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THE ROSS SEA (ANTARCTICA): A REVIEW OF THE GEOLOGICAL AND GEOPHYSICAL EXPLORATION

Abstract. A descriptive overview of the recent geological and geophysical findings in the Ross Sea area is presented in an easy approach to the non-specialist reader. After a quick reference to the Gondwana continent break-up, geological themes are divided between Land Geology and Marine Geology. A list of pertinent references is provided.

INTRODUCTION

The purpose of this paper is to introduce the non-specialist reader to the geology of the Ross Sea area. The impression resulting is that present knowledge of the geological structure of the Ross Sea and surrounding landmasses is extremely scarce due to the presence of ice covering both land and sea, and thus preventing direct exploration of outcrops and seafloor.

The tools adopted so far for the investigation of the area are traditional geological exploration in Marie Byrd Land and in Victoria Land (where the Italian Antarctic base is located), which border the Ross Sea to the east and west, respectively, and coring, drilling, and marine geophysical investigation through multichannel and high resolution single channel seismic reflection and seismic refraction exploration in the Ross Sea (Table 1). The marine geophysical techniques offer the principal advantage of allowing a widescale investigation of the ice-free portion of the submerged area and thus identification of regional geological features, while sampling of geological units on land, although scattered over the few available outcrops (only 2% of the Antarctic land area outcrops through the ice!), furnish evidence for the true nature and age of the geological units. The correlation between these two approaches, integrated with sub-bottom sampling, will provide the key for understanding the Ross Sea geology.

The Ross Embayment, (Figs. 1 and 2) which includes the Ross Sea and the Ross Ice Shelf, is bordered to the west and south by the Transantarctic Mountains, a 4,000 km long mountain chain extending from Cape Adare, in Northern Victoria Land on the Pacific coast, to Coats Land on the Weddell Sea (Atlantic coast). The Transantarctic Mountains provide one of the largest exposed areas of the Antarctic Continent, and include several peaks with elevations in excess of 4,000 m (4,528 m, Mt. Kirkpatrick, Queen Maud Mountains). To the east of the Ross Embayment, Marie Byrd Land is almost completely buried by the ice cover and most of the bedrock surface lies below sealevel (limited outcrops are present along the Pacific Coast).

The Ross Sea (about 750,000 km ^{2}, maximum depth 1,200 m, average depth around 500 m) is one of the largest circum-Antarctic marginal basins. It is bordered to the south by the Ross Ice Shelf, to the east by Marie Byrd Land, and to the west by the Transantarctic Mountains. To the north the Ross Sea is open to the South Pacific Ocean, to which it is connected by a well defined continental slope in the east, and by an irregular transition to the Pacific Antarctic Ridge in the west. The east and west Ross Sea continental slopes are separated by the Iselin

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Table 1 - Geophysical data.

YEAR	SHIP	INSTITUTION/PROJECT	COUNTRY	INVESTIGATION	REFERENCES
1972-73	D/V Glomar Challenger	Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES)/ DSDP	U.S.A.	Deep sea drilling (4 sites)	Hayes, Frakes et al., 1975
1974-75	—	/DVDP	U.S.A., New Zealand Japan	Continental drilling (14 sites) Drilling from ice-shelf (1 site)	McGinnis, 1981
1979	—	New Zealand Antarctic Research Centre/MSSTS	New Zealand	Drilling from ice-shelf (1 site)	Barrett, 1986
1980	S/V Explora	Federal Institute for Geosciences and Natural Resources (BGR)	Fed. Rep. of Germany	Multichannel Seismics (6,743 km)	Hinz & Block, 1983
1982	S/V Explora	Institut Francais du Pétrole	France	Multichannel Seismics (2,000 km)	
1983	R/V Hakurei-Maru	Japanese National Oil Corporation	Japan	Multichannel Seismics (1,670 km)	Sato et al., 1984
1984	R/V S.P. Lee	U.S. Geological Survey	U.S.A.	Multichannel Seismics (1,850 km)	Cooper et al., 1987
1984-86	—	New Zealand Antarctic Research Centre/CIROS	New Zealand	Drilling from ice-shelf (2 sites)	Barrett, 1989
1987-88	R/V Geolog Dimitri Nalivkin	Marine Arctic Geological Expedition (MAGE)	U.S.S.R.	Multichannel Seismics (4,117 km)	Zayatz et al., 1990
1987-88	S/V OGS-Explora	Osservatorio Geofisico Sperimentale (OGS)	Italy	Multichannel Seismics (2323 km)	Berger et al., 1988
1988-89	R/V Geolog Dimitri Nalivkin	Marine Arctic Geological Expedition (MAGE)	U.S.S.R.	Multichannel Seismics (3,175 km)	Zayatz et al., 1990
1988-89	S/V OGS-Explora	Osservatorio Geofisico Sperimentale (OGS)	Italy	Multichannel Seismics (4,102 km)	Brancolini et al., 1991
1989-90	S/V OGS-Explora	Osservatorio Geofisico Sperimentale (OGS)	Italy	Multichannel Seismics (2,533 km)	
1990-91	S/V OGS-Explora	Osservatorio Geofisico Sperimentale (OGS)	Italy	Multichannel Seismics (557 km)	

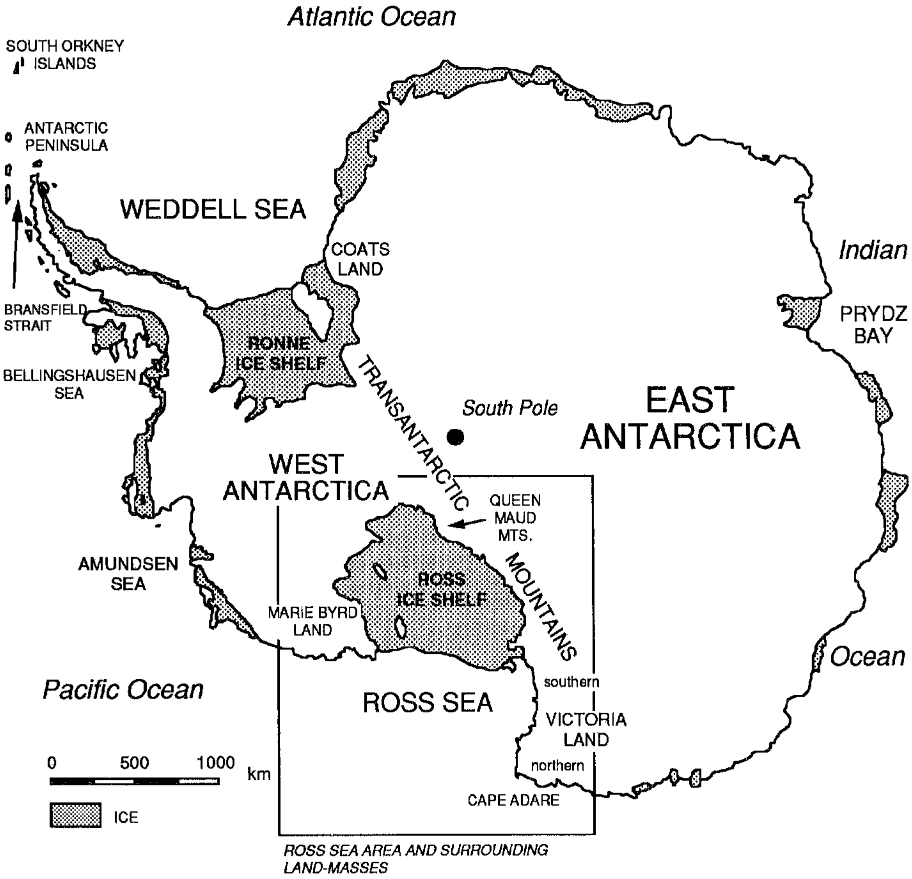

Fig. 1 — The Antarctic Continent. Main geographical names cited in text are indicated.

Bank, which protrudes into the South Pacific Ocean.

The Ross Sea extends entirely over the continental shelf, typically deeper than the low-latitude shelves, and slopes toward the continent due to the presence through time of a fluctuating ice shelf. Sub-basins and topographic highs trending approximately in a N-S direction roughly reflect the presence in the subsurface of structural highs and sedimentary basins. In the western Ross Sea, the striking topographic features are, from west to east, the Drygalsky Basin, the Mawson and Crary banks, the JOIDES Basin, the Pennell Bank and the Ross Bank, all sharply elongated in a direction parallel to the Victoria Land coastline. The eastern Ross Sea, on the other hand, is characterized by a gentle bottom topography.

ANTARCTICA BREAK-UP

The Antarctic continent (Fig. 1) is structurally and geologically divided into a western and an eastern sector. The boundary between the two is represented by the Cenozoic West Antarctic rift system (LeMasurier, 1978) which runs from the western margin of the Ross Sea to the eastern margin of the Weddell Sea along the Transantarctic Mountains, the main geological feature outcropping in Antarctica.

The present day coastline of East Antarctica (from the Weddell Sea to the Ross Sea eastward) is a continuous passive continental margin which originated during the diachronous break-up of Gondwana. From the scarce outcrops, the continental crust of East Antarctica is composed

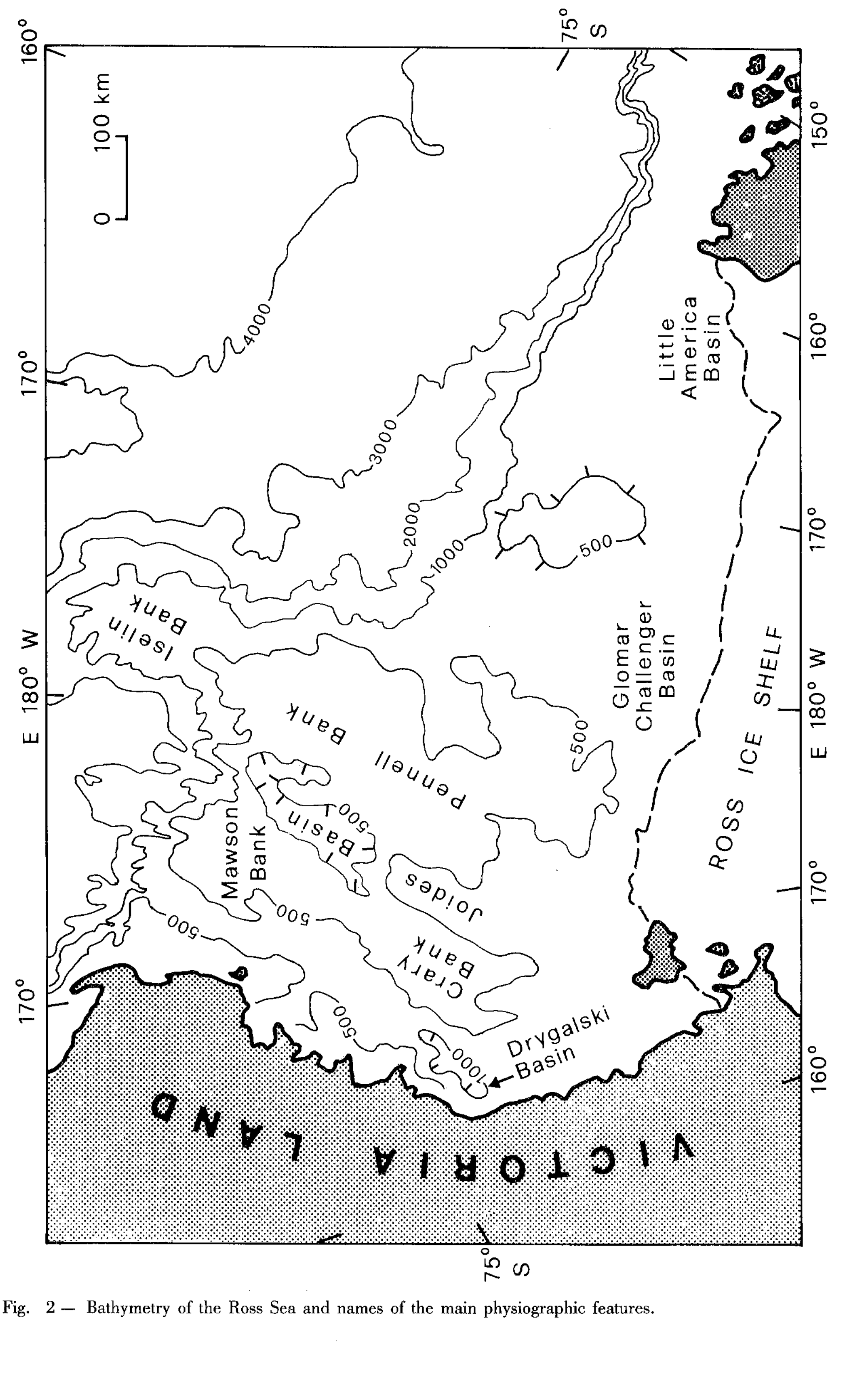

Fig. 2 — Bathymetry of the Ross Sea and names of the main physiographic features.

of a crystalline metamorphic basement of Paleozoic or older age unconformably overlain by continental deposits of Devonian to Jurassic age. In the marine seismic reflection record of this margin, a widespread angular unconformity recognized beneath Middle to Late Jurassic or Early Cretaceous strata (break-up unconformity) marks the beginning of rifting.

West Antarctica is a geologically complex area with an irregular shape composed of several crustal blocks and bordered by different types of plate margins, from transform to active with the opening of the Bransfield back-arc basin, and finally passive, on the Pacific margin of the Antarctic Peninsula, moving from the South Orkney Islands to the Bellingshausen and Amundsen seas. This margin owes its complex structure to a time-progressive ridge-trench interaction, and to the creation of oceanic crust at the spreading centers of the Scotia Plate. The geological structure of the Weddell Sea and the Ross Sea, the two major embayments of the Antarctic coastline that mark the transition between the Eastern and Western domains, is still poorely understood, mainly because of the presence of the largest Antarctic ice shelves (Ronne and Ross respectively) hiding most of the seafloor to marine geophysical investigations.

The genetic difference between East and West Antarctica is portrayed by Lawver and Scotese (1987) and Lawver et al. (1992) in one of the latest reconstruction of Gondwanaland based on oceanic paleomagnetic data (Fig. 3). It is evident that East Antarctica is a remnant of the interior of the super-continent, while the crustal blocks now clustered in West Antarctica were already part of the southern margin between the Gondwanaland craton and the Panthalassa ocean (along with present day New Zealand). Land geology suggests that this was already an active margin before break-up (Grunow et al., 1991).

According to the reconstruction of Norton (1982), rifting of the Gondwanaland continental crust begun right in the core of the super continent in the Middle Jurassic giving the present day east African Margin. By the time of magnetic anomaly M-1, in the Early Cretaceous, rifting had propagated to the present day South Atlantic and Indian Ocean, and by the time of magnetic anomaly 34 (Middle Cretaceous), a southern plate composed of South America, Antarctica, and Australia had formed, bordered to the north by a continous spreading center in the proto-Atlantic and Indian Ocean, and to the south by the Pacific active margin.

According to Cande and Mutter (1982), and Mutter et al. (1985), at this time, crustal rifting had already begun between Antarctica and Australia with the creation of oceanic crust at extremely low rates. Although some problems still exist in identifying the position of the present day Antarctic Peninsula with respect to the southern Andean Cordillera, the geological analogy between Tierra del Fuego and the Antarctic Peninsula, at least in the pre-Gondwanaland break-up and in the Late Creaceous-Tertiary (Dalziel, 1983) shows that the two areas were still connected in the Middle Cretaceous. The last event in the creation of the present day configuration of Antarctica was the opening of the Drake Passage during the Late Oligocene (Barker and Burrell, 1977). Evidence of cold deep water formation in the Weddell Sea has been found at the beginning of the Oligocene according to ODP Leg 113 (Kenneth and Barker, 1990), and the oldest oceanic crust identified in the Scotia Plate belongs to magnetic anomaly 10, approximately dated to 30 My.

THE GEOLOGIC RECORD OF LAND MASSES

The geology of the Ross Sea is mainly known from the limited outcrops of the landmasses surrounding the Ross Embayment (Figs. 4 and 5). The crystalline basement is everywhere composed of Precambrian and Early Paleozoic granitic and metamorphic rocks and is probably present over the entire Ross Sea area, because marble and calcsilicate gneiss of possibly Early Paleozoic age have been recovered at DSDP site 270 on a basement high (Hayes and Frakes, 1975), and have been tentatively correlated to the Skelton Group of Southern Victoria Land (Davey, 1987). These rocks were involved in different orogenic processes which culminated in the Ross Orogeny of Cambro-Ordovician age.

The land masses surrounding the Ross Embayment belong to different geological provinces, each characterized by its own tectonic and geodynamic evolution: the Transantarctic Mountains to the west (including the Northern and Southern Victoria Land provinces) and Marie Byrd Land to the east.

AP	Antarctic Peninsula	MBL	Marie Byrd Land
CP	Campbell Plateau	MOZ	Mozambique
CR	Chatham Rise	NNZ	north New Zealand
KN	Kenia	SL	Sri Lanka
LHR	Lord Howe Rise	SNZ	south New Zealand
LM	Lebombo Monocline	SP	Shillong Plateau
MAD	Madagascar	TI	Thurston Island

Fig. 3 — Reconstruction of Gondwana modified after Lawver and Scotese (1987); Lawver et al. (1992).

The Transantarctic Mountains

The Transantarctic Mountains (TAM) consist of a rift shoulder mountain chain, with elevations over 4,500 m, that have formed at the continent-continent passive margin between East and West Antarctica, and presently constitute the eastern edge of Eastern Antarctica.

The central TAM are composed of an Early Proterozoic high grade metamorphic core flanked by lower grade metamorphites of Late Precambrian age and are overlain by shallow water marine sediments of Cambrian age. Three groups have been identified:

Nimrod Group: amphibolites and meta-volcanics (Grindley, 1981);

Beardmore Group: meta-graywakes and phyllites (Gunn and Walcott, 1962);

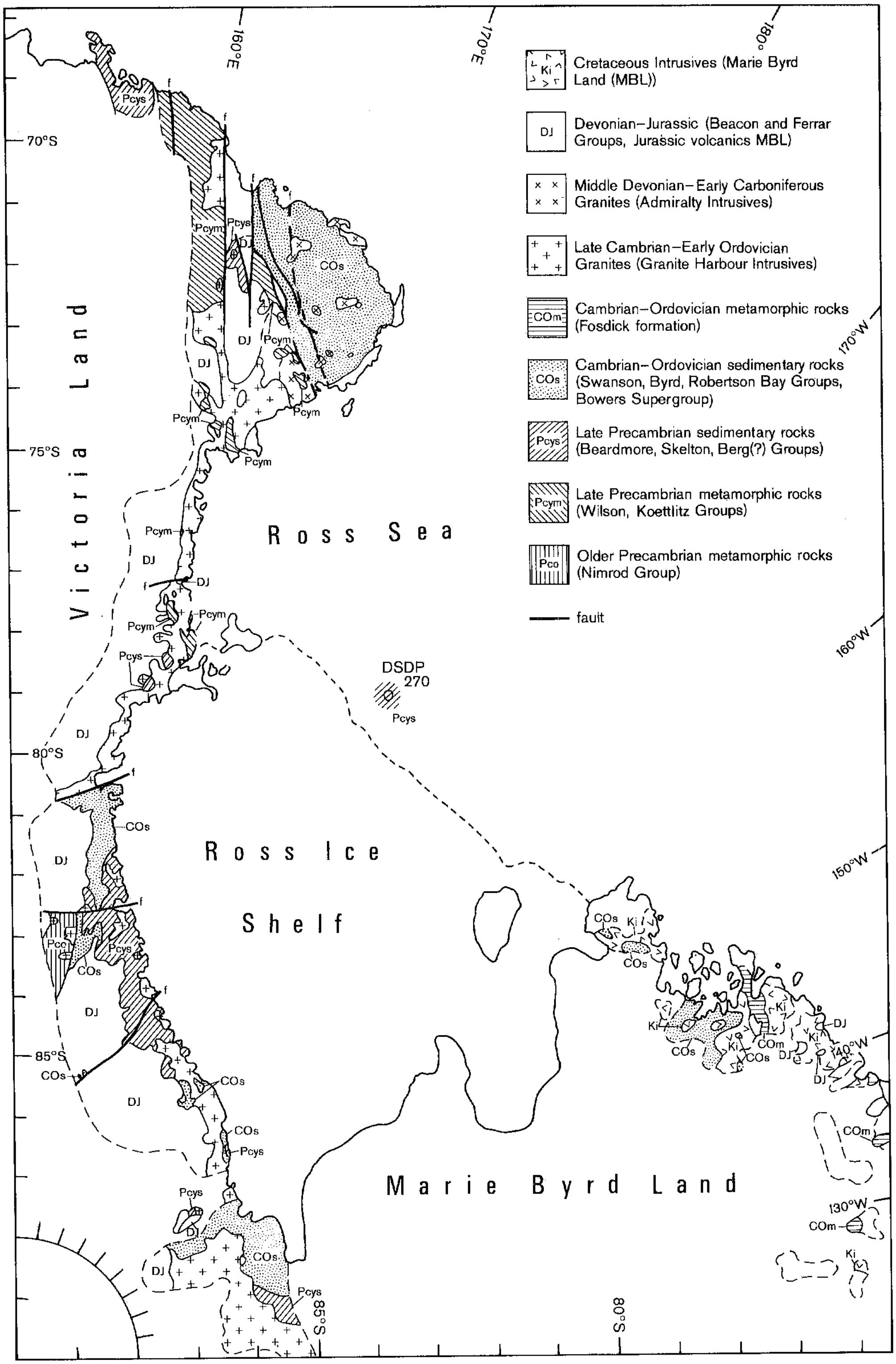

Fig. 4 — Generalized map of the Ross Sea area geologic provinces modified after Davey (1987) and Wong et al. (1987).

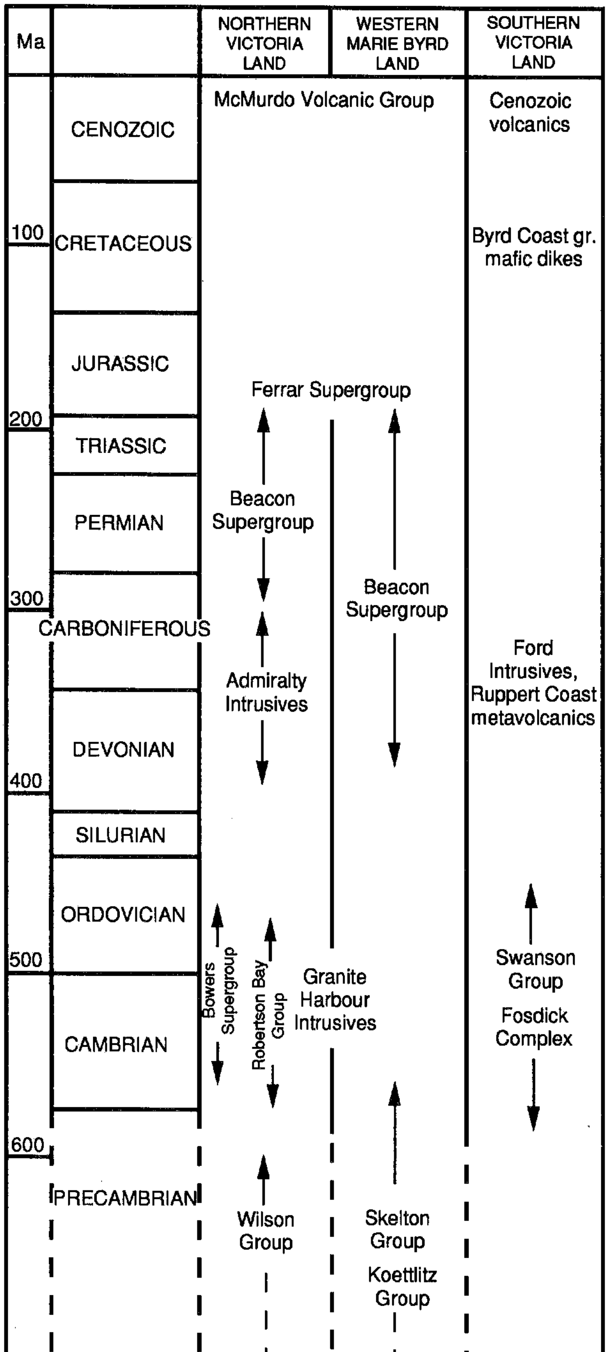

Fig. 5 — Stratigraphic correlation of the Ross Sea area geologic provinces after Wong et al. (1987).

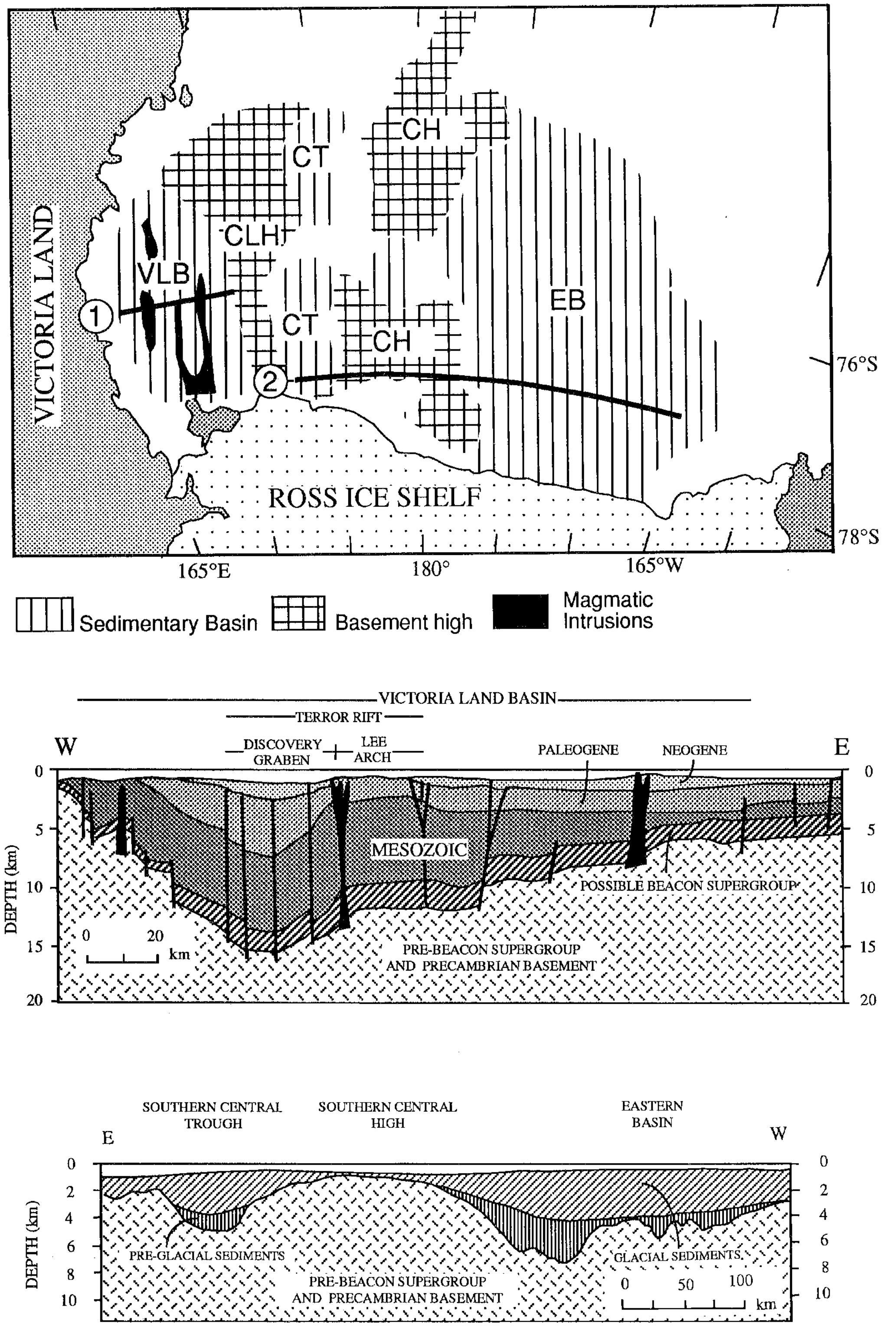

Fig. 6 — Structural scheme of the Ross Sea (modified from Hinz and Kristoffersen, 1987) and geological sections (modified from Cooper et al., 1987).

Byrd Group: limestones and conglomerates (Davey, 1987; Grindley, 1981; Gunn and Walcott, 1962).

The uplift of the TAM is the most significant structural event and it started on the Antarctic continent in the Early Cretaceous and continued with maximum intensity in the Late Paleogene and Neogene. Although the rate of uplift has been calculated at 100 m/My in the last 50 My (Gleadow et al., 1984; Fitzgerald et al., 1986), at least four episodes of uplift have been recognized since the Early Cretaceous by Stump and Fitzgerald, (1992).

Explanations for the uplift of the TAM include a "simple shear model" (Fitzgerald et al., 1986) which implies a low angle westward dipping shear plane causing asymmetric uplift and subsidence, and a "flexural uplift model" (Stern and ten Brink, 1989) which involves thermal uplift, erosion, and Vening-Meisnesz effect.

Northern Victoria Land

The geology of this area has been reviewed in many papers (Tessensohn et al., 1981; Bradshaw et al., 1982; Wodzicki et al., 1982; Bradshaw and Laird, 1983; Laird and Bradshaw, 1983; Davey, 1987), and systematically investigated by different geological expeditions, such as the Ganovex Team (Ganovex Team, 1987) and PNRA (Italian National Antarctic Research Program; Carmignani et al., 1989).

Traditionally, the basement rocks are divided into three main terranes with different geological evolutions (Gair et al., 1969; Kleinschmidt and Tessensohn, 1987; Ganovex Team, 1987; Bradshaw, 1989):

Wilson Group, which is the oldest unit outcropping in the area, and includes medium to high grade metamorphic rocks; they represent, in general, quarzfeldspatic and semipelitic schists and amphibolites (Late Precambrian-Cambrian).

Bowers Supergroup, which generally comprises low grade metamorphic rocks, and includes series of shallow marine sediments and volcanic flow deposits, fluvial conglomerates and quartzarenites. The total thickness of the Supergroup reaches 10,000 m. It is composed of three major units separated by unconformities; the *Sledgers Group* (3,500 m thick marine terrigenous sediments and volcanites), the *Mariner Group* (2,500 m of sedimentary rocks), and the *Leap Year Group* (4,000 m of non-marine sediments and volcanites), and by an older unit, the *Husky Conglomerate,* which consists mainly of amphibolitic conglomerates and breccias (Early Cambrian-Ordovician) (Davey, 1987; Laird, 1989; Laird and Bradshaw, 1983).

Robertson Bay Group, which is composed of low grade metasedimentary rocks interbedded with sandstone and siltstone indicating submarine fan deposition (Wright, 1981; Field and Findlay, 1983) of Cambrian-Ordovician age (Burrett and Findlay, 1985).

The Bowers Supergroup is separated from the Robertson Bay Group in the east by the Leap Year Fault, belonging to the strongly deformed zone called Millen Shear Zone (Bradshaw, 1989), and from the Wilson Group in the west by the Lanterman Fault Zone (Bradshaw et al., 1985). Both faults, of Cambrian-Ordovician age, are oriented in a NW- SE direction.

Several mechanisms have been identified to explain the structural relationships between the three terranes of Northern Victoria Land, such as strike-slip movements (Weaver et al., 1984), thrusting (Kleinschmidt and Tessenson, 1987; Gibson and Wright, 1985), transpression (Gibson, 1987), and flat and ramp structures developed during crustal accretion (Flöttmann and Kleinschmidt, 1991).

Four different orogenic phases from the Proterozoic to the Paleozoic have been identified:

Nimrod (Early-Middle Proterozoic);

Beardmore (Late Proterozoic) in the Central TAM (Grindley and McDougall, 1969; Elliott, 1975);

Ross (Cambrian-Ordovician) in the TAM (Gunn and Warren, 1962);

Borchgrevink-Ford (Late Ordovician-Silurian-Early Devonian) in Northern Victoria Land and Marie Byrd Land (Craddock, 1972).

The tectonic processes that brought the three terranes of Northern Victoria Land into their present position belong to the Ross Orogeny, which is responsible for the major deformations in the TAM, and the Borchgrevink-Ford orogeny. Adams et al. (1982) discuss the distinction between the Ross and Borchgrevink Orogenies according to K-Ar dating: an early low-grade metamorphic event (post-Early Cambrian, pre-Late Cambrian) recorded in the Wilson, Robertson Bay and Sledgers Groups associated with the Ross Orogeny distinguished from another low-grade metamorphic event (Silurian-Devonian) recorded in the Bowers Supergroup and associated with the Borchgrevink Orogeny. Tessensohn et al. (1981) only consider a dominant Ross Orogeny.

Grindley and Oliver (1983) consider the Ross Orogeny in Northern Victoria Land as a terminal orogeny, completing the accretion of folded metasedimentary Late Precambrian-Cambrian terranes on the Pacific margin of the East Antarctic Craton.

In Northern Victoria Land the metamorphic and tectonic evolution caused by the Ross Orogeny after the Cambro-Ordovician is represented by mild metamorphic processes in the Robertson Bay Terrane, uplift and erosion of the Bowers Terrane, and intrusion of the *Granite Harbour Intrusive* in the Wilson Terrane (Davey, 1987).

The Ordovician granitoid plutons that have intruded the folded Wilson Group are related to this orogenic phase. These granitoids, correlated by radiometric dating with the Granite Harbour Intrusive of the McMurdo Sound region, are dominantly S-type, having originated from the melting of the deeper parts of the metasedimentary pile, where migmatites commonly grade into anatectic granites (Wyborn, 1981). In Northern Victoria Land the co-existence of continental arc intrusions (the Granite Harbour Intrusive) and oceanic arc volcanics (basal part of the Bowers Supergroup, Glasgow Formation) suggests that during the Cambrian this part of the Antarctic Margin was a convergent plate boundary that changed character from intra-oceanic to continental along its length (Bradshaw et al., 1985).

In a later stage (Silurian-Devonian) the Borchgrevink-Ford Orogeny caused a re-activation of the tectonic deformation with gentle re-folding of the Robertson Bay Group, strong folding of the Bowers Supergoup, granitic intrusions (*Admiralty Intrusive*) in both terranes, and calc-alcaline volcanism (*Gallipoli Volcanics*) throughout Northern Victoria Land (Grindley and Oliver, 1983; Davey, 1987).

Southern Victoria Land

The Precambrian and Paleozoic basement is divided into two main groups:

Skelton Group: non-fossiliferous greenschist to anphibolite facies metasediments consisting of the *Anthill Limestones* (mainly limestone and marble) and of the *Cocks Formation*, which comprises metasedimentary and metavolcanic rocks (Skinner, 1982);

Koettlitz Group: schist, marble, gneiss and quartzite metamorphosed to amphibolite facies (Grindley and Warren, 1962; Findlay et al., 1984).

The two groups have undergone metamorphic and deformation processes within the Ross Orogeny and have been intruded by the Granite Harbour Intrusives, like the Wilson Group in Northern Victoria Land. Following this event, Northern and Southern Victoria Land had a similar depositional history.

From the Early-Middle Devonian to the Early Jurassic, a wide, principally alluvial sedimentary basin developed in Victoria Land, in which the *Beacon Supergroup* sediments were deposited. The supergroup unconformably overlies the units deformed by the Ross and Borchgrevink-Ford orogenies. Its basal part forms the *Taylor Group*, an alluvial plain, shallow marine sedimentary sequence of sandstones and siltstones (Barrett, 1981). An extensive Carboniferous glaciation removed a large part of the sequence, giving rise to glacial deposits, and it forms the basal unit of the overlying *Victoria Group*. The Beacon strata have been intruded by tholeiitic intrusives (*Ferrar Dolerite*, Brotzu et al., 1990), and are overlain by coeval flows of the tholeiitic *Kirkpatrick Basalt*, both thus forming the *Ferrar Supergroup* (Kyle et al., 1981), related to the Jurassic initial break-up of Gondwana (Elliott, 1975; 1985).

Considerable basaltic igneous activity started in the Late Miocene north of McMurdo Sound and in centers of the Transantarctic Mountains, Cape Hallett, Ross Sea Islands, Balleny Islands and Scott Island. The volcanic rocks consist of Miocene to Holocene alkali-basaltic and trachytic associations. Mount Erebus and Mount Melbourne are still active volcanic centers (Gonzalez-Ferran, 1982).

Hamilton (1972) divides this province into three major subprovinces: *McMurdo Sound*, which is characterized by high subaerial volcanoes; *Hallett*, which consists of long coastal domes of subglacial breccias surmounted by low subaerial volcanoes; and the *Balleny Islands*, which also form long domes, but rising from deep ocean. Recently the magmatism and its tectonic implications have been reviewed with further data by many authors (Müller et al., 1991; Lanzafame and Villari, 1991).

There are no rocks ranging in age from Middle Jurassic to Paleocene exposed, although reworked Cretaceous microfossils are reported from Late Cenozoic sediments (Webb and Neall, 1972; Webb, 1983). Paleocene rocks are poorly represented, while erratic blocks of Eocene calcareous sandstone occur in the moraines of the McMurdo Sound region (Rowe, 1974). Only Late Cenozoic to Quaternary sediments are known in glacial deposits of the Dry Valley region and along the Ross Sea coasts; Pliocene sediments are confined to narrow regions of the Transantarctic Mountains (Webb et al., 1984).

DVDP (Dry Valley Drilling Project) cores recovered Late Cenozoic (Late Miocene and younger) marine sediments resting on Early Paleozoic crystalline basement (McGinnis, 1981).

Marie Byrd Land

The Precambrian and Early Paleozoic basement along the western margin of Marie Byrd Land is divided into two main groups:

Fosdick Complex: amphibolitic gneiss and igneous rocks (Wilbanks, 1972);

Swanson Group: quartzose-like flysch sequences (Wade and Couch, 1982).

These basal rocks are intruded by the granodioritic plutons of the Devonian-Carboniferous *Ford Intrusives*, by the Late Cretaceous *Byrd Coast Granite* and by mafic dykes (Wade and Couch, 1982). A sequence of andesitic, dacitic and rhyolitic volcanics (*Rupper Coast Metavolcanics*) were emplaced during the Late Palaeozoic-Early Mesozoic (Wade, 1969; Grindley and Mildenhall, 1981).

The structural and lithological similarity between Marie Byrd Land and Victoria Land in pre-Mesozoic times indicates that the two regions were connected before the system of transcurrent faults related to the Transantarctic Rift began to stretch the lithosphere of the two regions in the Late Jurassic.

No Beacon terranes or rocks from Carboniferous to Middle Cretaceous outcrop in Marie Byrd Land. Eruptions of olivine basalt and hyaloclastite began at 26 My (LeMasurier and Rex, 1983) and currently this area is one of the major Cenozoic volcanic provinces in Antarctica. It is here possible to distinguish two units: 1) a basal unit which comprises a thick series of palagonitic breccias and alkali-basaltic lava flows, Early Eocene in age (probably fissural eruptions); 2) stratovolcanoes superimposed on the basal unit and dated at 13 My (LeMasurier and Wade, 1976).

GEOLOGICAL SETTING OF THE SUBMERGED AREA

Table 2 summarizes the main results of direct sampling of the seafloor and sub-bottom by drilling, dredging, and coring.

Seismic stratigraphy

Offshore geophysical studies and particulary multichannel seismic reflection surveys conducted since the 1960s by New Zealand (Houtz and Davey, 1973; Davey et al., 1982; Davey 1990), West Germany (Hinz and Block, 1984; Hinz and Kristoffersen, 1987), the United States (Cooper and Davey, 1987), France, Japan (Sato et al., 1984), the Soviet Union (Zayatz et al., 1990) and Italy (Berger et al., 1990; Brancolini, 1990; Brancolini et al., 1991) have shown in detail

Table 2 - Well data.

PROJECT	LOCATION	WATER DEPTH (m)	SUBBOTTOM DEPTH (m)	RESULTS	REFERENCES
DSDP 270	77°26.48'S 178°30.19'W	634	422.5	Subaerial, shallow-water and glacio-marine sediments, as old as Late Oligocene (site 270). Overlaying meta-sedimentary rocks	Hayes et al. (1975a); Hayes et al. (1975b)
DSDP 271	76°43.27'S 175°45.61'W	554	265	Diatom silty clay (Lower Pliocene - Recent)	Hayes et al. (1975a); Hayes et al. (1975b)
DSDP 272	77°07.62'S 176°45.61'W	629	443	Silty claystone and diatom silty claystone of Lower? Miocene and diatom bearing silty clay (Middle Miocene - Recent)	Hayes et al. (1975a); Hayes et al. (1975b)
DSDP 273	74°32.29'S 174°37.57'W	495	346.5	Silty clay, claystone and diatom silty clay (Lower? Miocene - Recent)	Hayes et al. (1975a); Hayes et al. (1975b)
DSDP 274	68°59.81'S 173°25.64'E	3326	421	Basalt (Late Eocene) and silty clay and diatom silty clay (Late Eocene - Recent)	Hayes et al. (1975a); Hayes et al. (1975b)
MSSTS-1	77°33.26'S 164°23.13'E	196	229	Thin sequence of late Oligocene and younger glacial and shallow-marine sedimentary and volcanic rocks	Barrett, 1986
CIROS-1	77°34.54'S 164°29.55'E	197	702	Late Eocene - Early Oligocene glacio-marine units and a Plio-Pleistocene glacial sequence	Barrett, 1989

the areal extent, the seismic stratigraphy, and the structure of three major sediment depocentres in the Ross Sea. These basins are, from west to east (Fig. 6): the *Victoria Land Basin*, the *Central Trough* and the *Eastern Basin.*

The *Victoria Land* sedimentary basin extends between the late Cenozoic volcanic provinces of Ross Island and Cape Washington, and includes in its northern part the Drygalsky topographic basin. The basin is thought to extend also beneath the Ross Ice Shelf (Cooper et al., 1987). The maximum sediment thickness calculated at the depocenter along the Discovery Graben is 14 km, the minimum thickness 4 km. Two principal sedimentary units, identified mainly through seismic refraction investigations and velocity analyses (Davey and Cooper, 1987), suggest the presence of low metamorphic sediments possibly correlatable to the Beacon Supergroup (lowest 6 km), overlain by a marine sedimentary sequence of Cretaceous-Paleogene to Present age (Cooper et al., 1987). The Late Mesozoic age of the base of the sequence has only been inferred. In fact, drilling has shown sediments as old as Early Oligocene, but the presence in these layers of reworked Late Cretaceous microfossils indicates that older strata must exist in the vicinity, as is suggested also by the high interval velocities (5.0 km/sec), which require extremely compact sedimentary rocks, and the general analogy to other peri-Antarctic rifted basins opened during the break-up of Gondwanaland.

Buried volcanic apparatuses and volcanic intrusions have been detected through seismic reflection investigations in the deepest portion of the basin and have been referred to the Mesozoic Ferrar Group outcropping on Victoria Land (Cooper et al., 1987). Further evidence of volcanic activity has also been found throughout the uppermost Cenozoic sedimentary sequence.

The N-S trending *Central Trough* sedimentary basin (Southern Central Basin and Northern Central Basin, after Hinz and Kristoffersen, 1987) corresponding to the JOIDES topographic basin is more than 500 km long and about 100 km wide, extending from the edge of the continental shelf to under the Ross Ice Shelf (Hinz and Block, 1984). A structural high located along the 75°S parallel separates the basin into two sub-basins. In the southern sub-basin the sediment thickness is approximately 6 km, the uppermost 3.5 km of which are correlated to post-Late Oligocene deposits (Hinz and Block, 1984).

The *Eastern* sedimentary basin, which extends over most of the eastern Ross Sea, covers an area of approximately 100,000 km^2 and is located entirely on the eastern Ross Sea continental shelf, from below the ice shelf to the edge of the shelf break (Hinz and Block, 1984). The DSDP sites 270, 271, and 272 located on the western margin of the basin have recovered a thin sequence of pre-glacial sediments (Late Oligocene) resting on a metamorphic basement overlain by glacial marine Late-Oligocene and Miocene sediments, which in the depocenter reach a maximum thickness of about 6 km. The unconformity which separates the two sedimentary units, dated to the Late Oligocene (25-26 My), has been related to the onset of the Circum-Antarctic Current and to the widespread Late Oligocene regression that can be observed over the entire southern hemisphere continental margins (Hinz and Kristoffersen, 1987).

In the northern part of the basin, prograding sediment wedges are created by the repeated advances of the shelf edge, and are calculated to have attained a maximum of 80 km in the last 15 My by Hinz and Block (1984), and the sedimentary sequences are mostly truncated on the shelf by subglacial erosion.

The correlation of seismic reflection data tied with DSDP drilling results has allowed the identification of seven acoustic units separated by seimic unconformities (Cooper at al., 1987). We refer to the paper by Busetti et al. (1994) for a detailed analysis of the basin-wide correlation and geological significance of these units.

The ridges between the basins are formed by the *Coulman High*, a narrow structural high trending north-south that separates the Central basin from the Victoria Land Basin, and by the *Central High*, that lies to the west of the Eastern Basin. The top of this high consists of Early Palaeozoic rocks (DSDP Site 270), and the thin sedimentary cover indicates that large portions of the Central High were above sea level prior to the deposition of the Oligocene breccia (site 270).

Structure and evolution

The Ross Sea is a rift system which has been active since the Mesozoic. Its structure is asymmetric, with the rift shoulder (TAM) rapidly uplifted during the Cenozoic on one side, and three deep sedimentary basins, developed in response to the extensional tectonics since the Mesozoic, on the other.

Evidence of tectonic displacement of seismic units within the Ross Sea progressively increases from east to west.

In the Eastern Basin, no faulting has been detected, and a syn-sedimentary subsidence has been proposed by Hinz and Block (1984) to explain the large sediment thickness.

The Central Basin is produced by a N-S trending graben structure that according to Weissel et al., (1977) is the remnant of an aborted spreading centre which intersected the western Ross Sea continental margin in the Late Paleocene. The axis of the basin is characterized by a positive gravity anomaly which suggests crustal thinning and/or intrusion of high density rocks (Hayes and Davey, 1975).

The Victoria Land Basin shows a complex structural evolution that implies two major periods of rifting: the first, referred to the Late Mesozoic (early rift), has created an asymmetric graben with a total displacement of 5-8 km along the western side. Crustal extension, resulting in down-faulting and subsidence of the Victoria Land Basin, coincided with the initial continental break-up of Antarctica, Australia and New Zealand; the volcanic bodies identified in the lower seismic unit of the Victoria Land Basin have been referred to this rifting phase. The structures preserved at the margins of the basin, like the Border Fault to the west, and the Coulman structural high to the east (Cooper et al., 1987) belong to the early rift.

The second rift, Paleogene to Present in age (late rift), has generated 2 to 3 km of vertical displacement and is marked by renewed volcanism and rapid uplift of the Transantarctic Mountains. A typical structure generated during this second rifting phases is the rapidly subsiding Terror Rift, where the deformation is stronger in the southern part, formed by the Discovery Graben and the volcanic Lee Arc. Secondary structures are small half-grabens formed on the Coulman High (Cooper et al., 1987). The second rifting of the Ross Sea never developed into the drifting stage. Crustal deformation was limited to stretching and thinning of the continental crust through normal and strike-slip faults, that in part are still active.

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