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Deep crustal structure of the area of intersection between the Shackleton Fracture Zone and the West Scotia Ridge (Drake Passage, Antarctica)

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ABSTRACT

The Shackleton Fracture Zone represents the present-day boundary between the Antarctic and Scotia plates in the Drake Passage. The West Scotia Ridge is an extinct spreading center, which formed the oceanic crust of the Scotia Plate in this region and that intersects with the Shackleton Fracture Zone. New multichannel seismic, gravimetric, magnetometric and multibeam swath bathymetry data were acquired during the ANTPAC 97/98 cruise with the Spanish vessel B/O HESPERIDES in the area and reveal that these structures are asymmetric and developed as a consequence of the overprinting of extensional and contractional deformation events. Thrusting of these young oceanic crusts produces crustal thickening and shallow oceanic reliefs and ridges.

INTRODUCTION

The Shackleton Fracture Zone (SFZ) is located in the Drake Passage, between South America and the Antarctic Peninsula. This fracture zone is currently seismically active and has an associated NW-SE elongate positive relief of more than 2000 m with respect to neighbouring oceanic areas (BAS, 1985). In addition, several elongated basins are associated to this structure. The fracture zone is the present-day sinistral transpressive fault that connects the Chile Trench with the South Shetland Trench and the southern boundary of the Scotia Plate (Fig. 1).

The fracture zone intersects with the West Scotia and Phoenix-Antarctica ridges, which belong to extinct spreading centers. The West Scotia Ridge (WSR) is shaped like a slow spreading centre, with an axial valley bounded by two elongated ridges. Although the most recent magnetic anomaly detected near the ridge axis is no. 5 (BAS, 1985), Maldonado et al. (submitted) recognise up to anomaly 3A.

The objectives of this contribution are to analyse the different geophysical data, mainly the deep seismic and gravity data newly acquired in the area, to establish the deep structure and contribute to the understanding of the tectonic evolution of this significant region, between South America and the Antarctic Peninsula.

DATA ACQUISITION AND PROCESSING

During the ANTPAC 97/98 cruise with the Spanish vessel B/O HESPERIDES, multichannel seismic (MCS), swath bathymetry, magnetometry and gravimetry profiles were obtained along several transects in the area of intersection of the SFZ and the WSR. Three MCS and gravimetry profiles were recorded orthogonally to the SFZ (PRSM06, PRSM08 and PRSM10) and two parallel to the fracture zone (PRSM07 and PRSM09), the eastern one (PRSM07) cutting across the WSR.

The seismic data were collected with a tuned array of five air guns (total capacity of 22.4 l) and a 2.4 km long, 96-channel streamer. The shot interval was 50 m and the pressure was 140 atm. The data were recorded with a DFSV digital system at 2 ms sampling record and 10 s record length. Profiles were processed with a standard sequence, including migration using a DISCO/FOCUS system.

Gravity data were acquired continuously with a Bell Aerospace TEXTRON BGM-3 marine gravimeter. Data were recorded every 10 s after a 3-minute filtering interval. The readings were transformed into field values applying the corresponding corrections. Gravity anomalies were calculated with the BASIC program Lanzada (A. Carbó, pers. comm.), using the navigation parameters. Gaps in navigation were corrected interpolating the data prior to the integration of the navigational parameters with the gravity readings.

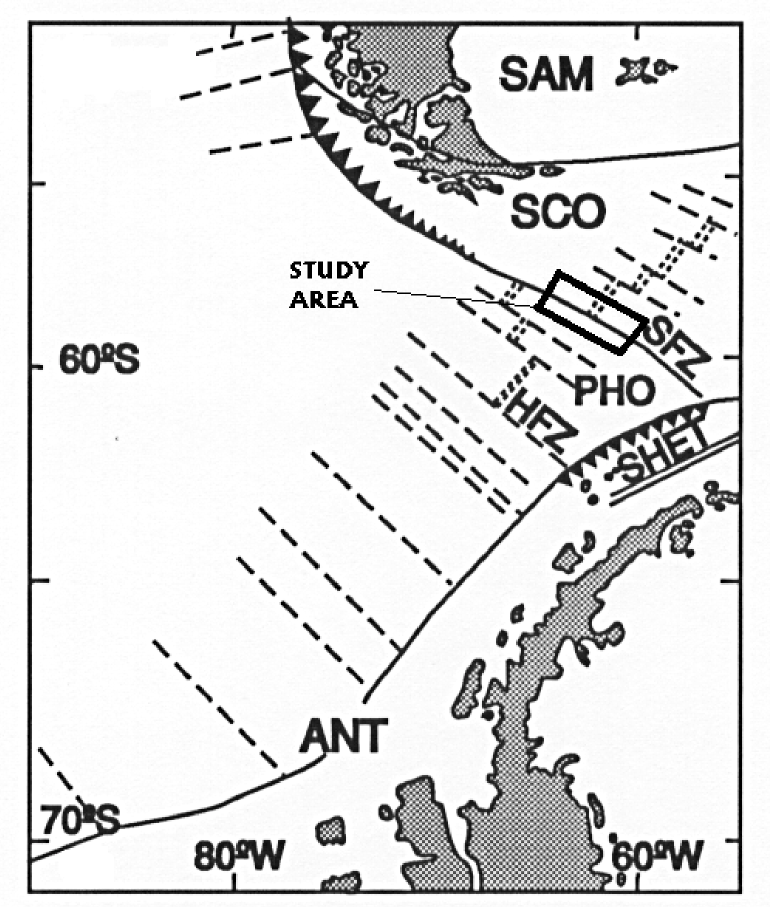

Figure 1 - Geological setting of the study area. SAM, South America Plate; SCO, Scotia Plate; ANT, Antarctic Plate; PHO, former Phoenix Plate; SHET, South Shetland Block; SFZ, Shackleton Fracture Zone; HFZ, Hero Fracture Zone.

SEISMIC STRUCTURE

The oceanic crusts in both the Scotia and Antarctic plates display a very similar seismic fabric that consists of a discontinuous sediment layer above three igneous layers with different reflectivity patterns. Sediments are very scarce, mainly confined to small basins. Very continuous reflectors represent the sediment fill. The uppermost layer of the igneous crust shows rough, high-amplitude reflectors at the top and numerous discontinuous high-amplitude reflectors and many irregular diffractions in a layer 0.2-0.8 s thick (TWT). This layer may represent oceanic crust layer 2, mainly composed of extrusives at the top, underlain by sheeted diabase dykes (Cannat et al., 1995). Below there is a thicker layer with sparse, weak reflectors that may represent oceanic crust layer 3, formed mainly of isotropic gabbros. The boundary between layers 2 and 3 is progressive and cannot always be located with precision. This layer locally contains strong dipping reflectors, tilted southwest. Eastward-tilted reflectors are also observed, some of which can be ascribed to low-angle normal faults. The deepest crustal level is characterised by high-amplitude subhorizontal, slightly tilted reflectors. These reflectors, which may represent the Mohorovicic seismic discontinuity, are very discontinuous. They are distributed between 1.8 and 3.2 s (TWT) below sea floor, but are preferentially located at about 2.8-3.0 s (TWT) depth. The upper mantle of the area is also reflective and can hamper the precise determination of the seismic Moho. The MCS profiles orthogonal to the SFZ show a prominent ridge generally bounded by depressions. The ridge is bounded on both flanks by major faults. In the southwestern flank there is a vertical left-handed strike-slip fault. The fault at the northeastern flank of the ridge has a transpressive nature revealed by low-angle, high-amplitude reflectors dipping southwestward below the ridge. The SFZ formations overthrust the Scotia oceanic crust. Seismic data do not accurately reveal the position of the Moho. The WSR (Line PRSM07) is asymmetrical. The rift valley floor is ponded with a depositional sequence 1 s thick (TWT) above the acoustic basement. The valley is bounded by high-angle normal faults on both flanks, but the southeastern flank is more prominent than the northwestern one. The top of the igneous crust is also disrupted by conjugated normal faults. A southeastward-dipping reverse fault, affecting the lowermost depositional units and the acoustic basement, is observed along the axis of the depression in the vicinity of the southeastern flank. As occurs in the SFZ, seismic data below the extinct spreading axis do not exactly reveal the location of the Moho.

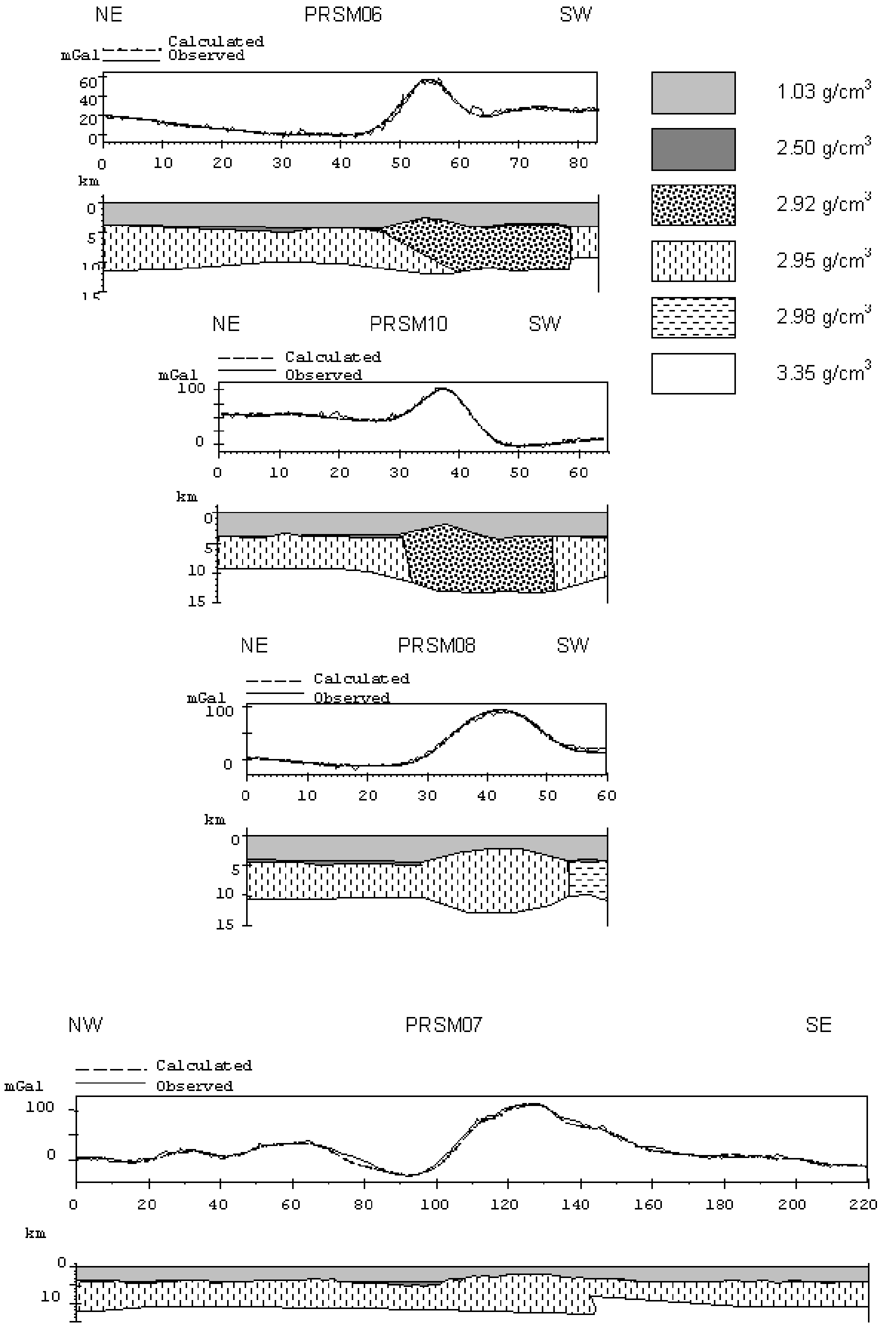

Figure 2 - Gravimetric models across the Shackleton Fracture Zone (PRSM06, PRSM08 and PRSM10) and across the West Scotia Ridge (PRSM07)

GRAVIMETRY

In order to characterize the geometry of the Moho below the SFZ and the WSR, we developed free-air anomaly two-dimensional models, based on the geometry established in the seismic profiles. We fixed the geometry of the sea-bottom and the base of the sediment layer. We also took into account the location of the Moho in distant regions, which are not affected by the SFZ and the WSR structures. The geometry of the Moho was modelled (Fig. 2) taking into account these constraints and the following values for the densities of the different bodies: sea water (1.03 g/cm^3), sediments (2.5 g/cm^3), layers 2 and 3 of the oceanic crust (2.95 and 2.98 g/cm^3), oceanic crust with serpentinites in the fracture zone (2.92 g/cm^3) and mantle (3.35 g/cm^3).

The models across the SFZ (Fig. 2) show crustal thickening in this region. Crustal thickness varies from 5 to 7 km in normal oceanic crust, up to 11 km in the SFZ and in the WSR. In two of the profiles (PRSM06 and PRSM10, Fig. 2) the slightly low density in the SFZ area may be a consequence of infilling in the crust of serpentinized upper mantle rocks. The model across the WSR also shows that the Moho geometry is asymmetric with respect to the central valley. The greatest crustal thickening is located in the southeastern flank.

DISCUSSION AND CONCLUSIONS

The oceanic crust is thickened in the SFZ and in the WSR. Both structures are asymmetric and may be considered to be the result of the overprinting of extensional and compressional deformation events involving thrusting of oceanic crust.
The SFZ is active at present and is similar in structure on both sides of its intersection with the WSR. The formations of the SFZ thrust the oceanic crust of the Scotia plate. This thrust has contributed to the bathymetric elevation and crustal thickening of the region. In addition, there are transcurrent faults with related crustal thinning areas. These fractures may have favoured the infilling of serpentinites in the oceanic crust. Oblique deep crustal reflectors may correspond to extensional shear zones that may have formed in transtensional areas related to transcurrent faults.
The WSR has a geometry similar to slow spreading centers, although it does show the overprinting of extensional and compressional structures. The crustal asymmetry observed in this ridge may be explained by a thrust of the oceanic crust with a slip of about 40 km. This thrust most likely occurred after the spreading ended and before the deposition of the last sedimentary units in the central valley. Spreading stopped in the Upper Miocene, probably as a consequence of the inversion in the tectonic regime from extensional to contractional. This thrust may be simultaneous to other contractional structures detected in the southern boundary of the Scotia plate (Lodolo et al. 1997) and in its northern boundary (Platt and Phillip, 1995).
In young oceanic crusts, thrust structures seem to be located preferentially in weak sectors (fracture zones and spreading ridges). The main consequence of this type of structure is crustal thickening, with a bathymetric elevation of the region.

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