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G. BRANCOLINI [1], S. FAIS [2], C. GANTAR[1], E. LODOLO[1] and C. ZANOLLA[1]

GEOPHYSICAL STUDY OF THE ROSS SEA (ANTARCTICA): TWO INTEGRATED SECTIONS

Abstract. Some multichannel seismic lines, recorded by the Osservatorio Geofisico Sperimentale (OGS) of Trieste during the 1987/88 cruise in the Ross Sea on behalf of the Italian "Programma Nazionale di Ricerche di Antartide" (PNRA) are displayed together with gravity and magnetic data to obtain two geological sections, in an attempt to present the general framework of the Ross Sea region. The first section has a south-north trend and crosses the Victoria Land Basin and the Ross continental slope. The second one has an east-west trend and crosses the Eastern Basin and the Central Trough. The structural configuration of the area is typical of a rifted passive margin. The rifting stopped before the break-up of the continental crust and the formation of the oceanic floor.

INTRODUCTION

The Ross Sea lies along the Pacific sector of Antarctica, bounded to the west by Victoria Land, where the Transantarctic Mountains outcrop; Marie Byrd Land defines its eastern border and the southern part of the Sea is covered by the vast, floating Ross Ice Shelf, the largest in Antarctica.

This area is one of the most extensively studied of the Antarctic continental margins, mainly because of its strategic location between East and West Antarctica, and owing to the presence of large ice free areas during the austral summer. Since the late 1960's, extensive geological and geophysical studies have been carried out by drilling, sampling and multichannel seismic reflection surveys.

The most prominent geological features can be summarized as follows:

1. There is quite a good correlation in the tectonic history between Victoria Land and Marie Byrd Land up to the Late Paleozoic; in the Mesozoic, the evolution of Victoria Land is typycal of a cratonic area, whereas in Marie Byrd Land the presence of an active margin in the same period can be seen.

2. At least three main rifting phases can be recognized in the Ross Sea area.

The first phase is marked by the estrusion of Jurassic tholeiites (Ferrar dolerites, Kirkpatric basalts) in the Victoria Land area.

The second one, probably in the upper Cretaceous, is responsible for the formation of three main elongated depocentres trending roughly south-north (Eastern, Central and Victoria Land basins, Fig. 1).

The third phase (Cenozoic) is associated with volcanic phenomena, differentiated in space and time: magmatic activity is widespread in the western Ross Sea and in the surrounding on-

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1 OGS, Osservatorio Geofisico Sperimentale, P.O. Box 2011, 34016 Trieste, Italy.

2 Istituto di Giacimenti Minerari, University of Cagliari, 09123 Cagliari, Italy.

shore areas, and consists mainly of alkali basaltic and trachytic associations. This activity occurred throughout the Cenozoic and is evident in the conspicuous magnetic anomalies; the most impressive tectonic result of this phase was the uplift of the Transantarctic Mountains, formed at the continent-continent boundary between East and West Antarctica. The mountains are comprised of undeformed, horizontal sedimentary strata (the Beacon Supergroup), deposited unconformably during the Devonian to Triassic periods on Precambrian-Cambrian to Early Paleozoic metasedimentary or granite basement. The principal mechanisms proposed to explain the uplift are as follow (Stern and TenBrink, 1989):
- heating of the upper lithosphere;
- elastic rebound induced by the Cenozoic rifting.

3. The transition between East and West Antarctica is characterized by a lateral lithospheric inhomogeneity on a regional scale. The depth of the Moho in the Victoria Land area has been estimated as 35-45 km, whereas in the adjacent Ross Sea basin a depth of 15-25 km is reasonably expected; a minimum of 15-18 km is attributed in the basinal areas. The total throw of the basement is estimated to be about 14 km from the top of the Transantarctic Mountains to the acoustic basement in the Victoria Land Basin.

4. Geophysical data show 4-6 km of sediments in the Eastern and Central basins and over 10 km in the Victoria Land Basin. The origin and the age of these sediments is only partially known: the oldest sediments reached by drilling are Oligocene shallow marine-transitional deposits with no evidence of glacial influence. Seismic data indicate, in the deeper part of the basins, the presence of a notable thickness of older sediments whose age and facies are still unknown. Depositional patterns and unconformities suggest that grounded ice sheets have episodically moved back and forth since the Cenozoic at the continental shelf edge (Cooper and Webb, 1991).

SOUTH - NORTH PROFILE

The south-north profile consists of the seismic, gravity and magnetic line IT88A-03 and part of IT88A-06, (see the Plate, section A). Other papers deal with the acquisition of the presented data (Berger et al., 1993) and with their processing (Gantar et al., 1993). The total length of the profile is about 490 km and the shot point (SP) interval is 50 m along these lines. The profile runs along the axis of the Victoria Land Basin from north of Franklin Island to west of Cape Adare, diagonally crosses the Coulman High and reaches the continental slope and the oceanic area.

In the southern part of the profile, corresponding to the Victoria Land Basin, the sedimentary sequence reaches a thickness of about 7 km. The transition between the Victoria Land Basin and the Coulman High is a gentle monocline without any evidence of major faults.

A very thin sedimentary cover (less than 2 km), is present in the Coulman High. The basement morphology is almost flat with some indications of erosion.

In the outer part of the shelf, magnetic and structural anomalies indicate the presence of several sills and dykes whose origin is related to the Cenozoic rifting phase (Boehm et al., 1993).

The Ross continental slope presents a typical prograding clinoform structure. In the outer part of the section, oceanic basement with examples of basaltic effusions is present.

Interpretation of the seismic horizons

The seismic sequences in the Ross Sea are described by Cooper and Webb (1991), and by Hinz and Kristoffersen (1987) and more detailed analysis is presented by Busetti et al. (1993).

The main seismic markers that have been considered in the present interpretation are the following:

UNCONFORMITY U3 is the uppermost widespread unconformity present in the western part of the Ross Sea. Its age should be Upper Miocene and it represents the last major advance of the Ice Sheet toward the Ross Slope, probably the Queen Maud glaciation.

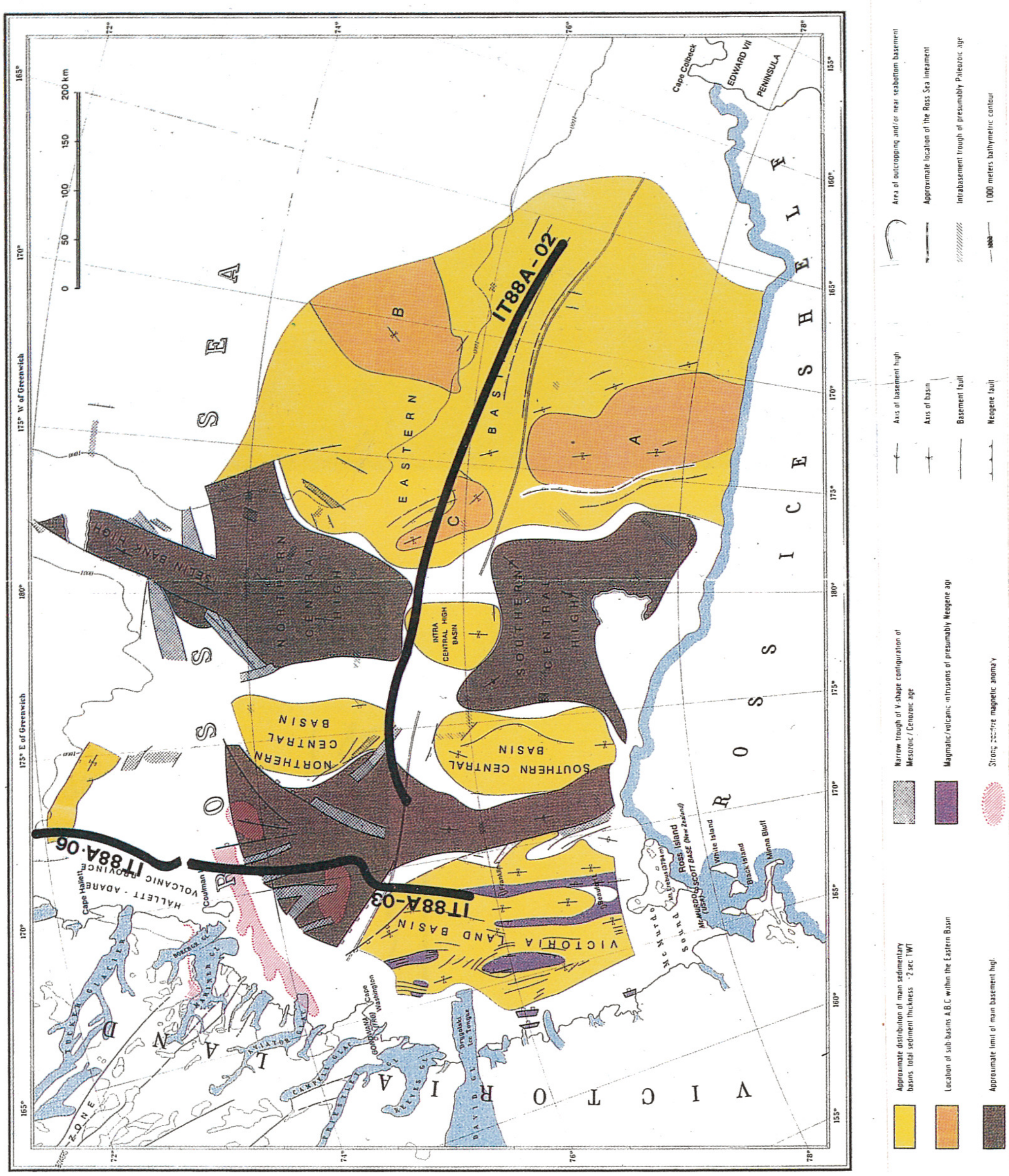
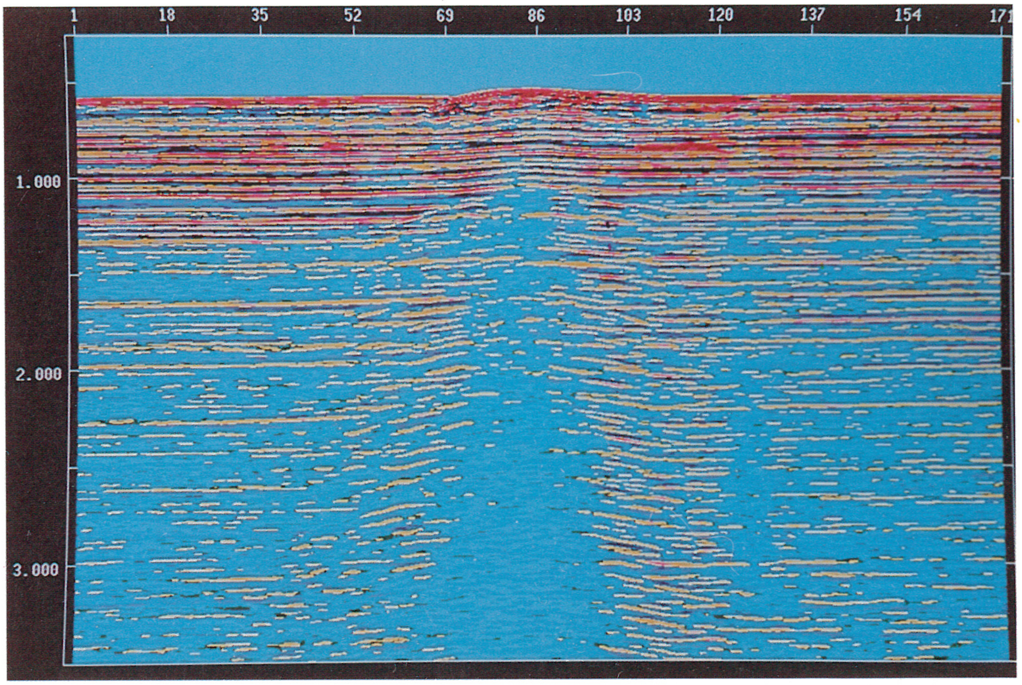


Fig. 1 - Structural map of the Ross Sea with the locations of the profiles presented (after Hinz and Kristoffersen, 1987).



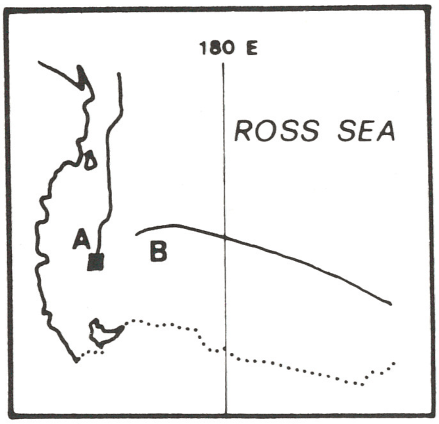
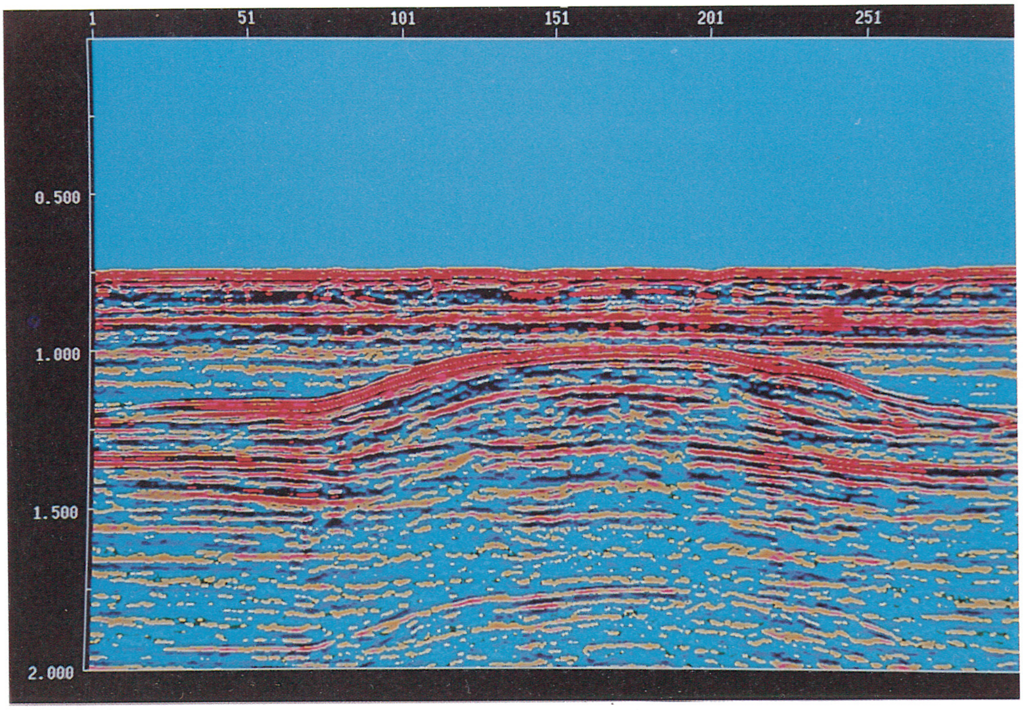


Fig. 2 - Outcropping volcanic body on seismic line IT88A-03 (in thick-type the location).

UNCONFORMITY U4 marks the top of the magmatic events and also testifies to a major glacial erosion. The sedimentary level in the upper sequence terminates onlap against U4. Towards the slope, it separates two prograding sequences. The age is Middle Miocene.

UNCONFORMITY U5 is the base of the prograding sequences and marks an important change in the depositional environment in the Ross Sea. The age is Lower Miocene.

UNCONFORMITY U6 represents the deepest marker in the sedimentary sequence reached by drilling (CIROS, DSDP 270). It consists of glaciomarine covers of the late Oligocene. The nature of the sedimentary strata under U6 is unknown.



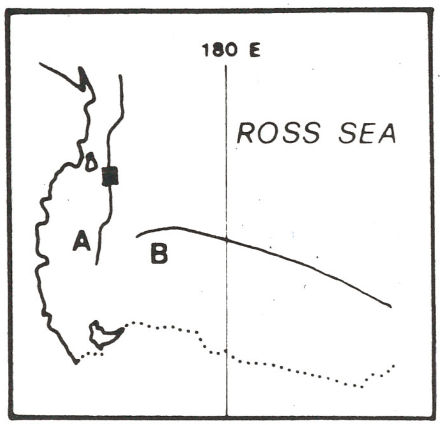
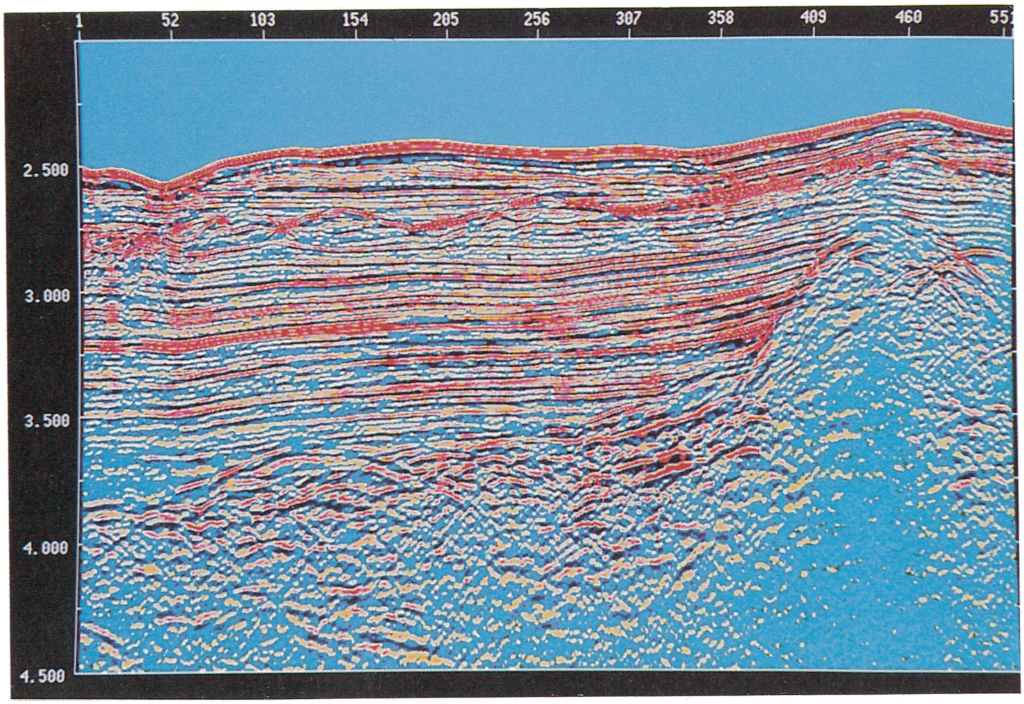


Fig. 3 - Intrusions on seismic line IT88A-03 (in thick-type the location).

HORIZON B corresponds to the "acoustic basement". Three possible definitions may be given:

- Metamorphyc and magmatic basement consisting of Precambrian or Paleozoic rocks tectonized during several orogenic phases, the last of which is the Ross Orogeny of the Cambro-Ordovician. In the structural high areas, the clastic Cenozoic sequence lies directly over the geological basement. In such cases, geologic and acoustic basement coincide (DSDP site 270);
- The Beacon Supergroup whose presence is well documented along the Transantarctic Mountains. There is no reason to exclude the presence of this formation, or of a more marine heteropic facies, in the Western Ross water-covered areas;



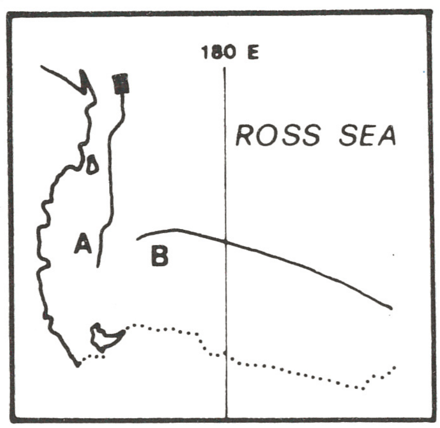


Fig. 4 - Oceanic effusions on seismic line IT88A-06 (in thick-type the location).

- The Ferrar Supergroup or Kirkpatrik basalts are likely to be present in the areas of the basin which were involved in the Jurassic rifting.

Some effusive and intrusive events can be recognized on the seismic profile (see Boehm et al., 1993) which reflect several different magmatic phases varying in time and space.

One of them crosses the whole sedimentary sequence in the Victoria Land Basin (Fig. 2, line IT88A-03, SP 100-400), and some other intrusive bodies are present in the outer shelf area (Fig. 3, line IT88A-03, SP 5600-6200). Towards the oceanic area, the magmatic events assume a dome-shape (Fig. 4, line IT88A-06, SP 5000-5400).

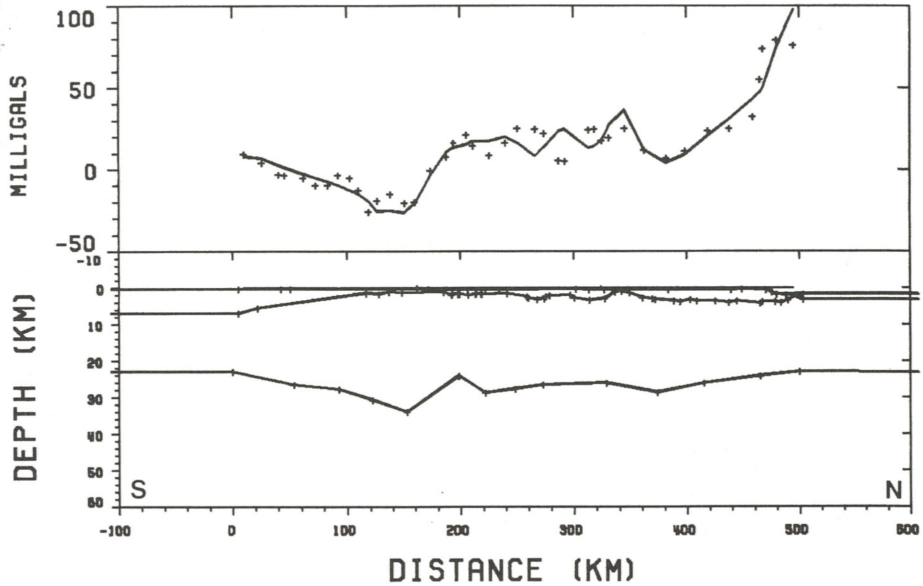


Fig. 5 - Crustal model according to gravity data along section A.

It is possible to distinguish three domains, related to the Cenozoic volcanic province of McMurdo and Cape Hallett:

1) The Northern domain, in the oceanic area, shows morphologies very similar to those revealed in the Balleny Island subprovince (Hamilton, 1972), with domes which rise from the oceanic crust.

2) The Coulman area, where the magmatic phenomena area limited by the Unconformity U4. There is no evidence of active volcanism in this area.

3) The Victoria Land Basin area, where active sub-bottom effusions, petrologically related to the McMurdo subprovince (Hamilton, 1972), are present.

Deep structural interpretation

The interpretation of the simple Bouguer gravity anomalies observed along the sections of the Plate can be done using two different guidelines: (1) by assuming that the density contrast at the Moho discontinuity is the main cause of the anomalies, at least of those of longer wavelength; or (2) by performing a more detailed modelling in which the seismic structural evidence is continued downwards whenever possible to infer density changes between the acoustic basement and the crust-mantle interface.

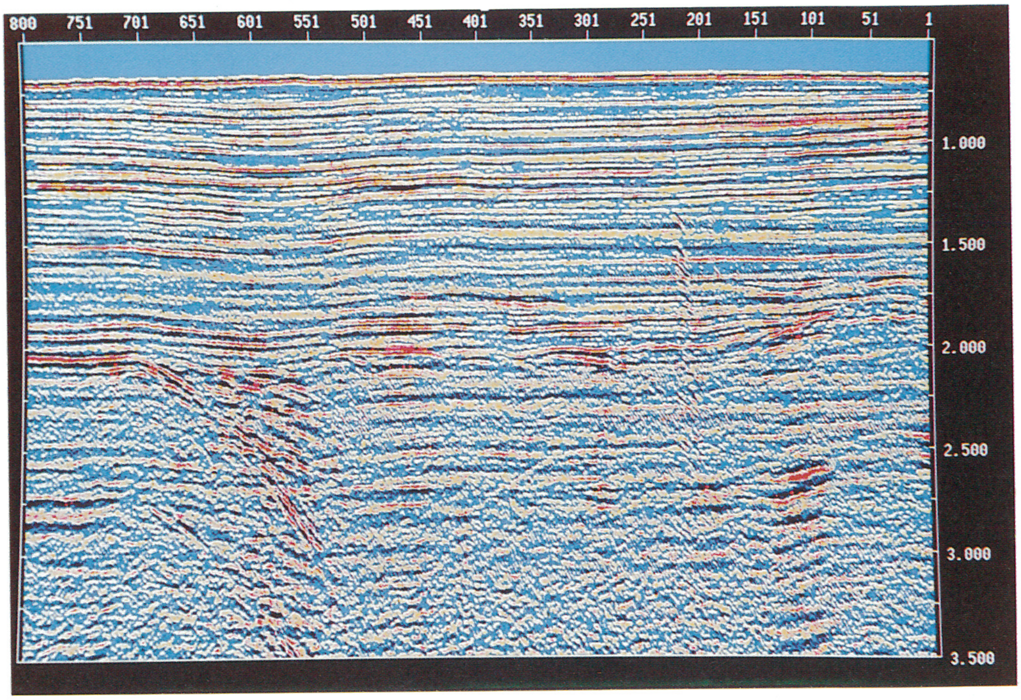
In this initial phase, a simple 2-D modelling of the Moho was chosen. The mass deficit down to the acoustic basement, as revealed by the seismic data, was corrected for by assuming the densities of 2.4 g/cm^3 for the upper layers and 2.7 g/cm^3 for the lower crust, undifferentiated under the acoustic basement, and 3.35 for the upper mantle were also attributed.

The relatively high density (2.7) for the lower sedimentary layers was confirmed by inversion procedures.

The density contrast at the Moho could be greater if there is a massive presence of ultramafic rocks under the acoustic basement, but this problem has been left to further investigations.

As starting point, it was assumed that the crustal thickness in the Victoria Land Basin is about 21 km in McMurdo Sound (McGinnis et al., 1985), and by extrapolation it was assumed that this thickness reduces to 19 km at the beginning of section A. This figure could be the minimum allowable value.

The resulting crustal reconstruction along section A is presented in Fig. 5, which shows



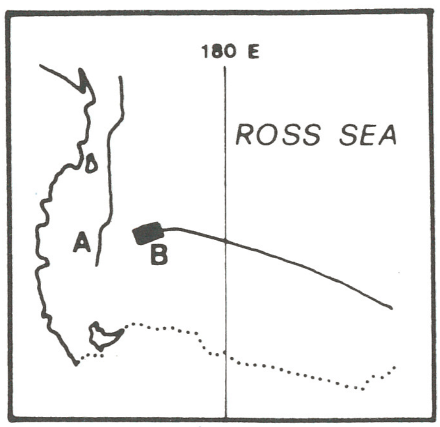


Fig. 6 - Half graben structures on seismic line IT88A-02 (in thick-type the location).

that the crust increases in thickness in the initial S-N portion, then becomes thinner toward the oceanic area without abrupt changes. The fitting error was 6.5 mGal.

Three different behaviours can be recognized along the magnetic profile: the first, along the Victoria Land Basin, relatively smooth; the second, near Coulman Island, with huge and long period anomalies, the most impressive of them being the Polar 3 anomaly; and the last one in the outer shelf area, with several short period anomaly sequences. There are no seismic features that can be related to the long period anomalies of the above mentioned second part of the profile and the source of these anomalies should therefore be located below the acoustic basement. As far as the last part of the profile is concerned, there are good correlations bet-

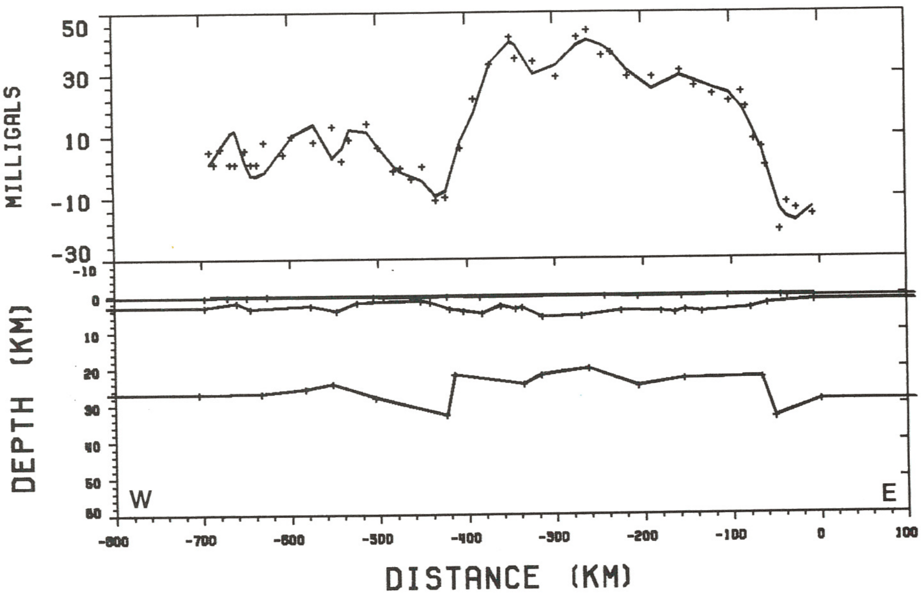


Fig. 7 - Crustal model according to gravity data along section B.

ween the intrusion detected on the seismic section and most of the anomalies.

EAST - WEST PROFILE

The east - west profile, shown in the Plate, section B, consists the whole of seismic line IT88A-02. This line was the only one shot at a SP interval of 75 m, and runs subparallel to the Ross Ice Shelf, crossing the main structural elements of the Ross Sea.

The Eastern Basin is characterized by gentle undulations of the basement and by thicknesses of sediments ranging up to 5 km. On the flanks of the basin, the sedimentary sequence has its minimum of about 1.5 km. A structural high in the western part of the Eastern Basin, between shot points 4400 and 4900, locates an 80 km wide sub-basin (Eastern Sub-basin), flanked by two megafaults. The sediment thickness is over 4 km in its central part.

The sedimentary setting in the Eastern Basin is generally downlapping on the basement since the line diagonally crosses the well developped prograding sequence of the basin (Busetti et al., 1993).

The Central High is a broad peneplain extending between SP's 5900 and 7100. The sedimentary cover is thin (about 1.5 km) and unconformably overlies the basement. The seismic facies of the basement is very rough and indicates that large portions of the Central High were eroded prior to the deposition of the Oligocene breccia recovered at DSDP site 270.

Half-graben structures in the basement (Fig. 6) are related to extensional stress fields.

Interpretation of the seismic horizons

The interpretation of the seismic sequences in the Eastern Basin is made starting from DSDP's 270, 271 and 272 (Hinz and Kristoffersen, 1987; Busetti et al., 1993).

The interpreted seismic markers are as follows:

UNCONFORMITY U1 is present only in the Eastern Basin. It corresponds to a glacial episode in the Plio-Quaternary, during a very large advance of the Ross Ice Sheet. U1 terminates against the sea floor which, in most parts of the Ross Sea, is an erosional surface.

UNCONFORMITY U2 like U1, is an erosional surface, but it is less continuous than U1, especially in the central part of the basin.

UNCONFORMITY U3 in the Eastern Basin, appears fairly continuous in the prograding sequence, testifying a break or a major change in the supply of sediments.

UNCONFORMITIES U4 AND U5 are better defined in the western part of the section, than towards the Eastern Basin, where their signature becomes less defined. U5 is also the base of the prograding sequence.

UNCONFORMITY U6 represents the deepest marker in the sedimentary sequence which can be distinguished in the basinal areas. It terminates onlap against the basement highs that bound the Eastern and the Central basins.

HORIZON B represents the "acoustic basement" of the south-north profile, the nature of which has already been discussed.

Deep structural interpretation

The gravity modelling of the deeper structures in section B is presented in Fig. 7 by adopting the same density distribution as in section A. The starting Moho depth was assumed to be 20 km. The fitting error attained is 5.1 mGal.

Along the first third of the profile starting from the west, the depth of the Moho appears to increase slowly, then it abruptly rises at least 4 km at the transition from the Central High to the Eastern Basin and continues at around 16-18 km under this basin. A sudden jump may also occur towards the coasts of Edward VII Land, but gravity data coverage is missing there since the profile ends.

The small crustal thickness under the Eastern Basin confirms the distensive tectonic character in the opening of the Ross Sea, in a older phase, and the "jump" near the middle of the profile B could indicate a linear transcurrent trend superimposed over the rotational movements.

In this first third of the profile, the depth of the Moho appears to be greater than that hypothesized: this could be due to the presence of different density contrasts immediately under the basement of the sedimentary sequence, which could alter the conclusions drawn from the simple hypothesis made for this interpretation of the gravity profiles.

For the magnetics, there is evidence of notable events between SP's 2200-2400, SP's 3100-3700, and others between SP 4600 and 4900 (Plate, section B). Unlike section A, seismic data of section B do not show any indication of intrusive phenomena inside the sedimentary sequence. The source of these magnetic anomalies should therefore be located under the acoustic basement (and possibly related to the presence of the above mentioned denser rocks).

CONCLUSIONS

Two geological cross-sections obtained from an integrated analysis of the geophysical data acquired during the 1987-88 survey in the Ross Sea area have been presented.

The first runs from south to north along Victoria Land Basin and the northern Coulman High; the second has an E-W direction and crosses the main structural elements of the Ross Sea.

Some indications about the evolution of the Ross Sea can be obtained from a study of these sections:

a) The first rifting in the Ross Sea precedes the arrival of the sediments in the depocentres because there is no evidence of syn- or pre-rifting sequences in the Eastern Basin and in the Central Through.

b) The western Ross Sea is affected by a recent rifting phase. As a consequence active volcanism is recognized in the Victoria Land Basin whereas cenozoic magmatic intrusions are present in the Coulman Island area.

c) The thickness of the crust in the deepest part of the Eastern Basin is less than that in the rest of the area and can be considered an intermediate type of crust. In the rest of the area, the depth of the Moho could be greater than that supposed here to account for the variations in gravity anomalies, which in many cases may not correspond only to the effect of the thickness of the sediments accumulated in the basins but also significantly to bodies having density contrasts and not correlated with the sedimentary processes.

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