lacking.

Thirdly, it appears that the Pacific margin of Antarctica has been the location of repeated tectonic disturbances, throughout a considerable span of geological time. From the late Proterozoic until the early Cenozoic, successive phases of activity have overlapped each other geographically (to varying degrees), partially obliterating previous events. Also, as Craddock (1970) pointed out, the individual orogenies have indefinite and arbitrary limits.

Finally, it should be borne in mind that the present distribution and relationship of tectonic units to each other, particularly in West Antarctica, need not have remained constant throughout geological time. There is strong evidence to support the idea that the Ellsworth Mountains of West Antarctica may have been rotated, in the early Mesozoic, from an original position on the eastern side of the Weddell Sea, as a result of differential movements between East and West Antarctica.

### Chapter 3      The tectonic regions of Antarctica

Using the criteria outlined in the previous chapter, it has been possible to distinguish nine major tectonic regions in the Antarctic. Five of these display stages of erosion, sedimentation, tectonics, plutonism and volcanism, associated with the operation of a single geological cycle and are referred to as tectonic provinces (Quennel and Haldemann, 1960); three are areas of Cenozoic-Recent igneous activity, characteristic of a particular set of tectonic conditions; and the remaining region, comprising a large block of deformed, metamorphosed and granitised continental crust, which has not undergone significant tectonic disturbance since early geological time, is termed a shield.

Although the five tectonic provinces are similar in many respects, it is important to realise that no two tectonic provinces are exactly alike. The sequence of development may not be the same and some stages may be missed out altogether. Equally important is the idea that the stages may not be synchronous throughout any one province - sedimentation may be taking place in one region, whereas deformation may be occurring in another.

Each unit will be dealt with in turn, beginning with the oldest.

#### A. The East Antarctic shield.

The East Antarctic shield is the oldest and most extensive tectonic region in the Antarctic. It comprises most of the larger part of the continent (see fig. 3),

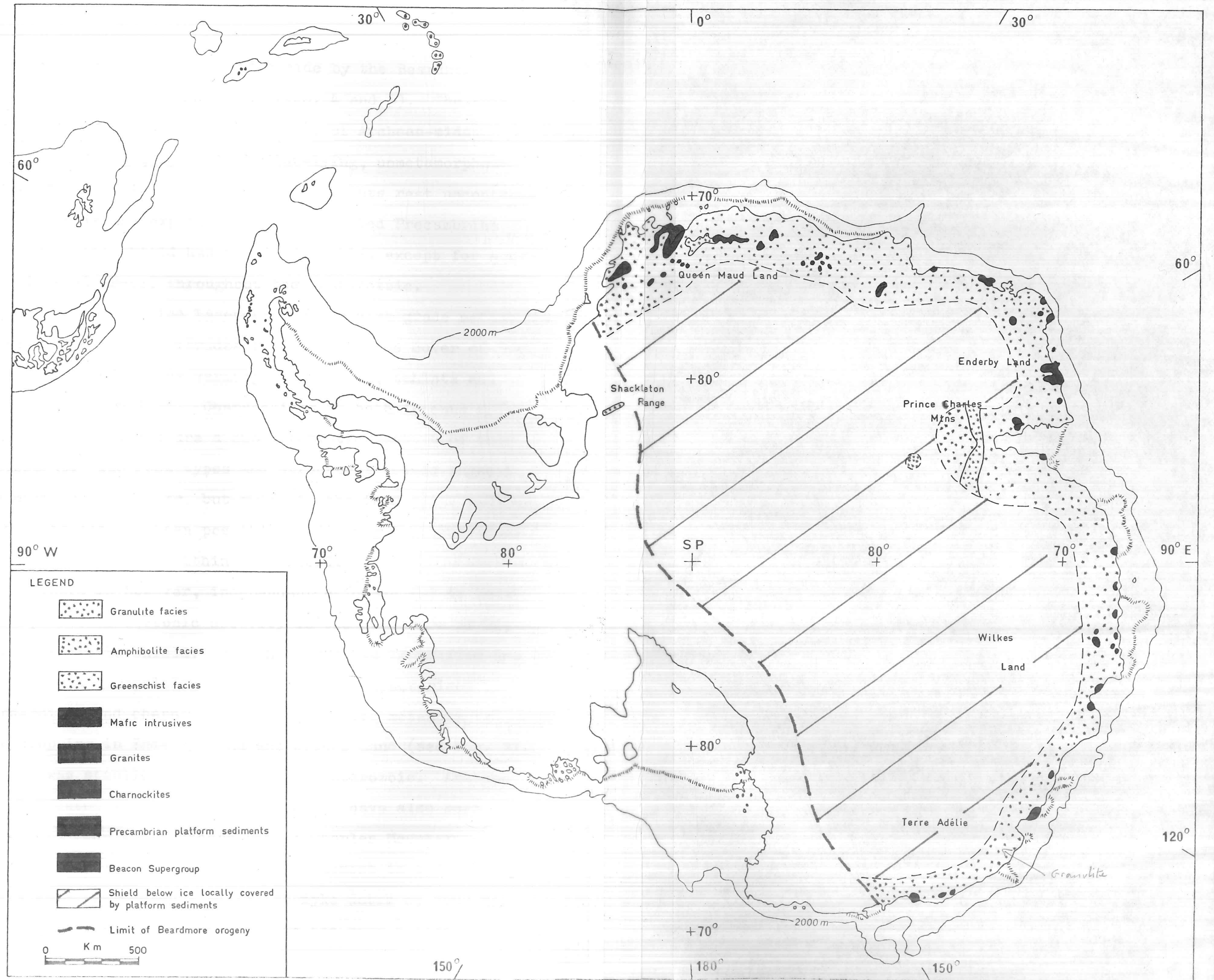


Fig. 3 The East Antarctic shield



and is bounded on the Pacific side by the Beardmore and Ross tectonic provinces (see figs. 4 and 5). The shield consists of a crystalline basement of Archean-middle Proterozoic age, upon which flat-lying, unmetamorphosed late Proterozoic and Palaeozoic sediments rest unconformably. Although it has experienced a complicated Precambrian history, the shield has remained stable, except for a few peripheral areas, throughout the Phanerozoic.

The crystalline basement forms a high grade metamorphic terrain where it protrudes from beneath the cover of ice, consisting of a wide variety of gneisses, schists and plutonic intrusives. Charnockites of both igneous and metamorphic origin are a characteristic feature of this basement. The rock types and structural trends suggest a multiphase history, but owing to the inadequate radiometric data, it has not been possible to distinguish individual tectonic provinces within the shield.

There is however, independent evidence for at least two phases of tectonic activity in the evolution of the East Antarctic shield. Ravich (1972) has identified an older stage comprising Archean rocks, characterised by enderbites and charnockites and granulite metamorphism, outcropping in Enderby Land and Wilkes Land (see fig. 3), which was stabilised by the early Proterozoic. Archean rocks, dated at between 2800-2600 Ma, have also been reported from the southern Prince Charles Mountains by Tingey (1976). Here, a granitic basement is overlain by metasediments cut by a pegmatite dyke dated at 2580 Ma. Similar sediments nearby, contain the only banded

ironstones known from the Antarctic Precambrian (Tingey et al. 1976). No true greenstone belts have yet been identified from these Archean regions of the basement.

Ravich (1972) also records a second phase of activity in the middle Proterozoic. At this time, linear belts of the Archean were deformed and suffered retrogressive metamorphism to amphibolite and greenschist facies. Migmatites and granitic intrusives are common, but enderbites and charnockites are lacking, which implies a higher structural level and lower temperatures.

Radiometric dates falling within the 1200-1000 Ma range, have been obtained from crystalline basement rocks in the Transantarctic Mountains, and from migmatites in Wilkes Land. In the Transantarctic Mountains this has been referred to as the Nimrod orogeny (Grindley and McDougall 1969). It should be emphasised however, that the ages of these periods of orogenic activity are open to question.

In Queen Maud Land (see fig. 3), the crystalline basement is overlain by late Proterozoic-early Palaeozoic platform sediments and volcanics of the Ritscher Supergroup. These rocks have suffered only slight metamorphism and deformation (Neethling, 1972). A younger platform sequence of middle Palaeozoic-(?)early Mesozoic age, overlies the Ritscher Supergroup in Queen Maud Land, and is found in direct contact with the basement in the Prince Charles Mountains. This forms part of the Beacon Supergroup.

The numerous glacial erratics around the coastline of East Antarctica (Craddock, 1972), together with the evidence for the existence of two major sedimentary

basins in Wilkes Land and Terre Adélie (Drewry, 1976), suggest that these two epicratonic platform sequences may underlie extensive areas of the East Antarctic ice sheet.

#### B. The Beardmore tectonic province.

Late Proterozoic sediments and volcanics, deposited in a series of elongate basins along the line of the Transantarctic Mountains (see fig. 4), were deformed, metamorphosed and intruded between 680-620 Ma. This phase of activity was first recognised from the central Transantarctic Mountains by Grindley and McDougall (1969), who introduced the term Beardmore orogeny. Elliot (1975) describes a Beardmore orogen, which closely resembles the tectonic province outlined in this section.

In the late Precambrian, thick sequences of graywacke-shale, locally overlain by acidic volcanics, were deposited in the Transantarctic Mountain region, between North Victoria Land and the Pensacola Mountains and possibly extending as far as the Shackleton Range. In the Nimrod Glacier region (see fig. 4), this sequence overlies older rocks. Here, over 500m of schist, marble and quartzite of the Cobham Formation, underlie 6700m of metagraywacke-shale of the Goldie Formation. The former is considered to have been deposited in moderately shallow water, probably the inner margin of a continental shelf, whereas the latter accumulated as a turbidite deposit in relatively deep water. It is overlain, with angular unconformity, by archaeocyathid limestones of lower Cambrian age (Laird and Mansergh, 1971).



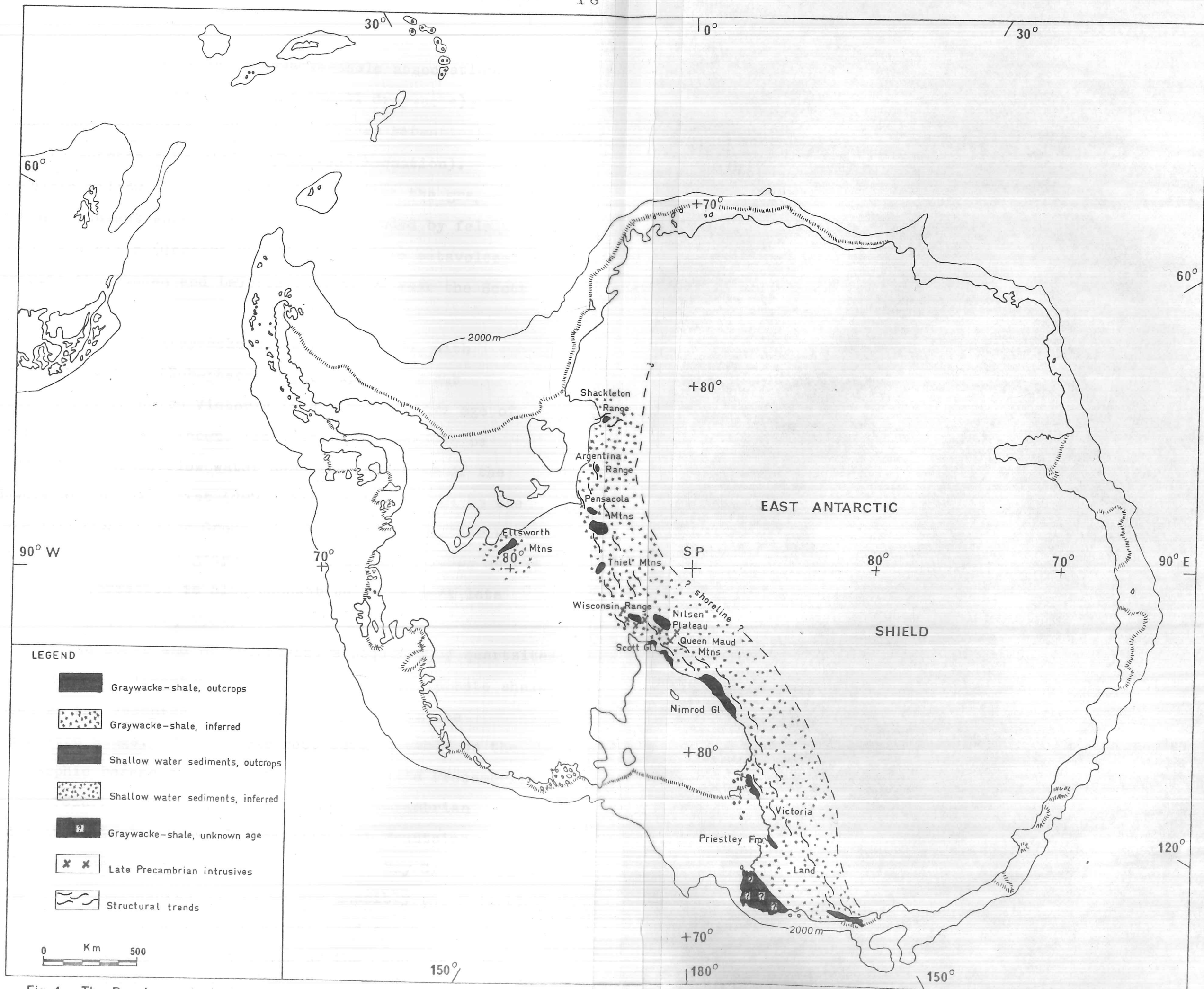


Fig. 4 The Beardmore tectonic province



Similar deep water, graywacke-shale associations crop out in South Victoria Land (Teall Graywacke), the Queen Maud Mountains (LaGorce and Duncan Formations) and the Pensacola Mountains (Patuxent Formation). Basaltic pillow lavas are interbedded with the graywackes of the Patuxent Formation, which is intruded by felsic plugs and sills (Gorecki Rhyolite). Felsic metavolcanics overlie the Duncan and LaGorce Formations near the Scott Glacier.

A thick metagraywacke-shale association, with spilitic basalts (Robertson Bay Group) crops out extensively in North Victoria Land. The precise age of these rocks is not known. They are considered to be older than the shallow water Cambrian sediments of the Bowers Group, by Elliot (1975) and may be related to the late Precambrian Berg Group, which crops out further west in Wilkes Land. The graywacke-shale sequence known as the Priestley Formation is also thought to be in part late Precambrian (Ricker, 1964).

At the other end of the chain, a sequence of quartzites, conglomerates, limestones, sandstones and subordinate shale, known as the Turnpike Bluff Group crops out in the Shackleton Range. These rocks rest unconformably on the metamorphic basement and are thought to be late Precambrian in age (Clarkson, 1972). Shallow water Precambrian sediments are also known in the Ellsworth Mountains.

With the exception of the Robertson Bay Group, the rocks of the Ellsworth Mountains and possibly the Priestley Formation, all these rocks were deformed and metamorphosed to low grade before the beginning of the Cambrian. The

folds trend regionally sub-parallel to the present mountain chain, and the development of axial plane cleavage is widespread. Some authors (Laird and Mansergh, 1971) believe that the deformation associated with the Beardmore orogeny was more intense than that which accompanied the succeeding Ross orogeny.

In the Pensacola Mountains, a minimum age for the deformation is given by the unconformable relationship of the Cambrian Nelson Limestone, to the Patuxent Formation. A maximum age of 1200 Ma comes from radiometric work on the Gorecki Rhyolite. In the Shackleton Range, deformation of the Turnpike Bluff Group is thought to be of late Precambrian age, but the structural trends are at right angles to those in other regions.

Metavolcanics and plutonic rocks from the Nilsen Plateau, Wisconsin Range and Thiel Mountains, all give late Precambrian radiometric ages. The Wisconsin Range batholith for example, has been dated at  $627 \pm 22$  Ma by Faure et al. (1968).

The sediments of the Beardmore tectonic province accumulated in a series of late Precambrian troughs along the Pacific margin of the East Antarctic shield. Deposition in these troughs may not have been contemporaneous. The age and relationship of the Robertson Bay Group and Patuxent Formations, to the sequences of the central Transantarctic Mountains is uncertain. In addition, the deformation may not have been synchronous throughout the province. The Robertson Bay Group appears to have escaped deformation until the middle Palaeozoic orogenesis associated with the Borchgrevink tectonic province.

### C. The Ross tectonic province.

The early Palaeozoic Ross tectonic province, extends from North Victoria Land, across the continent, as far as the Shackleton Range (see fig. 5). Throughout this region, the period immediately following the Beardmore orogeny was characterised by erosion. In the early Cambrian, a shallow, epicontinental sea extended over the area, in which carbonate sediments began to accumulate. These carbonates were succeeded by clastic sediments and felsic volcanics.

The carbonate deposits are best developed in the Miller Range of the central Transantarctic Mountains, where the 900m thick Shackleton Limestone is exposed, unconformably overlying the Goldie Formation. Within the lower part of this sequence, archaeocyathid bioherms of early Cambrian age are abundant. There is additional evidence of archaeocyathid limestones in the Argentina Range. In the Horlick Mountains, the lower Palaeozoic strata comprises a mixed carbonate-clastic sequence with rhyolite pyroclasts (Leverett Formation), whereas the middle Cambrian Nelson Limestone of the Pensacola Mountains is overlain by rhyolite flows, breccias and volcanogenic sandstones of the Gambacorta Formation.

An inarticulate fauna of late Cambrian age has been described from the middle and upper divisions of the shallow marine clastic sequence known as the Bowers Group, which crops out in North Victoria Land (Laird et al. 1972). This fauna bears a marked resemblance to that recorded in the shallow marine Heritage Group of the Ellsworth Mountains.

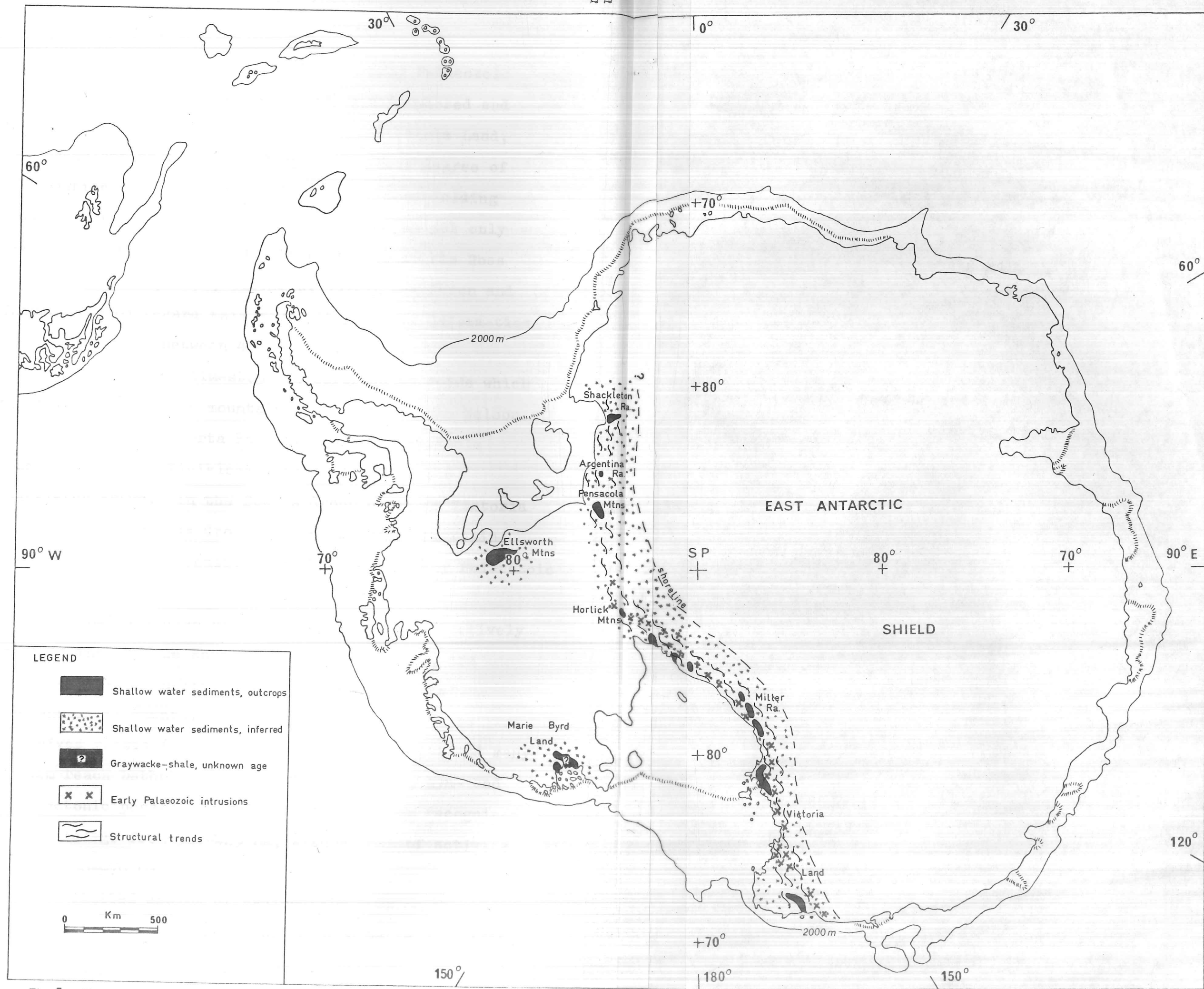


Fig. 5 The Ross tectonic province



The sediments deposited in this early Palaeozoic epicontinental sea, were deformed, metamorphosed and intruded between 525-425 Ma. In South Victoria Land, the rocks appear to have undergone a higher degree of deformation than elsewhere. Three phases of folding have been identified in this area, though as yet only the latter can be assigned with certainty to the Ross orogeny (Lopatin, 1972; Smithson, 1972). Smithson and Toogood (1970) regard this youngest phase of deformation to have occurred between 480-450 Ma.

The Shackleton Limestone is deformed by folds which trend parallel to the mountain chain, as are the Nelson Limestone and Gambacorta Formation of the Pensacola Mountains and the Blaiklock Glacier Group of the Shackleton Range. In the Bowers Group of North Victoria Land and the Heritage Group of the Ellsworth Mountains however, there is a conspicuous absence of early Palaeozoic deformation.

Cambro-Ordovician plutonic intrusives, collectively known as the Granite Harbour Intrusive Complex, are widespread in South Victoria Land and the central Transantarctic Mountains. The composition of these intrusives ranges from quartz diorite to granite and many of them reach batholithic proportions. Pre-, syn- and post-tectonic phases of emplacement have been recognised, ranging in age from 525-425 Ma, with a peak of activity between 500-470 Ma.

The limited amount of radiometric work on the eugeosynclinal metasediments of western Marie Byrd Land,

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The limited amount of radiometric work on the eugeosynclinal metasediments of western Marie Byrd Land,

indicates a pre-middle Palaeozoic age of deposition. Elliot (1975) considered these rocks to have been deposited and deformed contemporaneously with rocks of the Ross tectonic province. The work of Wilbanks et al. (1972) however, suggests that these rocks, though possibly as old as the late Precambrian, were first deformed in the middle Palaeozoic.

In addition to the orogenic activity in the Transantarctic Mountains, large areas of the Precambrian crystalline basement of East Antarctica, in Queen Maud Land and Wilkes Land suffered thermal reactivation at about 500 Ma. The relationship of these two events to each other, is not known.

#### D. The Borchgrevink tectonic province.

This province is best developed in North Victoria Land (see fig. 6), where the presence of metamorphic and igneous rocks yielding middle Palaeozoic radiometric ages, led to the recognition of a Borchgrevink orogeny (Craddock, 1970). No pre-orogenic sedimentary phase, post-dating the stabilisation of the Ross tectonic province is yet known in North Victoria Land, though shallow marine strata of this age, undeformed by the Borchgrevink orogeny, occur in the Ellsworth and Transantarctic Mountains. Undeformed Permian sediments rest unconformably on the rocks affected by the Borchgrevink orogeny in North Victoria Land.

The rocks deformed by the Borchgrevink orogeny include the graywacke-shale sequence of the Robertson

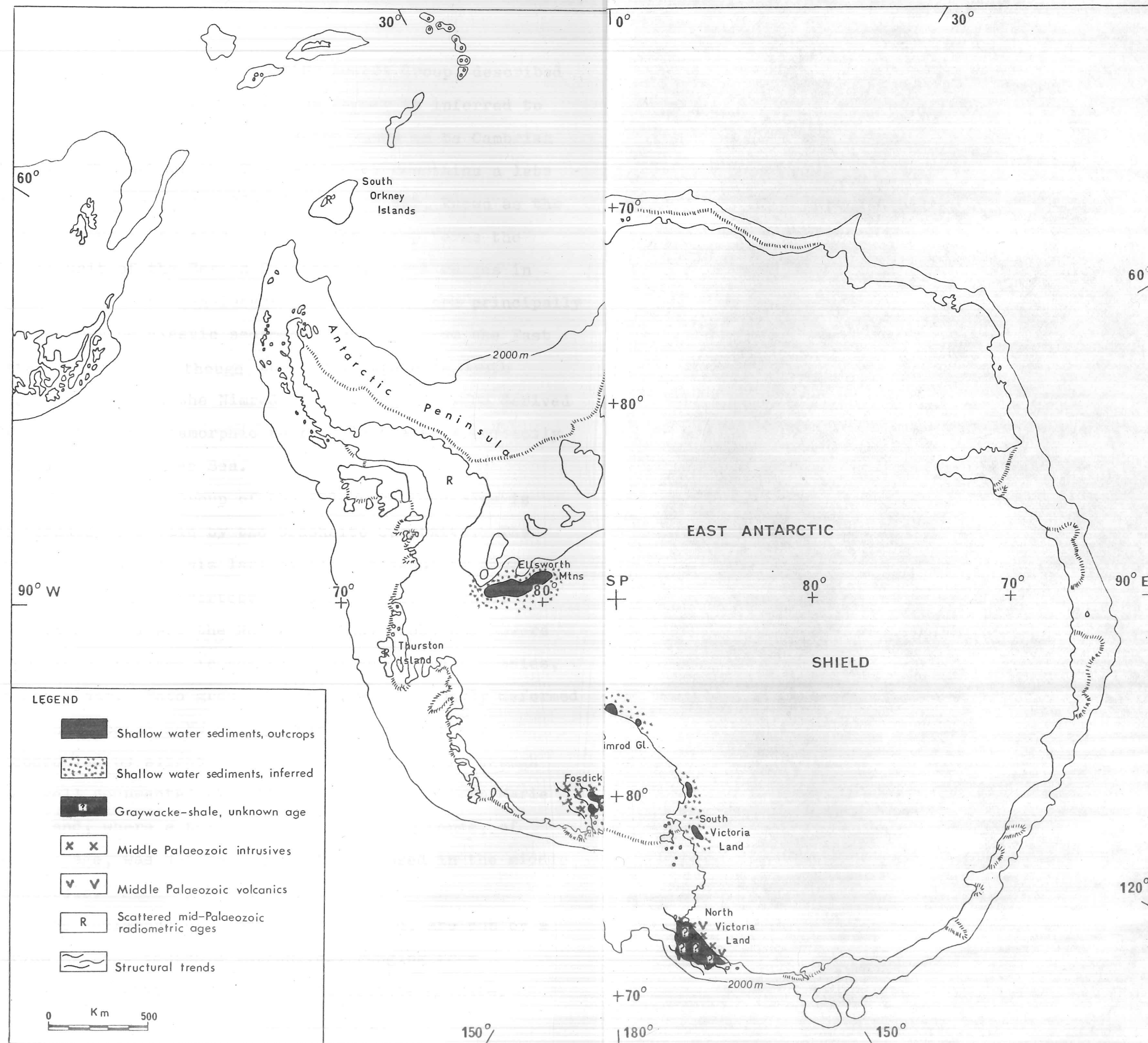


Fig. 6 The Borchgrevink tectonic province



Bay Group and the shallow marine Bowers Group, described in the preceeding sections. The former is inferred to be late Precambrian and the latter known to be Cambrian in age. Throughout the Transantarctic Mountains a late Devonian sequence, locally of Silurian age, known as the Taylor Group is exposed. The Taylor Group forms the lowest unit of the Beacon Supergroup, which ranges in age from the Devonian-Jurassic. The rocks are principally shallow marine clastic sediments, derived from the East Antarctic shield, though the basal strata in South Victoria Land and the Nimrod Glacier region, were derived from a similar metamorphic terrain in the area presently occupied by the Ross Sea.

The Heritage Group of the Ellsworth Mountains is conformably overlain by the Crashsite Quartzite. The upper sections of this largely clastic sequence contain a lower Devonian invertebrate fauna (Boucot, 1963).

To what extent the Robertson Bay Group and Bowers Group were involved in the Ross and Beardmore orogenies, is not clear. Both groups however, were strongly deformed about horizontal N-NW axes. This deformation was accompanied by slight metamorphism. A similar, though less well documented situation, exists in western Marie Byrd Land, where a thick eugeosynclinal sequence, of unknown age, was deformed and metamorphosed in the middle Palaeozoic.

The sediments of North Victoria Land, are cut by a series of post-tectonic intrusives, ranging from hornblende-biotite-granodiorite to biotite granite.

These rocks are collectively known as the Admiralty Intrusives (Grindley and Warren, 1964) and radiometric studies indicate that they were emplaced between 385-300 Ma. The Gallipoli Porphyries may represent the extrusive equivalents of these plutons. Intrusives of a similar composition and age are also known in the Fosdick Mountains of western Marie Byrd Land and on Thurston Island (Wilbanks et al. 1972; Halpern, 1968).

Isolated radiometric ages, falling within this period, have been reported from metamorphic and igneous rocks in the South Orkney Islands and Antarctic Peninsula. The relationship of these deformed rocks, to the Borchgrevink tectonic province is not clear.

There are four possible explanations for the absence of a pre-orogenic sedimentary phase in the Borchgrevink tectonic province. First, a pre-orogenic phase may never have been deposited. Secondly, it may have been removed by erosion, before the deposition of the Permian. Thirdly, the sequence may exist and has not yet been found. Finally, it may exist, but has been wrongly identified.

The Precambrian age for the Robertson Bay Group, quoted by Elliot (1975), is based solely on lithological correlation with sediments of the Beardmore tectonic province. Further investigations may reveal the Robertson Bay Group to be younger than the Bowers Group and to represent the missing sedimentary stage. Similarly, in western Marie Byrd Land, the only direct evidence for the age of the eugeosynclinal sediments, is given by the middle Palaeozoic intrusions. A great deal more research needs to be accomplished in these areas and in the

Antarctic Peninsula region, before the full extent of the Borchgrevink tectonic province is delineated.

E. The Weddell tectonic province.

Various terms have been forwarded in the past to denote the regions around the margin of the Weddell Sea, which were deformed in the early Mesozoic. Craddock (1970) applied the term Ellsworth orogeny, to the early Mesozoic deformation in the Ellsworth Mountains. Ford (1972) described an early Mesozoic phase of deformation in the Pensacola Mountains, for which he suggested the name Weddell orogeny. Dalziel and Elliot (1973) delineated a Gondwanian orogeny, encompassing the early Mesozoic deformation of the Atlantic sector of the Pacific margin of Gondwanaland. Elliot (1975) went on to include this activity in the Antarctic, under the heading Gondwanian orogen.

In the present work, the term Weddell tectonic province is introduced, because the writer feels that it does not imply preconceived notions of correlation with areas of early Mesozoic deformation in the other southern continents. Speculations on the correlation of Antarctic tectonic regions with those of the other southern continents, are presented in a later chapter.

In the Antarctic Peninsula region, graywacke-shale sequences, thought to be contemporaneous and regarded as predominantly of upper Palaeozoic age, are widespread (see fig. 7). In the South Shetland Islands, they comprise the Miers Bluff Sequence and in the South

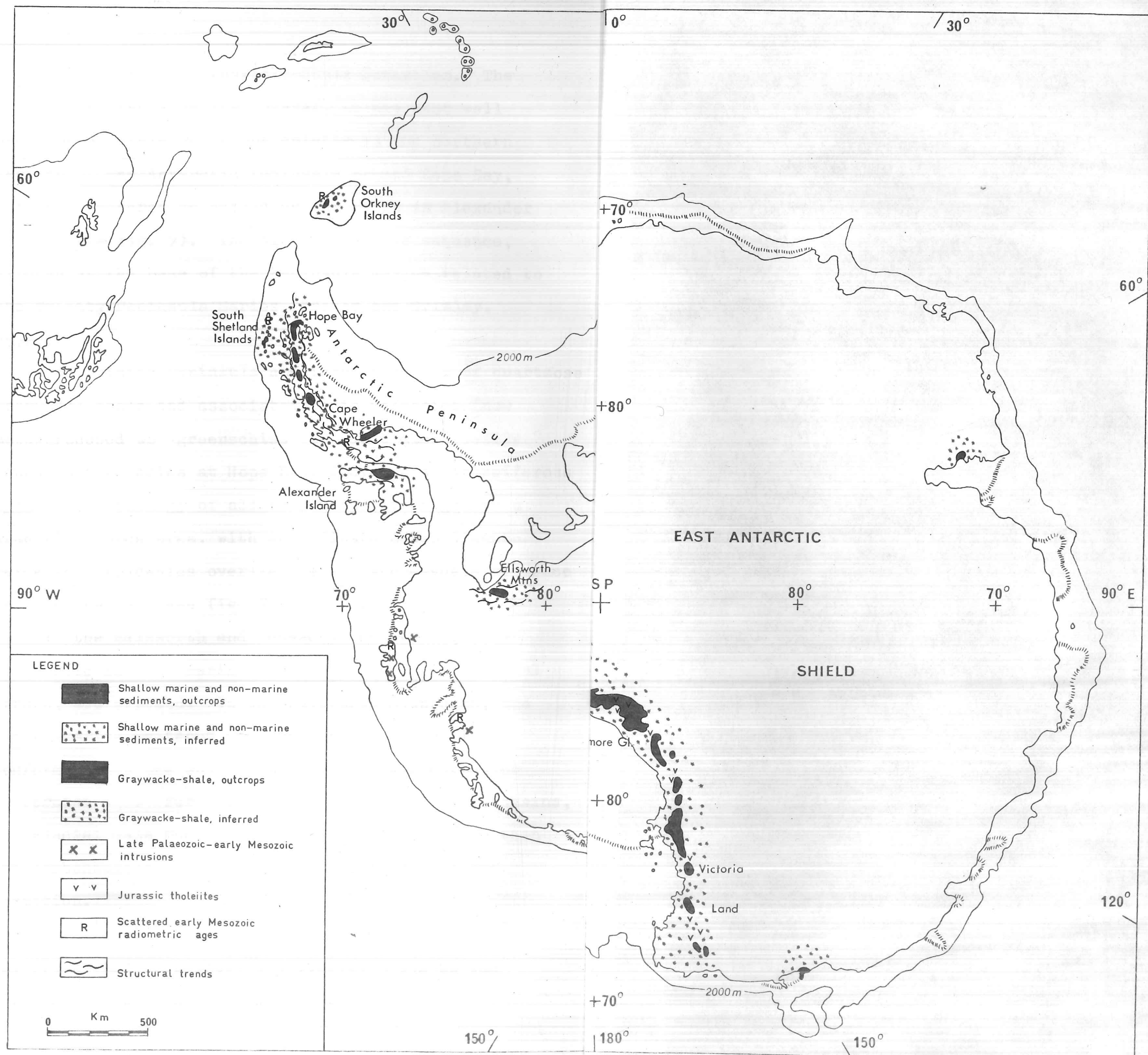


Fig. 7 The Weddell tectonic province



Orkney Islands, the Graywacke-Shale Formation. The Trinity Peninsula Series however, is the most well documented. This crops out chiefly in the northern section of the Antarctic Peninsula around Hope Bay, but is considered to extend as far south as Alexander Island (see fig. 7). The siltstone-shale sequence, exposed at the base of the Peninsula may be related to the Trinity Peninsula Series (Fraser and Grimley, 1972).

The Trinity Peninsula consists of 13000m of quartzose graywacke-shale and associated basic volcanics (now metamorphosed to 'greenschist'). Plant microfossils found in the series at Hope Bay, indicate a Carboniferous age. The lithology of all these deposits suggests a granitic source area, with subordinate metasediments.. Thick acid volcanics overlie the siltstone-shale sequence at Cape Wheeler (see fig. 7).

In the Ellsworth and Pensacola Mountains, late Palaeozoic shallow marine sediments, including glacial strata, are exposed. In the Ellsworth Mountains, the glacio-marine Whiteout Conglomerate, is overlain conformably by the shallow marine Polestar Formation of Permian age. Further east in the Pensacola Mountains, the glacial Gale Mudstone is inferred to be older than the carbonaceous floodplain deposits of the Pecora Formation.

Throughout the Transantarctic Mountains, late Palaeozoic and early Mesozoic strata, known as the Victoria Group, conformably overlie the Taylor Group



and overstep the early Palaeozoic and Precambrian basement. Near the Beardmore Glacier, the strata comprise early Permian glacial beds. These are overlain by black shale, similar to that currently forming in the Baltic Sea (Elliot, 1975). The shale unit is followed by a massive deltaic sandstone, which grades into a floodplain sequence with coals. The abundant *Glossopteris* flora in the floodplain sequence indicates a mid-upper Permian age. In South Victoria Land, the floodplain sequence rests directly on the glacial strata.

The Permian *Glossopteris* bearing strata, between the Scott Glacier and North Victoria Land are overlain by a thick clastic sequence, which accumulated in an alluvial plain environment. Lower Triassic vertebrate fossils have been reported from the basal divisions of this sequence (Elliot, 1970). Near the Beardmore Glacier, volcanic detritus and airfall tuffs form the upper part of the succession.

The late Palaeozoic strata of the South Orkney Islands, South Shetland Islands and Antarctic Peninsula, suffered intense deformation in the early Permian. Upper Jurassic strata unconformably overlie these rocks in the Antarctic Peninsula. The fold axes are regionally subparallel to the trend of the Antarctic Peninsula. In the Ellsworth Mountains, the whole sequence of Precambrian-Permian strata appears to have been deformed for the first time in the early Mesozoic. Here the fold axes are parallel to the alignment of the mountain chain.

Only in the Pensacola Mountains, are rocks of the

Beacon Supergroup involved in this period of deformation. The folding produced, is markedly at right angles to that in the Ellsworth Mountains and follows the trend of the underlying structures of the Ross and Beardmore tectonic provinces. There is also a noticeable decline in the intensity of the deformation, from west to east across the range. Elsewhere in the Transantarctic Mountains, the effects of the early Mesozoic deformation and uplift, may be reflected in the palaeocurrent reversals, between the Permian and Triassic strata of the Victoria Group and the more restricted nature of the Triassic outcrops.

Regional metamorphism accompanying the early Mesozoic deformation was slight, locally reaching upper greenschist facies in the Trinity Peninsula Series. Minor plutonic intrusions are recorded in the Ellsworth and Whitmore Mountains, which have been dated by Halpern (1968) as upper Triassic - lower Jurassic.

Tholeiitic igneous rocks however, are found in association with strata of the Beacon Supergroup in the Transantarctic Mountains (see fig. 7). Doleritic sills of the Ferrar Group are widespread, and basaltic lavas overlie the Victoria Group in the central Transantarctic Mountains and South Victoria Land. Lower Jurassic sediments are interbedded with these basalts and radiometric work indicates that this suite of rocks was emplaced between 191-147 Ma.

#### F. The Antarctic Peninsula tectonic province

The regions forming the Pacific margin of West

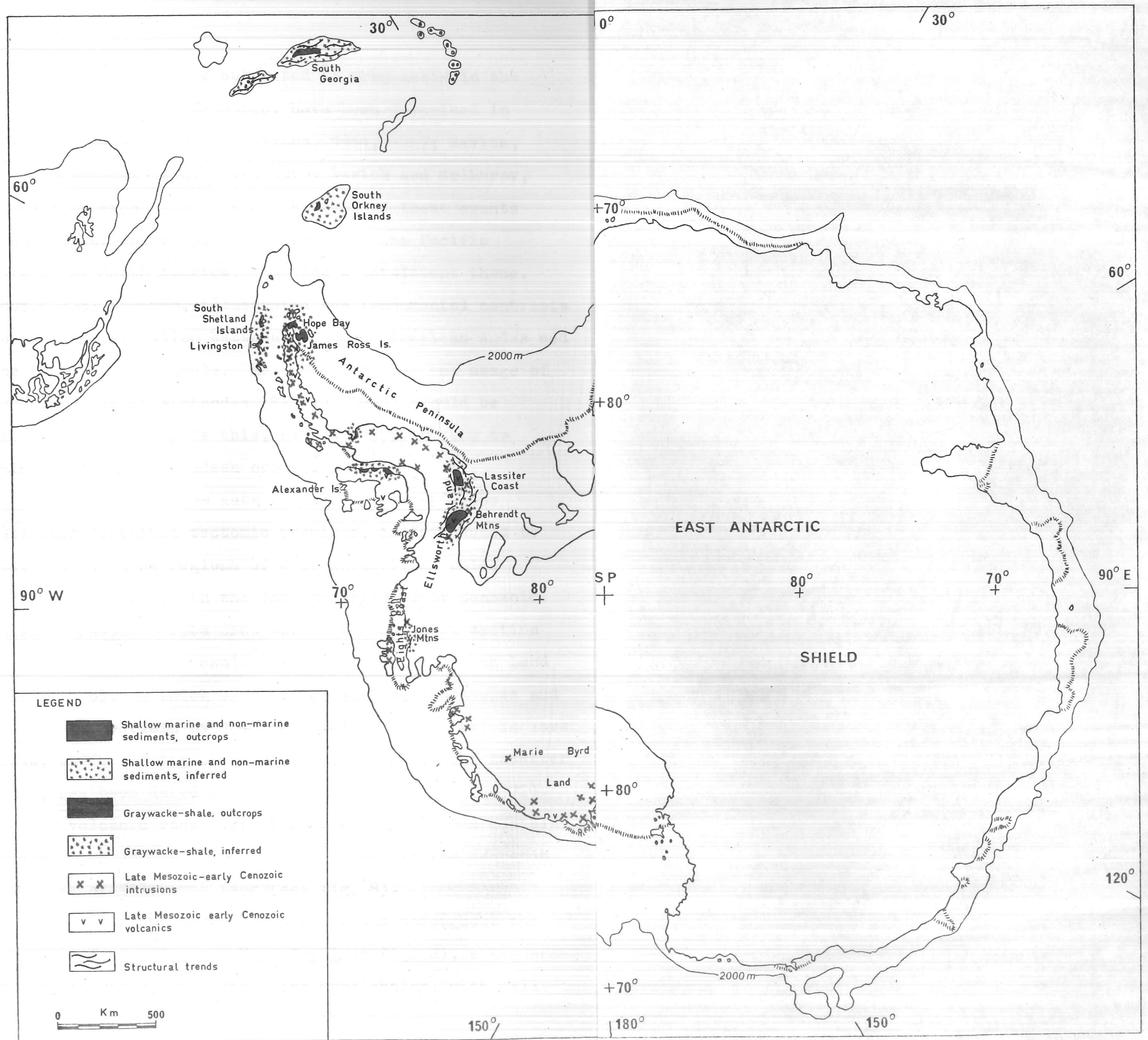


Fig. 8 The Antarctic Peninsula tectonic province

Antarctica, which were subjected to orogenesis in the late Mesozoic-early Cenozoic, have been described in detail by many authors (Hamilton, 1964, 1967; Ravich, 1968; Craddock, 1970, 1972, 1975; Ravich and Grikurov, 1972). In each case, the correlation of these events with similar activity, taking place on the Pacific margins of South America, remained a persistent theme. Katz (1973) however, illustrated the fundamental contrasts in tectonic evolution between the South American Andes and the Antarctic Peninsula. He advocated that the usage of such terms as Antarctandes (Ravich, 1968) should be discontinued. Despite this, Elliot (1975) refers to this region as the Andean orogen.

Following on from Katz (1973), a new term, the Antarctic Peninsula tectonic province, is introduced to distinguish those regions of West Antarctica, which suffered orogenesis in the late Mesozoic-early Cenozoic. Marine Jurassic strata crop out in the southern section of the Antarctic Peninsula and in eastern Ellsworth Land (see fig. 8). A thick sequence of shales, sandstones and siltstones overlain by 1000m of dacitic and andesitic lava flows, tuffs and agglomerates, outcropping on the Lassiter Coast, has been dated as late Jurassic (Williams, 1972). Similar volcanic rocks interbedded with sediments containing middle-upper Jurassic faunas, also occur in the Behrendt Mountains of Ellsworth Land (see fig. 8).

Late Mesozoic sediments are exposed throughout the Antarctic Peninsula. At Hope Bay (see fig. 8), a sequence of conglomerates, sandstones and dark shales, with well



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preserved plant remains, rests unconformably on the Trinity Peninsula Series. Katz (1973) suggests a late Jurassic-early Cretaceous age for these sediments, on the basis of the correlation of the Hope Bay flora with the Rajmahal flora of the Indian neo-Gondwana formations. In addition, several of the species present, are common in the European Neocomian. These plant beds grade upwards into tuffaceous horizons and lava flows of calc-alkaline affinity. This upper Jurassic volcanic group, which reaches a maximum thickness of 3000m, extends as far south as 69°S.

On the eastern side of the Antarctic Peninsula, there are extensive outcrops of late Mesozoic-early Cenozoic sediments in the James Ross Island area (see fig. 8). The lower 1500m of the sequence, which consists predominantly of conglomerates, is overlain by thicker, more widespread and finer grained, clastic strata with Campanian ammonities. A sandstone-shale sequence, with granitic clasts, possibly derived from plutons intruded in the late Mesozoic, overlies these Cretaceous rocks and is thought to be Eocene in age.

A Tithonian-Neocomian sedimentary series crops out on Livingston Island, in the South Shetland Islands and middle Jurassic plant bearing beds are known on Snow Island. The Livingston Island sequence grades vertically from a marine to a continental facies, with calc-alkaline volcanicity. Similar volcanic strata, exposed elsewhere in the South Shetland Islands, are also regarded as upper Jurassic-Cenozoic in age. Isolated outcrops of conglomerate, of late Mesozoic age, have been reported from the South Orkney Islands.

Shallow marine Jurassic strata are found on the east coast of Alexander Island (see fig. 8), at Ablation and Belemnite Points. Farther south, a thick shallow marine, clastic sequence, with abundant volcanic detritus, known as Fossil Bluff Series, is exposed. These rocks have yielded a late Jurassic-early Cretaceous flora and are considered by Horne (1967) to have accumulated in a deltaic-interdeltaic environment of a shoreline facies.

Tuffaceous strata giving K-Ar. ages of 70 Ma and regarded as the extrusive equivalent of the late Mesozoic plutonic intrusions, outcrops in western Alexander Island. Scattered outcrops of volcanic strata, generally regarded as Late Mesozoic in age, occur in Marie Byrd Land and in the Jones Mountains, felsic dykes cutting volcanic strata, have yielded Cretaceous ages.

The orogenic activity associated with the Antarctic Peninsula tectonic province, differs fundamentally from all the known previous phases of orogenesis in the Antarctic. Regional metamorphism was largely absent and deformation only locally of importance. The orogenic activity is manifested by widespread granodioritic plutonism and regional uplift in the late Mesozoic.

The Jurassic rocks of the Lassiter Coast and eastern Ellsworth Land, are strongly deformed and cut by thrusts. The fold axes are regionally subparallel to the trend of the Antarctic Peninsula. The deformation largely pre-dates the mid-Cretaceous phase of plutonism. Elsewhere, the late Mesozoic strata are only gently folded and faulted.

Calc-alkaline plutonic intrusive rocks are widespread

in the Antarctic Peninsula, the South Shetland Islands and South Orkney Islands. Radiometric data available for these intrusive rocks, indicates emplacement between early Jurassic-early Cenozoic (160-45 Ma). Late Mesozoic plutonic intrusives are also found in Marie Byrd Land and along the Eights Coast (see fig. 8). The intrusive activity was accompanied by regional uplift and block tectonics.

#### G. Cenozoic volcanic provinces.

Late Cenozoic volcanic rocks, of predominantly basic composition crop out extensively in the Ross, Borchgrevink and Antarctic Peninsula tectonic provinces. They are also known from the South Sandwich Islands and at one point on the coast of East Antarctica (see fig. 9). There are records of activity extending back into the Miocene and in some instances, notably the South Sandwich Islands and Ross Island, active volcanism continues at the present. These areas of volcanicity are of considerable tectonic interest, since they indicate a number of distinct tectonic environments.

i) The South Sandwich Islands - an island arc, with active subduction and tholeiitic/calc-alkaline volcanism.

ii) The Antarctic Peninsula - a composite region, with initial tholeiitic/calc-alkaline volcanism, followed by more recent sub-alkaline activity.

iii) Marie Byrd Land, Victoria Land, the Transantarctic Mountains and Gaussberg - characterised by alkali volcanism.

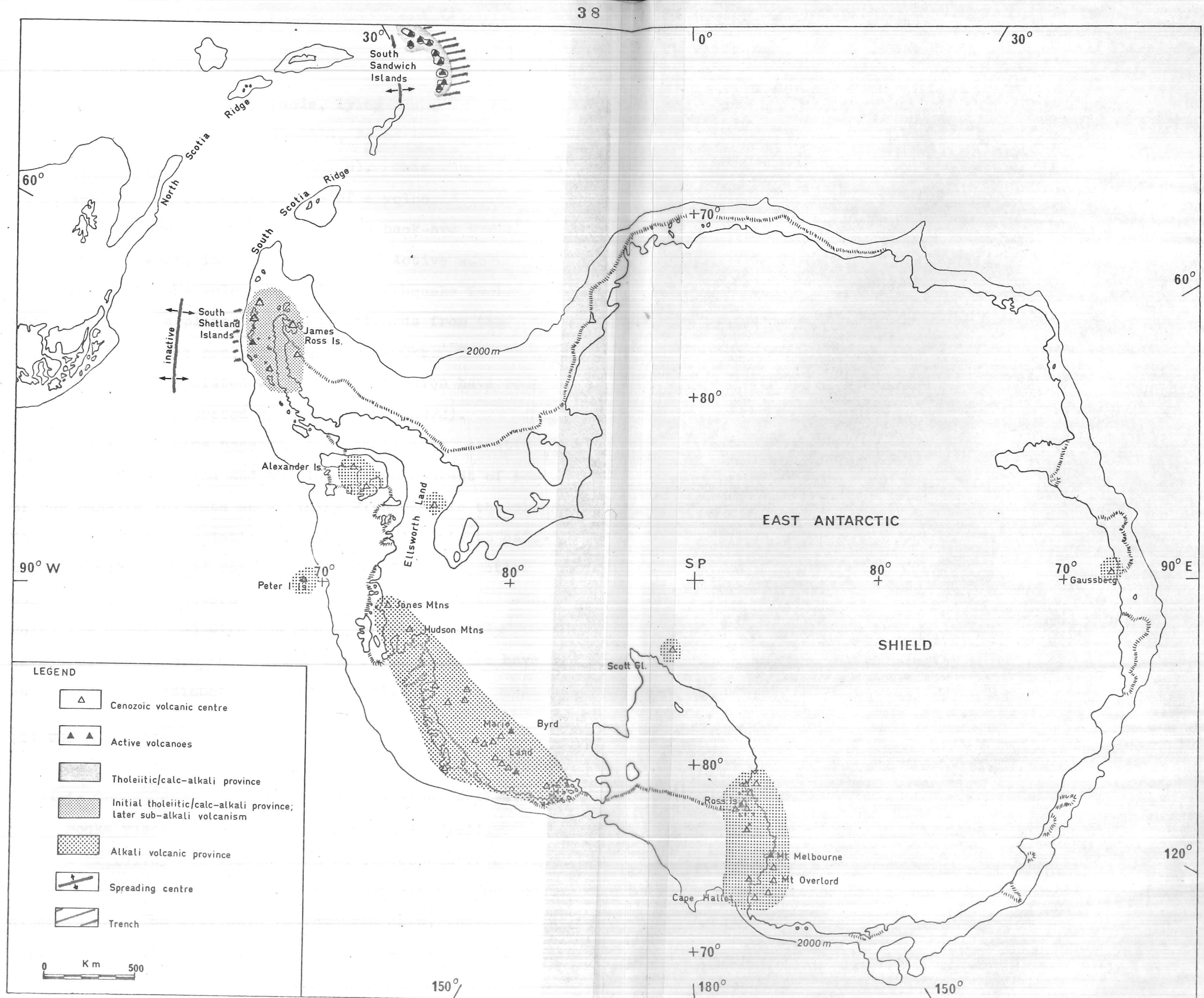


Fig. 9 Cenozoic volcanic provinces



### i) The South Sandwich Islands

A chain of volcanic islands, lying along the 27°W line of longitude, between 55-60°S, forms the eastern margin of the Scotia Sea (see fig. 9). This chain possesses all the characteristics of a volcanic island arc, with an ocean trench to the east and a back-arc spreading centre to the west, in the Scotia Sea. Active subduction is indicated by the volcanism and by earthquake focii, which lie along a plane, inclined westwards from the trench, beneath the arc, to a depth of 200km. The volcanic rocks associated with this subduction have been described and interpreted by Baker (1968, 1972).

Quartz normative basalts, rich in alumina, constitute the dominant rock type and the low potash content of some of the basalts suggests an affinity with oceanic tholeiites. It appears that a gradation from true tholeiitic to calc-alkaline volcanism is represented. Sea-floor magnetic anomalies in the eastern Scotia Sea, indicate that volcanism associated with the South Sandwich arc may have begun about 8.0 Ma, though the rocks examined have so far yielded radiometric ages < 4.0 Ma.

### ii) The Antarctic Peninsula

The Cenozoic volcanic rocks of the James Ross Island Volcanic Group, comprise basic lavas. Chemical analysis of these rocks places them in the alkali basalt field.

Baker (1972) considered them to correspond to olivine tholeiites, because normatively they contain olivine and hypersthene. The available radiometric data, indicate that the ages of these rocks range from 4.6 - 1.4 Ma.



On the other side of the Antarctic Peninsula, Cenozoic volcanic rocks are more extensively developed, particularly in the South Shetland Islands, where the only active volcanoes of this region are found. The earliest volcanic rocks of the South Shetland Islands, are regarded as Miocene in age. These lavas have been described as predominantly basaltic andesites of tholeiitic affinity, together with calc-alkaline andesites. Younger volcanics in the same area show a more alkali trend in composition, comprising alkali olivine basalts and hawaiites. They are placed in the soda branch of the alkali basalt-trachyte group and are correlated with the James Ross Island Group (Baker, 1972).

The earlier phase of volcanism is thought to be associated with the now inactive subduction zone dipping south east, beneath the South Shetland Islands, whereas the recent sub-alkali volcanism appears to be controlled by block tectonics and rifting. Strontium isotope ratios for these later volcanics, indicate derivation from the mantle.

### iii) Marie Byrd Land and Victoria Land

The remaining Cenozoic volcanic rocks are normally associated with a tensional environment of block tectonics and rifting. They consist mainly of alkali basalts and their derivatives and are developed chiefly in Marie Byrd Land and Victoria Land.

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unit of stratovolcanoes with felsite flows and pyroclastics. The volcanism may have begun in the Eocene, though the state of dissection, exhibited by the majority of the volcanoes, suggests a late Cenozoic age. LeMasurier (1969) considers the alignment of the stratovolcanoes, which suggests a rectangular block-fault system, to be analogous to the system of East African rifts.

Olivine basalts and breccias are also found in the Jones Mountains and Hudson Mountains of the Eights Coast; eastern Ellsworth Land, where they are dated at 6.0 Ma; south western Alexander Island and Peter I Island, which may be as old as 13 Ma (see fig. 9).

In South Victoria Land, stratovolcanoes with subaerial lava flows and pyroclastics, ranging in composition from olivine-pyroxene basalt to anorthosite trachyte, form the McMurdo volcanic province. Similar rocks are found farther north between Mount Overlord and Mount Melbourne. In North Victoria Land, the Hallet volcanic province consists of 2500 m of palagonitic breccias and alkali basalt lava flows.

A late Cenozoic volcano of extremely K-rich leucitic basalt, has been reported from Gaussberg in eastern Antarctica and olivine basalt lava flows of a similar age are found in the Transantarctic Mountains, near the head of the Scott Glacier.

## Chapter 4 The tectonic evolution of Antarctica

The subdivision of Antarctica into two major regions, one the East Antarctic shield, comprising a Precambrian to early Palaeozoic metamorphic complex, overlain unconformably by late Precambrian and Palaeozoic platform sediments and the other, West Antarctica, consisting of a series of Palaeozoic and Mesozoic tectonic provinces, is of fundamental importance to an understanding of the continent's tectonic history.

Superimposed upon this twofold division however, is a major structural discontinuity, corresponding roughly to the abrupt change in crustal thickness, along the front of the Transantarctic Mountains. To the east of this line, over the region including the East Antarctic shield and much of the Beardmore, Ross and Borchgrevink tectonic provinces, the crust is between 35-45 km thick, whereas to the west, in the Weddell and Antarctic Peninsula tectonic provinces, the crust is only 25-30 km thick. Despite extensive research, the precise nature of this boundary remains a matter of conjecture.

The western part of the continent appears to be composed of at least three blocks (see fig. 2) of roughly equal size, centered in the Ellsworth Mountains; the Antarctic Peninsula and Ellsworth Land and Marie Byrd Land respectively. Although these blocks are at present "welded" together, it is important to realise that their geographical positions relative to one another and to the East Antarctic shield, may not always have remained constant.

Russian tectonic geologists seek to explain these blocks as fragments of Precambrian crystalline basement, modified by later epicratonic processes. Other workers, notably Craddock (1970, 1972, 1975) and Elliot (1975) regard Antarctic tectonic evolution in terms of a series of mobile belts, some of which may have been in part epicratonic, that were accreted laterally onto the Pacific margin of the East Antarctic shield.

In this piece of work, neither of these interpretations is considered to be wholly acceptable. A new scheme combining these two ideas is presented, which more closely satisfies the rigorous conditions imposed by the current state of geological knowledge of the Antarctic.

From the late Precambrian to the early Mesozoic, a series of tectonic provinces, were accreted laterally onto the Pacific margin of the East Antarctic shield. The locus of sedimentation migrated successively away from the East Antarctic shield. Thus, although the earliest sediments may have been in part epicratonic, the later sediments were deposited partly upon a basement composed of rocks of the preceeding tectonic cycle and partly on oceanic crust.

The break-up of Gondwanaland, which began in the early Mesozoic resulted in the fragmentation of the Pacific margin of Antarctica and radically changed the tectonic environment. These fragments, represented today by the upstanding blocks of West Antarctica, were modified by epicratonic processes associated with the development of the Antarctic Peninsula tectonic province. In the late Cenozoic, volcanic activity in West Antarctica and Victoria



Land, suggests the initiation of a tensional environment of block tectonics and rifting, which continues to operate at the present.

The East Antarctic shield consists of a high grade metamorphic terrain, intruded by a wide variety of plutonic igneous rocks. Isotopic and structural analyses of these rocks indicate a complex geological history, but at present, the lack of information precludes the delineation of individual tectonic provinces within the shield.

Charnockites from Enderby Land, dated at 3000 Ma, constitute the oldest known rocks in Antarctica, but in general, Archean geology is sparsely recorded. An Archean basement, of granitic composition however, is thought to have formed between 2800-2600 Ma. In the Prince Charles Mountains, granitic rocks of this age, are overlain unconformably by supracrustal metasediments, which include banded ironstones. The consolidation of these Archean regions, accompanied by granulite metamorphism and the formation of enderbites and charnockites, was completed by the early Proterozoic.

In the middle Proterozoic, linear belts of the Archean were remobilised and suffered retrogressive metamorphism to amphibolite and greenschist facies. There are scattered records of a second period of reworking between 1200-1000 Ma, referred to as the Nimrod orogeny. Undeformed late Precambrian platform sediments, possibly as old as the middle Proterozoic, rest unconformably on both the Archean basement and middle Proterozoic mobile belts.

In the late Proterozoic, a series of sedimentary troughs

formed along the line of the Transantarctic Mountains. In these basins, deep water sediments, derived from the East Antarctic shield began to accumulate. There is evidence from the Nimrod Glacier region, that the initial phase of sedimentation occurred in a shallower epicratonic environment, though the bulk of the sediment pile comprises a deep water sequence of graywacke-shale. Basic volcanic rocks, including basaltic pillow lavas, are interbedded with deep water sediments in the Patuxent Formation of the Pensacola Mountains and the Robertson Bay Group of North Victoria Land. It should be stressed however, that the precise ages of these units and their relationship to the other late Precambrian sequences, are open to question.

In the central Transantarctic Mountains, felsic volcanics overlie the graywacke-shales and indicate that the troughs had either become filled with sediment, or been uplifted, by the time igneous activity commenced.

All these sedimentary and volcanic sequences, with the exception of the Robertson Bay Group, whose age is uncertain, were deformed before the onset of Cambrian times. Structural data from South Victoria Land, suggests that the deformation was, at least locally, polyphase. This uplift and deformation was accompanied by the emplacement of granodioritic intrusions, which reach batholithic proportions and regional metamorphism to low grade. These features are typically associated with compressive margins and active subduction.

By the close of the Precambrian, a period of erosion, which succeeded the orogenic phase of the Beardmore tectonic province, had reduced the relief of the area to a gently

undulating plain. In the early Cambrian, renewed subsidence along the Pacific margin of East Antarctica, enabled a shallow sea to transgress eastwards across the eroded Beardmore tectonic province, onto the shield. In the region of the central Transantarctic Mountains, an extensive carbonate platform developed, within this shallow epicontinental sea. Subsidence appears to have kept pace with sedimentation, throughout the Cambrian, permitting the accumulation of 9000m of carbonate sediments. Elsewhere, in the Pensacola Mountains and South Victoria Land, clastic sediments, derived from the East Antarctic shield predominate over the carbonates.

In the Pensacola and Horlick Mountains, this phase of sedimentation was terminated by the extrusion of felsic and rhyolitic volcanics. Once again this suggests that deposition had ceased and that uplift had started, by the time igneous activity began. The presence of clastic sediments in the higher levels of the carbonate sequence of the central Transantarctic Mountains, also indicates the initiation of a period of uplift, towards the end of the Cambrian.

Shallow marine sediments were deposited in the Ellsworth Mountains, contemporaneously with the sediments of the Ross tectonic province. The rocks of this region, though bearing marked lithological similarities to those in the Transantarctic Mountains, display a tectonic history in complete contrast to that known for the Transantarctic Mountains. They were first deformed in the early Mesozoic, during the period of orogenesis associated with the

Weddell tectonic province. This supports the idea, that the Ellsworth Mountains are not now in the same position, relative to East Antarctica and the remainder of West Antarctica, that they occupied in the early Palaeozoic. They may have been rotated, from a position on the present north eastern margin of the Weddell Sea, during the break-up of Gondwanaland.

A lower Palaeozoic deep water facies, on the seaward margin of this epicontinental shelf, has not been identified with certainty. The graywacke-shale sequence of Marie Byrd Land however, may in part, be Cambrian in age, though this sequence was not affected by the Ross orogeny. These rocks, like those of North Victoria Land, were first deformed in the middle Palaeozoic by orogenic movements associated with the Borchgrevink tectonic province. This structural relationship between Marie Byrd Land and North Victoria Land, indicates that the two regions may once have formed part of a single province, disrupted during the fragmentation of Gondwanaland, in the Mesozoic.

Orogenesis in the early Palaeozoic (the Ross orogeny) affected rocks throughout the Transantarctic Mountains. Only in the Ellsworth Mountains, North Victoria Land and possibly Marie Byrd Land, did rocks of this age, escape orogenesis. Regional metamorphism to low grade, reaching amphibolite facies in South Victoria Land, was accompanied by deformation and the intrusion of a suite of granodioritic plutons (Granite Harbour Series). Widespread thermal reactivation of the margins of the East Antarctic shield also occurred at this time, but the relationship of this activity to the Ross orogeny in the Transantarctic Mountains

is not clear.

The sequence of events inferred for the Ross tectonic province, bears a close similarity to that shown in the preceeding section for the Beardmore tectonic province. It is interesting to note that though the site of sedimentation and active margin of East Antarctica migrated westwards, the locus of orogenesis, which concluded the development of the two provinces, appears to have remained constant. The full extent of the Ross orogeny however, may have been obscured by later activity.

No records of rocks dating from the middle Ordovician - middle Silurian are known from the Transantarctic Mountains and it is presumed that throughout this region the period was characterised by erosion and non-deposition. Sedimentation recommenced in the early Devonian, with the accumulation of shallow marine and non-marine deposits in South Victoria Land and the Nimrod Glacier region. Only in the Ellsworth Mountains, where an apparently unbroken Precambrian-Permian sedimentary sequence exists, are rocks dating from the Ordovician and Silurian inferred, with any degree of certainty, to be represented.

In Marie Byrd Land however, a minimum age for the graywacke-shale sequence of the Fosdick Mountains, is given by igneous intrusions. Thus, deep water post-Cambrian, pre-middle Devonian sediments may be present in this succession. In addition, the late Precambrian age for the graywacke-shales of the Robertson Bay Group is based purely on lithological correlation with sequences associated with the Beardmore tectonic province. The possibility that



these rocks may be younger than the Cambrian Bowers Group of North Victoria Land, cannot be dismissed.

In the middle Palaeozoic, the rocks of both Marie Byrd Land and North Victoria Land suffered deformation, igneous intrusion and low grade metamorphism. The structural trends produced during this period of orogenesis (the Borchgrevink orogeny) are coincident in the two regions. This supports the hypothesis that Marie Byrd Land and North Victoria Land formed a single tectonic region at this time. The limited geophysical information from the sediments in the Ross Sea, indicates a structural trend discordant to that of the Borchgrevink orogeny, which may have been produced at a later date. The uplift associated with the Borchgrevink orogeny may have been responsible for the marked interruption in deposition, between the Taylor and Victoria Groups of the Transantarctic Mountains.

The limited extent and disrupted nature of the Borchgrevink tectonic province, inhibits the understanding of this period of the continent's tectonic evolution. There is however, sufficient evidence to postulate the existence of an active compressive margin on the Pacific border of the continent, between Marie Byrd Land and North Victoria Land, in the middle Palaeozoic. The possible extension of this margin towards the Antarctic Peninsula, where a few middle Palaeozoic igneous and metamorphic radiometric ages have been obtained, is at present uncertain.

Rocks of the succeeding upper Palaeozoic and early Mesozoic crop out on a more widespread scale and are

relatively well documented. Thick sequences of graywacke-shale, with basic volcanics, were deposited in the Carboniferous and early Permian, in the South Orkney and South Shetland Islands and along the Antarctic Peninsula. Further east, in the Ellsworth Mountains, Carboniferous marine glacial sediments, overlain by Permian floodplain deposits, complete the unbroken Precambrian-Permian sedimentary succession in that region.

In the Transantarctic Mountains, early Permian glacial sediments rest on the undisturbed Devonian Taylor Group. These glacials are succeeded by shallow water carbonaceous floodplain deposits, which yield an abundant middle-upper Permian *Glossopteris* flora. Between the Scott Glacier and North Victoria Land, sedimentation continued into the Triassic. Here, clastic alluvial plain sediments began to accumulate, which contained a significant volcanic element by the close of the Triassic.

Orogenesis affected the rocks around the present margins of the Weddell Sea, in the early Mesozoic. Throughout the Transantarctic Mountains, sedimentation continued undisturbed by these movements, except for the western section of the Pensacola Mountains, which was deformed in the late Permian. Elliot (1975) stressed the significance of the early Mesozoic orogenesis, in the understanding of the Pacific margin of Antarctica. It is the youngest event, pre-dating the break-up of Gondwanaland.

Assuming the present geographical configuration of West Antarctica to have remained constant, it is difficult to relate the structural trends of the Weddell tectonic

province to a single orogenic episode. The discordant early Mesozoic structural trends, together with the absence of late Precambrian and Palaeozoic deformation in the Ellsworth Mountains, provide compelling evidence for the suggestion that the Ellsworth Mountains have not always occupied the same position. By rotating this 'block', to a position on the north east coast of the Weddell Sea, it is possible to envisage the development of a compressive margin, along the Pacific border of the Antarctic continent, throughout the upper Palaeozoic. This culminated in a period of orogenesis in the early Mesozoic.

Rocks disrupted by the early Mesozoic orogeny, are overlain unconformably by shallow marine Jurassic sediments in the Antarctic Peninsula. In the Pensacola Mountains they are cut by a basic intrusion of Jurassic age (the Dufek Massif). This major pluton is related to the extensive development of Jurassic tholeiites, throughout the Transantarctic Mountains, associated with the rifting of Gondwanaland and fragmentation of the Pacific margin of Antarctica. This is complicated by the emplacement of post-orogenic granitic intrusions in the Antarctic Peninsula. Insipient rifting, prior to the opening of the Weddell Sea, may have occurred at this time.

After the early Mesozoic orogeny, several localised, partly fault-bounded basins were formed along the Antarctic Peninsula and in eastern Ellsworth Land. Throughout the Jurassic and Cretaceous, these basins became filled with terrestrial and shallow marine sediments of variable thickness. Strong subsidence in the lower Cretaceous,

during the deposition of the Legoupil Formation, may reflect an early stage in the development of the Bransfield rift structure (Katz, 1973). A similar tectonic setting can be inferred for the upper Jurassic-lower Cretaceous sediments of south eastern Alexander Island.

Late Mesozoic orogenesis along the Pacific border of Antarctica is manifested in widespread granodioritic plutonism, accompanied by regional uplift and block tectonics. Only on the Lassiter Coast and in eastern Ellsworth Land are compressive movements, pre-dating the igneous intrusions, recorded. The late Cretaceous sediments of James Ross Island, remained essentially undisturbed. This marks a change in the regional tectonic setting from a 'Pacific type' continental margin, with an active subduction zone, to a more stable 'Atlantic type' continental margin, undergoing extension and rifting (Mitchell and Reading, 1969).

Further uplift in the Cenozoic was accompanied by faulting and longitudinal rifting along the sides of the Antarctic Peninsula and the extrusion of great volumes of sub-alkali basaltic igneous rocks. No marine Tertiary deposits are known from the Antarctic Peninsula, though a considerable amount of erosion must have taken place to expose the plutons. The depositional basins associated with this erosion are presumably situated in the present sea-covered areas, surrounding the Peninsula, where they have undergone little if any deformation. On the western side of the Peninsula, it is possible that sediments in

the Bellingshausen Sea, date back to the Jurassic, when subduction along the Pacific margin of Antarctica, is thought to have ceased.

At least two separate basins, containing Cenozoic deposits, have been located by drilling in the Ross Sea and in West Antarctica, geophysical data suggests the presence of Cenozoic sediments in the Byrd Subglacial Basin (Drewry, personal communication, 1977). Although no Cenozoic sediments are known around the margins of the East Antarctic shield, Drewry (personal communication, 1977) considers that Cenozoic sediments are represented in the Wilkes Basin.

The development of the Scotia Sea, which began in the Cenozoic, continues today with the eruption of tholeiitic to calc-alkaline volcanics in the South Sandwich Islands. Back-arc spreading is also taking place, to the west of this island arc, in the eastern basin of the Scotia Sea. In Victoria Land and Marie Byrd Land the extrusion of alkali basalts, indicates a contrasting tectonic environment, analogous to the rift system of East Africa. The alkali basalts of the Scott Glacier region and Gaussberg, accompanied the Cenozoic block tectonic uplift of the Transantarctic Mountains and the margins of the East Antarctic shield. In the Antarctic Peninsula, the earlier tholeiitic to calc-alkali volcanism may be related to the inactive spreading centre in Drake Passage, whereas the later volcanism of sub-alkali type is associated with rifting along the margins of the Antarctic Peninsula.



## Chapter 5 Antarctica and the concept of Gondwanaland

Since the early reconstructions of Wegener (1915) and Du Toit (1937), Antarctica has occupied a unique and vital position within Gondwanaland, the conjectured late Palaeozoic supercontinent of Suess (1906). It forms the centre piece of the jigsaw, to which all the other southern continents, Africa, South America, India and Australia, are once thought to have been attached. Thus, no interpretation of the tectonic evolution of Antarctica would be complete, without some reference to the continent's role in the development of Gondwanaland.

Knowledge of the geological constraints which Antarctica imposed upon these early morphological fits, was severely limited. Even so, it is interesting to note that the most accurate reconstructions today, are considered to be those which only slightly modify Du Toit's work. Geophysical investigations in the Southern Ocean, together with detailed geological mapping in Antarctica, especially since the International Geophysical Year, have greatly improved our understanding of the continent's history. Yet despite this, the sampling, by comparison with that of other continents, remains sparse and inadequate and as illustrated in the previous chapter, many of the ideas about Antarctic tectonics are speculative.

In the 1950's, it became apparent from work carried out on the ocean floors, that not only the continents, but also the ocean basins themselves, were 'drifting'. In view of this, the hypothesis of continental drift, put forward by Wegener (1915), was replaced by a more appropriate term - plate tectonics. If they are to be

considered valid, modern reconstructions must be framed within the context of the three types of plate boundary that are thought to exist, compressive, tensional and conservative.

The geological frameworks of the southern continents are broadly similar. Each comprises a basement of crystalline rocks, partially overlain by younger, undeformed cover successions. Although these crystalline basements are composed almost wholly of Precambrian rocks, they are traversed by a network of tectonic provinces, which were not stabilised until the early Palaeozoic. Around the present margins of the continents, the basements are covered by Phanerozoic sediments, deposited in basins, some of which display features associated with orogenesis.

It is therefore suggested, that the tectonic evolution of Antarctica, should be viewed as an integral part of the tectonic evolution of the present Southern Hemisphere. In doing this, it is possible to distinguish four major stages of development, which are outlined below.

a) STAGE 1. The formation of the Precambrian cratons (Archean-middle Proterozoic).

b) STAGE 2. The consolidation of Gondwanaland (late Proterozoic - early Palaeozoic).

c) STAGE 3. Gondwanaland as a single unit (middle Palaeozoic-early Mesozoic).

d) STAGE 4. The break-up of Gondwanaland (Mesozoic-Recent).

a) STAGE 1. The formation of the Precambrian cratons

The crystalline basements of each of the southern continents, contain a number of equidimensional nuclei of older Precambrian rocks, which have remained essentially stable, throughout the late Precambrian and Phanerozoic. These regions are overlain by extensive cover successions and are termed Precambrian cratons (see fig. 10). The cratons are composed of two fundamentally different tectonic units i.e. Archean provinces, which were stabilised by about 2600 Ma and early and middle Proterozoic linear belts, which were stabilised at various times between 1800-1000 Ma. Three cratons have been identified in Africa and one is known from each of South America, India and Australia. It is not yet possible to outline cratonic regions in Antarctica, though it would be reasonable to assume that the East Antarctic shield is composed of at least one major craton.

The Archean provinces, of the cratons, have much in common. Each appears to consist largely of granitic or migmatitic rocks, incorporating irregular greenstone belts, made up of slightly metamorphosed supracrustal sediments and volcanics. The granites frequently yield radiometric ages in excess of 3000 Ma and are amongst the oldest dated rocks on earth. The inclusion of xenoliths of metasediment in these granites, in the Transvaal Province of the Kalahari craton, provides evidence for pre-existing host rocks.

The greenstone belts, which are frequently aligned (e.g. in the Archean regions of the Kalahari and Congo

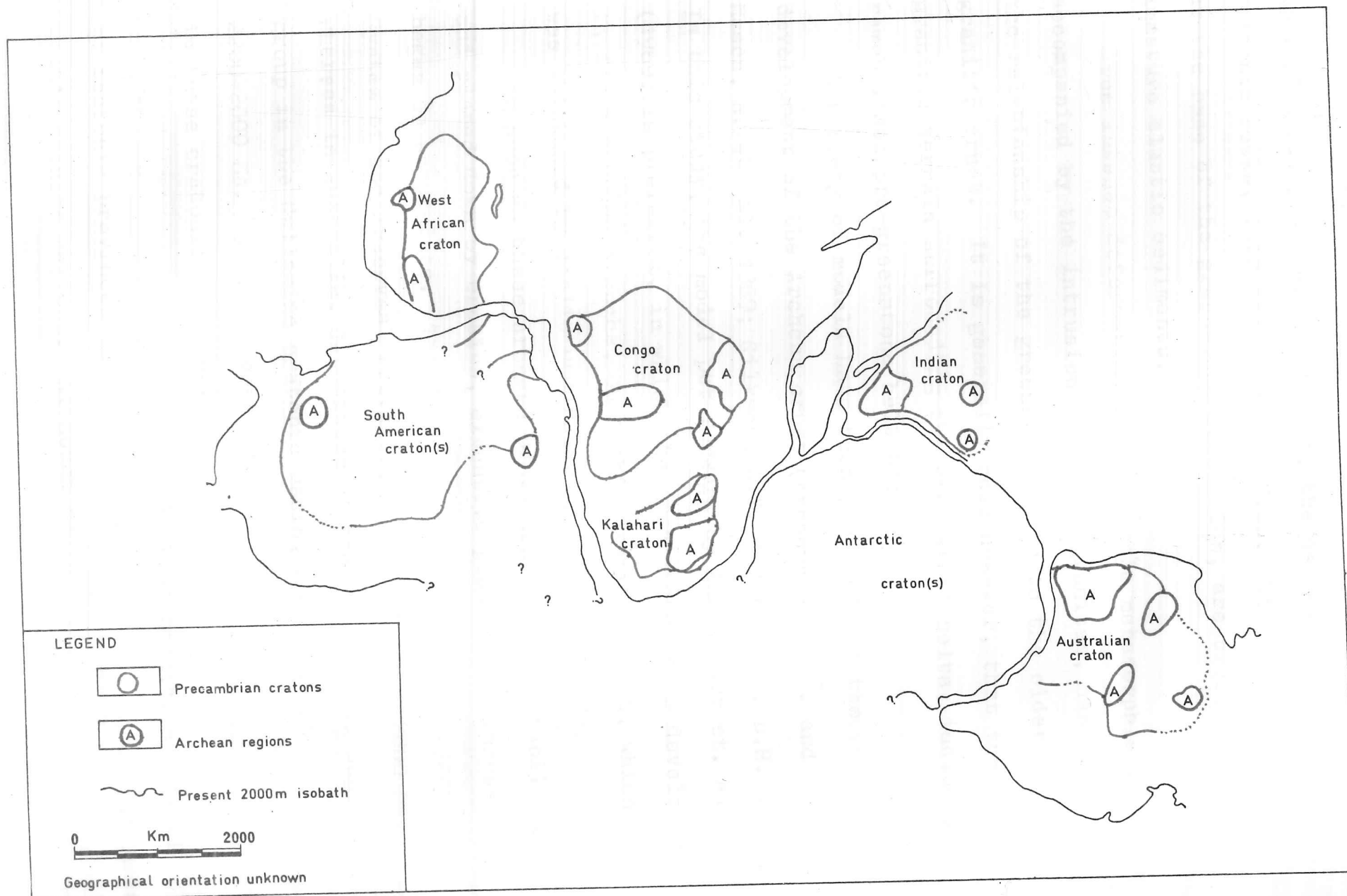


Fig. 10 The Precambrian cratons

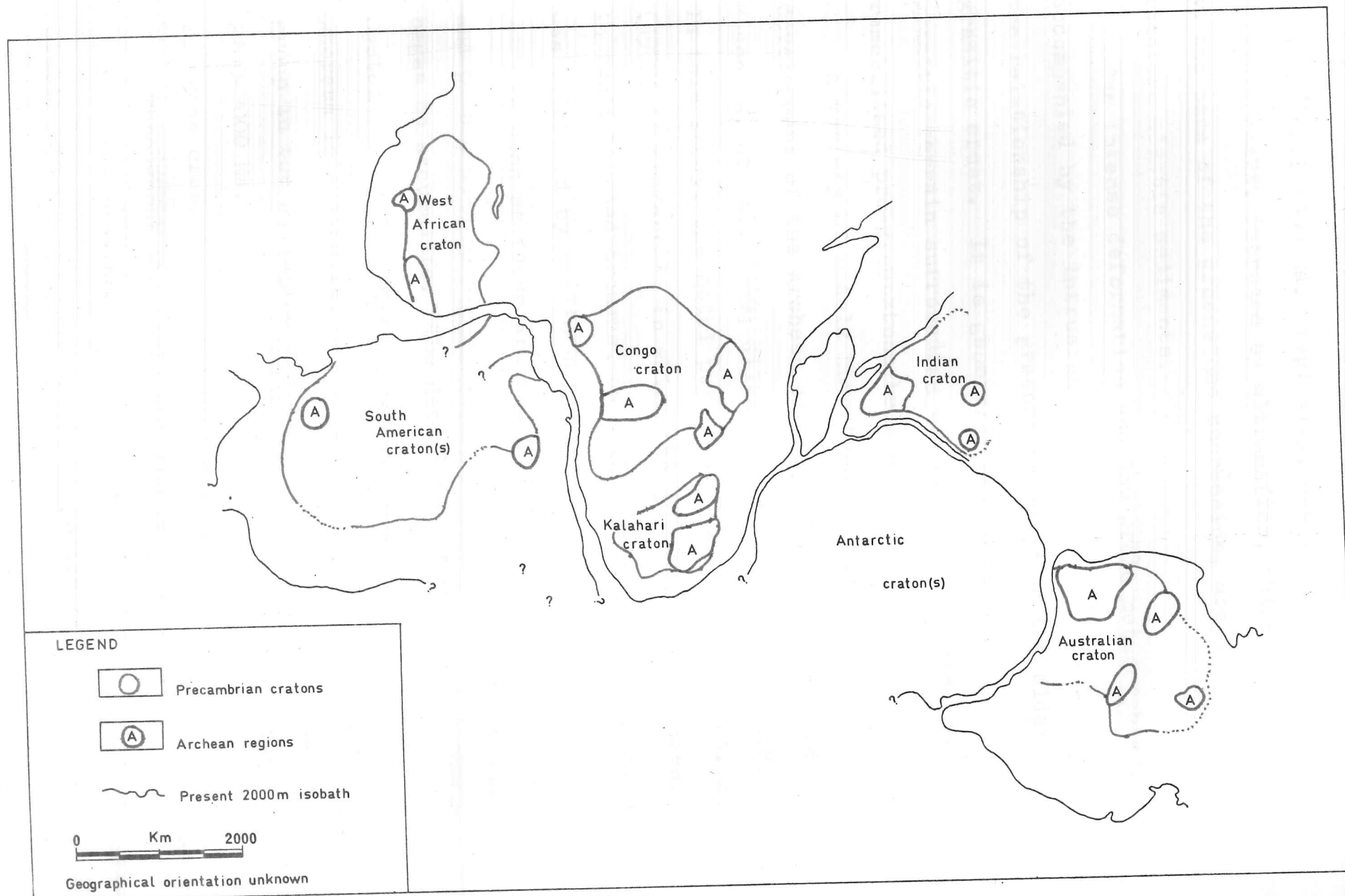


Fig. 10 The Precambrian cratons



cratons, they trend roughly east-west), yield minimum ages of about 3000 Ma. Typically, the calc-alkali volcanic rocks, intruded by ultramafics, which predominate at the base of the greenstone succession, are overlain by immature clastic sediments.

The intense deformation and low grade metamorphism, accompanied by the intrusion of K-rich granites, has obscured the relationship of the greenstone belts to the older granitic crust. It is generally held however, that the granitic terrain surrounding the greenstone belts, includes remobilised pre-greenstone belt basement.

A variety of models have been proposed for the development of the Archean crust (Anhaeusser, C.R. and Mason, R. et al. 1969; Gilkerson, A.Y. 1971; Green, D.H. 1972). In this study, the model put forward by Anhaeusser et. al. (1969) is preferred, in which the greenstone belts developed in fault-bounded troughs, on a thin granitic crust, which was thickened by sialic underplating about 3000 Ma.

As soon as these Archean provinces had been stabilised and planed down by erosion, extensive platform sediments began to accumulate. The deposition of the Witwatersrand System of the Transvaal Province, commenced about 2800 Ma, whereas in Australia, deposition of the Mount Bruce Supergroup in the Nullagine cratonic basin, occurred between 2200-2000 Ma. Banded ironstones are typically included in these cratonic sequences.

Throughout the early and middle Proterozoic, a network of tectonic provinces developed around the margins of the stable Archean regions. Although radiometric data are

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widely scattered, there appears to be a concentration of ages between 2000-1800 Ma (e.g. the Ubendian-Rusizian belt of western Tanzania and the Halls Creek belt of Australia), and 1200-1000 Ma (e.g. the Karagwe-Ankole belt of East Africa).

The striking similarity of geological development in the early Precambrian, is well displayed in the southern continents. In Antarctica, the Precambrian record is sparsely documented and tectonic geologists should be wary of making premature correlations of events known in Antarctica with those outlined above.

The question inevitably arises, as to whether there is enough justification for the extension of the operation of plate tectonics, well documented from the late Phanerozoic, into the early Phanerozoic and Precambrian. Although no definite answer is as yet forthcoming, it does appear that by the end of the Archean, large continental sized masses were in existence. The available palaeomagnetic data suggests that these masses were moving, both relative to each other and to the poles. This however, need not necessarily indicate that the style of tectonics which is thought to have operated in the late Phanerozoic, can be extended back into the Proterozoic.

#### b) STAGE 2. The consolidation of Gondwanaland.

The late Precambrian and early Palaeozoic period, was marked by extensive stabilisation of the crust. In Africa, these events are collectively referred to as the Pan African; in South America, it is known as the Brazilide;

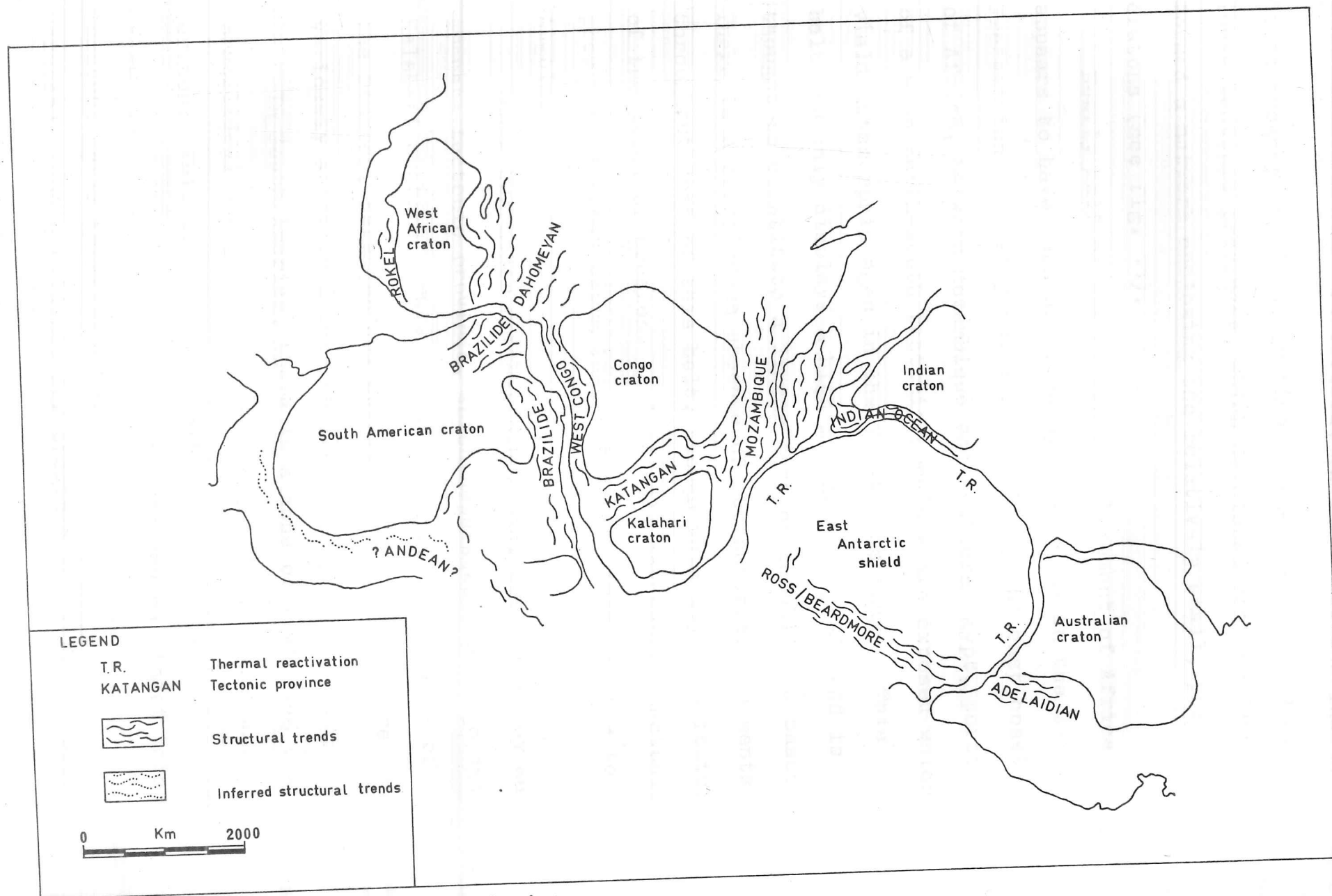


Fig. 11 The consolidation of Gondwanaland

in Australia, as the Adelaidean; in India, as the Indian Ocean orogeny and in Antarctica as the Ross-Beardmore. These tectonic provinces, which developed contemporaneously, formed a network enclosing the relatively small, pre-existing cratons (see fig. 11).

Nearly half of the crystalline basement of Africa appears to have been affected by orogenesis in the late Precambrian and early Palaeozoic. Along the east coast of Africa, between Mozambique and southern Egypt, portions of a wide north-south tectonic province are exposed which yield metamorphic ages in the 700-400 Ma range. This belt commonly displays a high metamorphic grade and is thought to constitute a linear zone of remobilised basement. There is a conspicuous absence of supracrustal sediments throughout most of this belt, though this may be a feature of the level of erosion. A less well documented tectonic province is known along the west coast, from Nigeria to Angola.

These two major north-south zones, are linked by an arcuate tectonic province, which separates the Congo and Kalahari cratons. This province comprises portions of the Damaran, Katangan and Lufilian belts, which were variously stabilised between 720-420 Ma.

In South America, there is a zone of reworking (the Brazilides) along the eastern margin of the South American craton. This lines up well with the activity in the West Congo (see fig. 11). On the the western margin of this craton, early Palaeozoic supracrustal sediments are exposed, though evidence for orogenic activity has been

obscured by later events, associated with the Andean tectonic province.

The Indian Ocean orogeny (600-500 Ma) affected the extreme southern and south eastern coastal regions of the Indian Peninsula and Sri Lanka. In Australia, the Precambrian craton is flanked on the east by the Adelaide tectonic province, which was subjected to orogenesis between 570-500 Ma.

Finally, in Antarctica two distinct, but closely related, tectonic provinces developed along the Pacific margin of the East Antarctic shield. Widespread thermal reactivation of the margins of the East Antarctic shield also took place at this time. The correlation of the Adelaide tectonic province with the Ross tectonic province, is often cited as evidence for the former union of Australia and Antarctica. It should be noted that the period of orogenesis associated with former, is older than that of the latter. In this respect, it is important to realise, that although deformation or igneous intrusion represented particular stages in the development of a tectonic province, the manifestation of these stages need not necessarily have been synchronous throughout the province.

With the exception of the Katangan, all these tectonic provinces coincide with the present margins of the main continental masses, whereas the Precambrian cratons form the interiors. Read and Watson (1975) concluded that when the break-up of Gondwanaland occurred, the rifts formed preferentially along the lines of these tectonic provinces,



and not across the stable Precambrian cratons.

c) STAGE 3. Gondwanaland as a single unit.

As a result of the late Precambrian and early Palaeozoic orogenesis, the previously separated Precambrian cratons were 'welded' together to form a single, larger stable unit - Gondwanaland (see fig. 12). Palaeomagnetic data indicates that throughout the remainder of the Palaeozoic, Gondwanaland drifted across the Southern Hemisphere. Orogenic activity was confined to peripheral tectonic provinces, developing chiefly on the leading edges of this supercontinent, whereas in the interior extensive platform sequences accumulated in a series of shallow basins.

The evolution of the peripheral tectonic provinces is best displayed in eastern Australia, where a series of marginal troughs developed throughout the mid-upper Palaeozoic. At least six phases of orogenesis have been identified in this region, between the Silurian and the Permian. In general the centres of activity appear to have gradually migrated eastwards, as successive tectonic provinces were accreted laterally onto the margins of the Australian craton.

In Antarctica, the sequence of events is less well known. It is suggested on page 50 that the Pacific margin of Antarctica may have been fragmented during the break-up of Gondwanaland. Nevertheless, two tectonic provinces, separated both in time and space, can<sup>be</sup> distinguished. The Borchgrevink tectonic province was subjected to

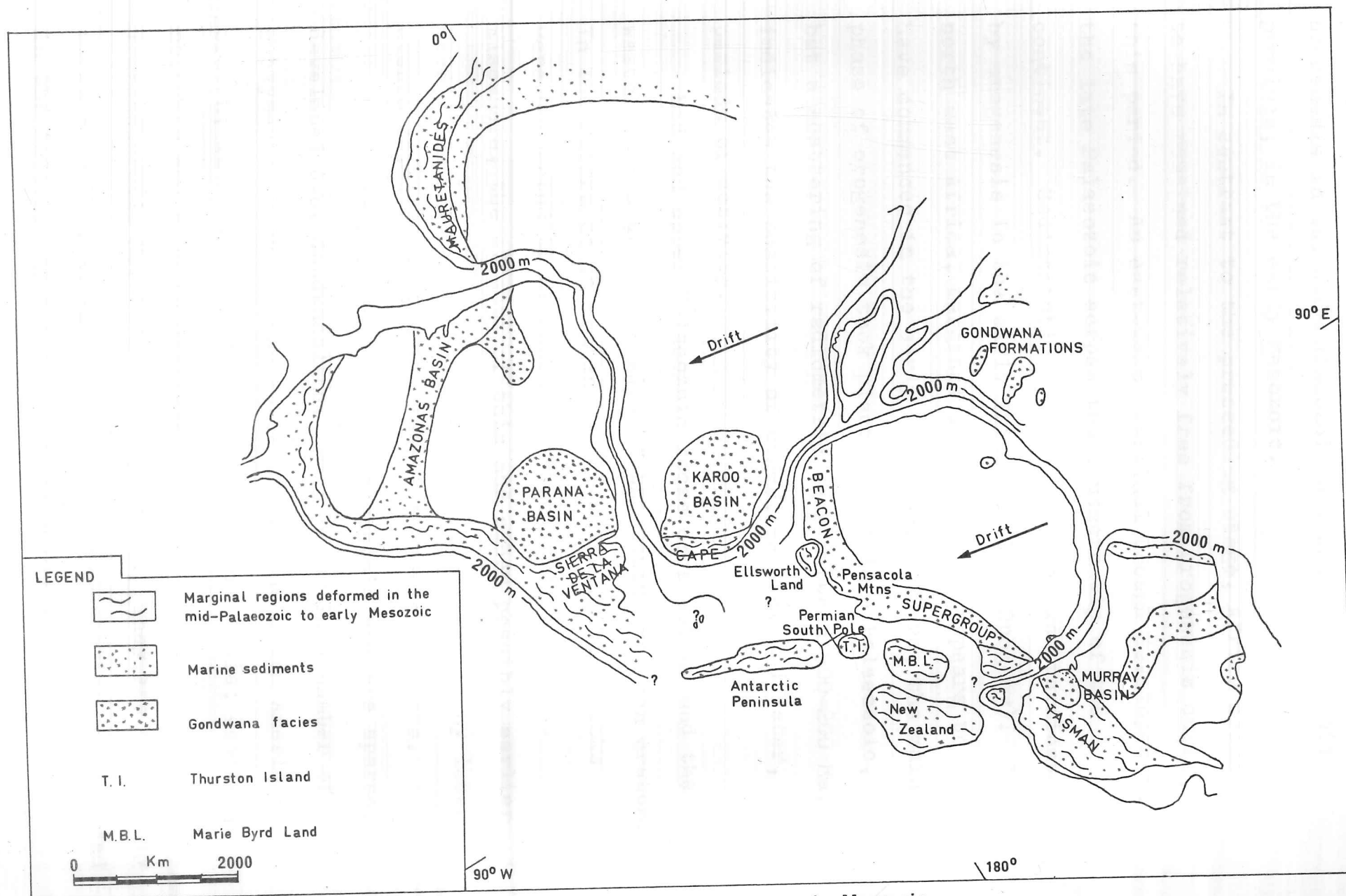


Fig. 12 The development of Gondwanaland in the mid-Palaeozoic to early Mesozoic

orogenesis in the mid-Palaeozoic and Weddell tectonic province, in the early Mesozoic.

In contrast to the preceeding stage, Africa seems to have remained relatively free from orogenesis during this period. An east-west, marginal trough developed in the late Palaeozoic across the southern tip of the continent. Sedimentation in this trough, was terminated by orogenesis in the early Triassic (Cape Orogeny). In north west Africa, marginal sedimentation appears to have commenced in the early Palaeozoic. Here, the main phase of orogenesis took place in the late Palaeozoic, but a scattering of radiometric ages between 500-200 Ma, indicates the possibility of other, earlier and later, periods of activity.

Mid and upper Palaeozoic rocks crop out around the western and southern margins of the South American craton. In the Sierra de la Ventana of Argentina, these rocks were subjected to orogenesis in the early Mesozoic. Elsewhere, the effects of this and other possibly earlier orogenies, have been partly or completely masked by later events associated with the Andean tectonic province.

Platform sediments of mid-Palaeozoic age are sparsely developed over Gondwanaland. They occur in a number of embayments extending eastwards across the South American craton; in North Africa; Arabia; northern India; central, northern and western Australia and in the central Transantarctic Mountains of Antarctica. They are dominantly shallow marine, though terrestrial sedimentation is recorded in the Amadeus Basin of central Australia.

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This pattern of sedimentation was disrupted by a major period of continental glaciation in the Permo-Carboniferous which affected all the southern continents. King (1957) considered that the maximum centres of this glaciation were not contemporaneous, but sequential from west to east, as the supercontinent drifted across high southern latitudes. The glacial beds are characteristically associated with continental sediments in the interior, whereas towards the margins glacio-marine sediments are locally developed.

After glaciation, sedimentation in the interior continued in a series of vast basins e.g. the Great Karoo Basin of southern Africa, or the Parana Basin of southern Brazil. In Antarctica, the equivalent deposits are represented by the Victoria Group of the Beacon Supergroup. These rocks are exposed throughout the Transantarctic Mountains and at one point on the coast of the East Antarctic shield. They may underlie extensive areas of the East Antarctic ice sheet.

d) STAGE 4. The break-up of Gondwanaland

The long period of internal stability came to an end in the mid-Triassic. A system of rifts developed along what were to become the present continental margins, allowing marine sediments to penetrate into the interior of Gondwanaland (see fig. 13). Tholeiitic igneous rocks, forming a distinct province, were erupted in a broad arc, stretching from northern Brazil to eastern Australia. The continental sedimentation, which had begun in the



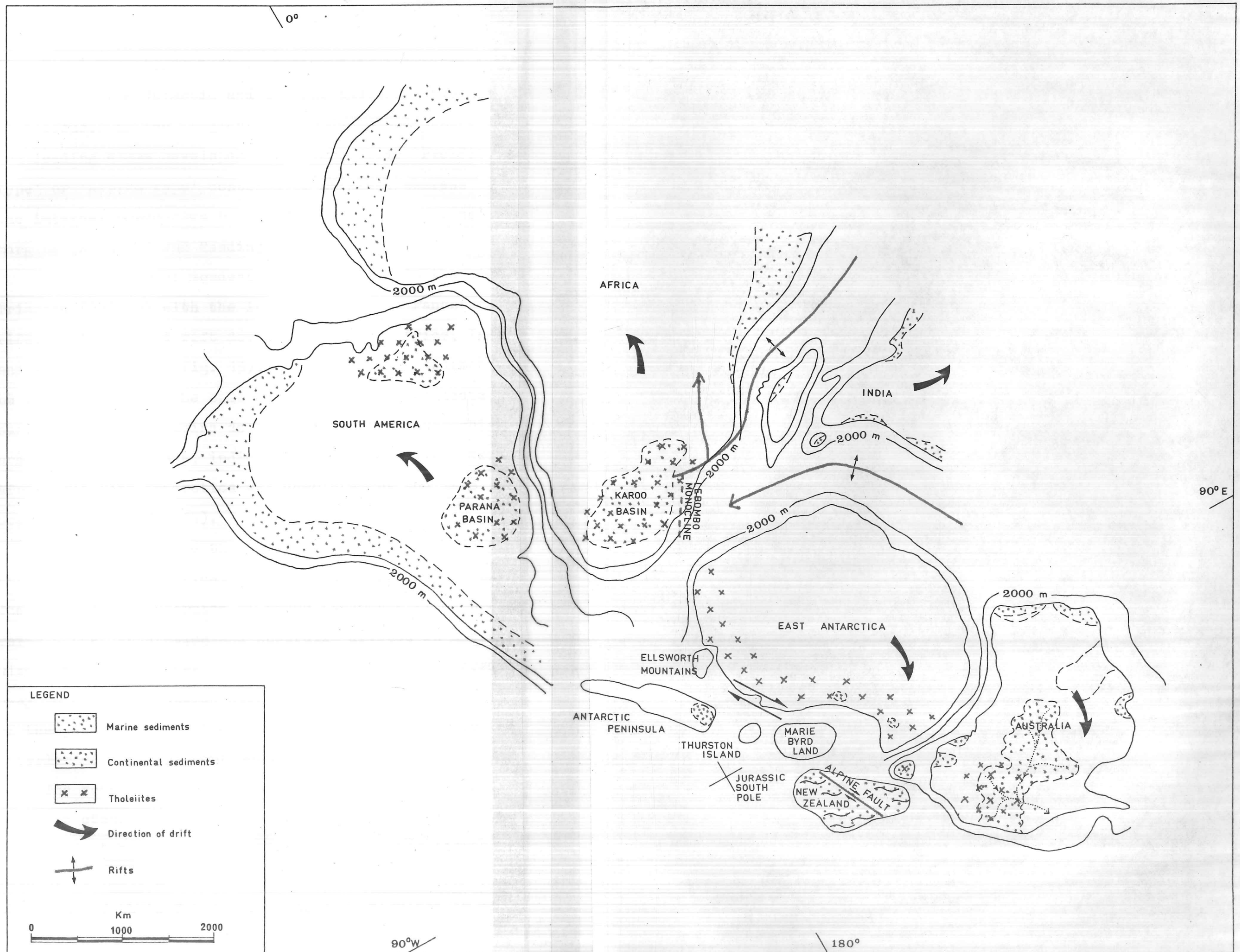


Fig.13 The break-up of Gondwanaland



late Permian cratonic basins continued on a more restricted scale, into the Jurassic and in some instances the late Cretaceous. As the fragments of Gondwanaland separated, the leading edges developed into compressive 'Pacific type' or 'Alpino type' continental margins, whereas the internal boundaries became stable 'Atlantic type' margins (Mitchell and Reading, 1969).

The break-up of Gondwanaland commenced in the mid-Triassic (220 Ma) with the initiation of the Panantartic rift. A 'Y'-shaped rift developed between Africa, India and Antarctica (see fig. 13), allowing marine sedimentation to penetrate along the east coast of Africa and India. The earliest marginal marine deposits in southern Mozambique are of Cretaceous age, indicating that the split between Africa and East Antarctica was completed by the late Cretaceous (see fig. 14).

These rifts broke the supercontinent into three pieces, Africa and South America; India and Antarctica and Australia. The pattern of dispersion of these fragments since break-up reveals that Antarctica and Australia drifted in a clockwise direction, whereas the remaining continents moved away in an anticlockwise direction. This may be a result of the penetration of the rifts from the exterior to the interior of the supercontinent.

The rotational separation of Antarctica and Australia, from the other continents, led to differential movements between East and West Antarctica, along a zone corresponding roughly to the edge of the stable Precambrian craton. The operation of these forces may also have resulted in the

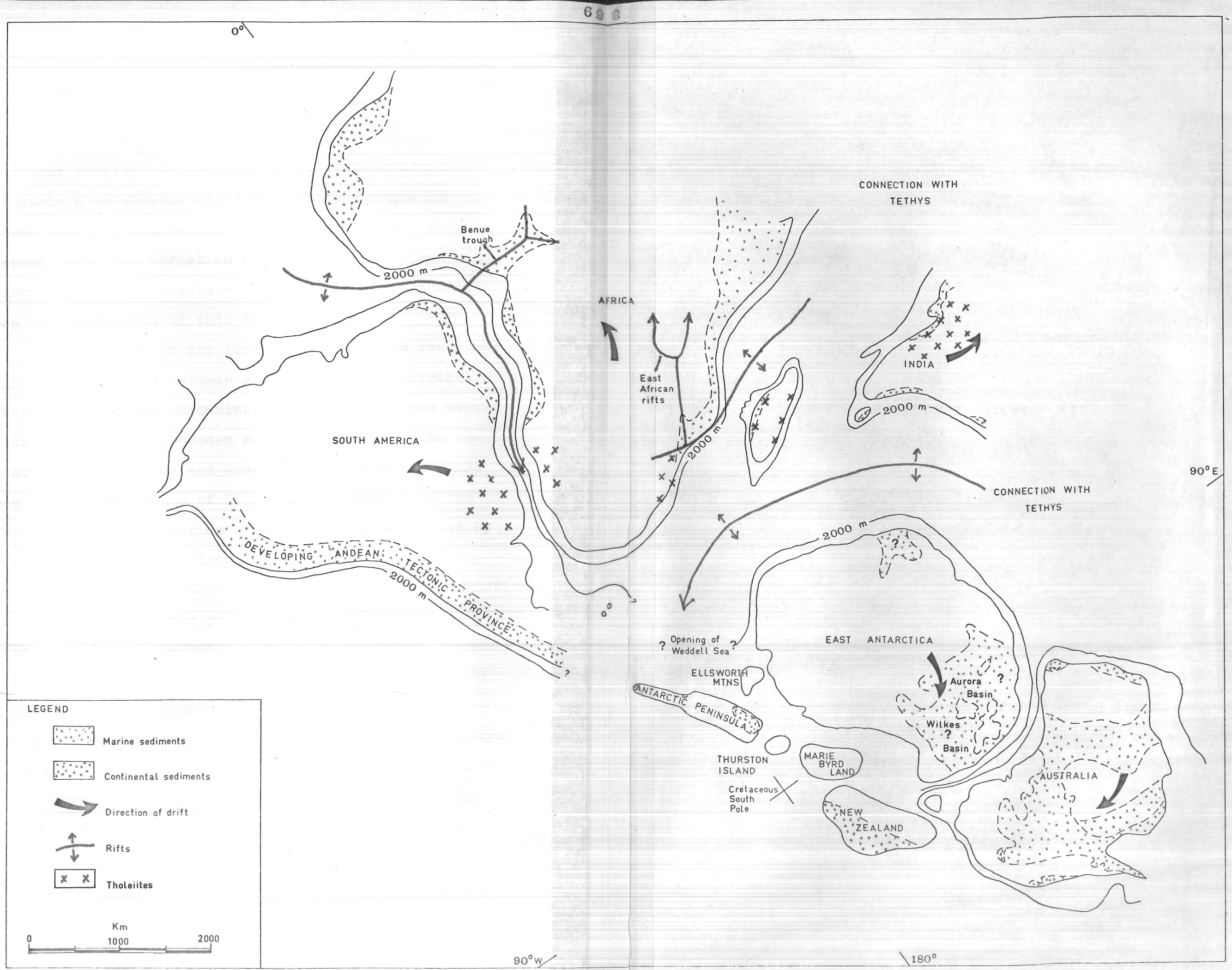


Fig. 14 The early Cretaceous

480 km dextral displacement along the Alpine fault of New Zealand, which took place in the upper Jurassic. The West Antarctic region broke up into at least three distinct blocks. In contrast to the late Mesozoic and Cenozoic developments along the Pacific margin of South America, active subduction in West Antarctica ceased, with the formation of an 'Atlantic type' margin. Rifting associated with opening of the Weddell Sea may have begun at this time.

By the close of the Jurassic (135 Ma) an insipient rift had developed between Africa and South America. This permitted the accumulation of late Mesozoic marine sediments in fault-bounded marginal basins, along the west coast of Africa and east coast of South America, e.g. the Benue trough of Nigeria. At the end of the Cretaceous, South America and Africa were separated by 3000 km of new ocean floor.

On the Pacific margin of South America, the formation of the Andean tectonic province, indicates compressive plate motion and the subduction of ocean crust. The northward drift of Africa and India eliminated the Mesozoic ocean (Tethys) and resulted in a collision with the Eurasian continent, which initiated Alpino-Himalayan orogenesis.

Ocean-floor spreading in the South Pacific Ocean began approximately 81 Ma (Molnar et al. 1975) when New Zealand split away from West Antarctica. The evidence of a different relative direction of motion, associated with a contemporaneous spreading ridge in the





Fig. 15 The early Cenozoic

Tasman Sea led Molnar et al. (1975) to conclude that East and West Antarctica were being rifted apart. The spreading in the Tasman Sea ceased approximately 60 Ma and the Panantarctic rift extended eastwards to initiate the separation of Australia from Antarctica about 55 Ma (see fig. 15).

The clockwise rotation of East Antarctica eventually resulted in a collision with the West Antarctic blocks, in the early Cenozoic. The oroclinal bending at the base of the Antarctic Peninsula may have been produced at this time. The continued westward drift of South America from Africa, was accompanied by bending of the southern tip of Tierra del Fuego and the northern section of the Antarctic Peninsula, and the formation of the Scotia Sea.

At the present (see fig. 16) Antarctica is almost completely surrounded by a spreading ocean ridge (the Panantarctic rift), which lacks a complimentary subduction zone. This means that the Antarctic plate is growing in size, as the Panantarctic rift migrates northwards, away from the Antarctic. There is evidence to support this from the South Atlantic, in the form of the Walvis Ridge. The alkali volcanism of the late Cenozoic, is associated with a phase of block tectonics and rifting, which may herald another period of break-up.



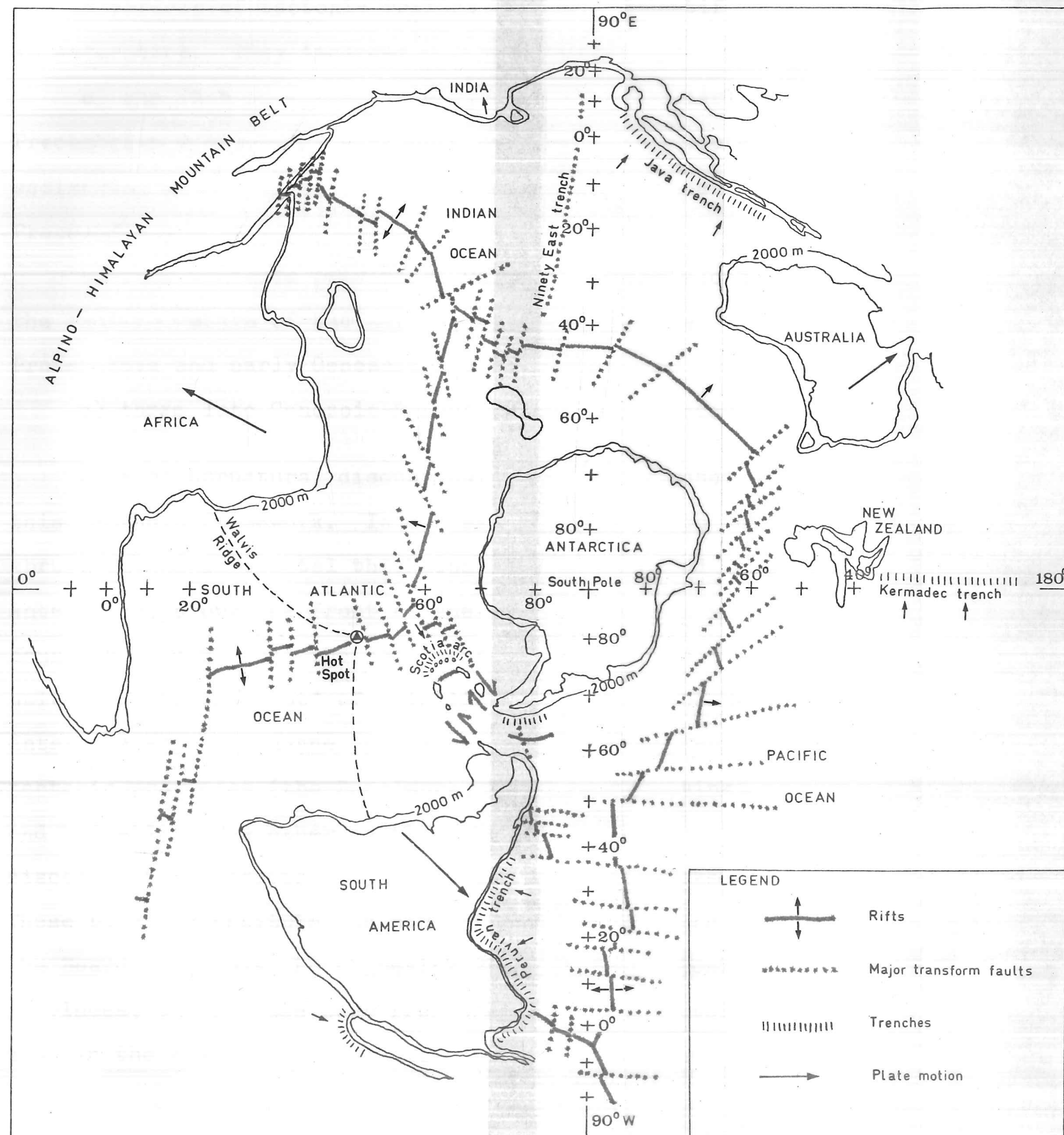


Fig.16 The major tectonic features of the present Southern Hemisphere.  
South-polar stereographic projection

## Concluding remarks

A variety of tectonic regions have been identified in Antarctica. They include:

a) the East Antarctic shield, comprising an early Precambrian metamorphic basement, overlain by platform sediments, which has remained stable since the late Precambrian;

b) five tectonic provinces, which developed along the Pacific margin of the shield, between the late Proterozoic and early Cenozoic and

c) three late Cenozoic-Recent volcanic provinces.

A major structural discontinuity is superimposed upon this tectonic framework. It corresponds roughly to the abrupt change in crustal thickness between East and West Antarctica, along the front of the Transantarctic Mountains and divides the continent into two units. The unit lying to the east\* of this line, comprises the East Antarctic shield and the epicratonic portions of four tectonic provinces (the Beardmore, Ross, Borchgrevink and Weddell). The other unit to the west† of the discontinuity, comprises a number of distinct blocks. These blocks constitute the non-epicratonic portions of the Beardmore, Ross, Borchgrevink and Weddell tectonic provinces, which broke away from the main continental mass in the Mesozoic. Small slices of Precambrian basement may also have separated, though as yet, no

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\* East is used here in relation to the Greenwich meridian.

† West is used here in relation to the Greenwich meridian.

traces of Precambrian rocks have been found in West Antarctica. After fragmentation, sediments accumulated in a number of basins which developed between these West Antarctic blocks. The deposits in the Byrd Subglacial Basin may date from the Jurassic.

An insight into some of the problems associated with the tectonic evolution of Antarctica is gained by viewing the tectonic scheme in the broader context of Gondwanaland. Clearly, the fragmentation of the Pacific margin of East Antarctica and the differential movements between East and West Antarctica in the Mesozoic, can be related to the break-up of Gondwanaland. The opening of the Weddell Sea probably took place at the same time.

The elucidation of the tectonic evolution of Antarctica however, is not complete. A great many problems remain to be resolved. The precise nature of the structural discontinuity between East and West Antarctica is still a matter of conjecture and further advances are dependant upon more detailed geophysical investigations of the deep crustal structure of West Antarctica and the surrounding ocean basins.

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