Indian Journal of Marine Sciences
Vol. 37(4), December 2008, pp. 419-423

# Crustal structure deduced from Gravity Modeling off Prydz Bay, East Antarctica

U. K. Singh[1*], S. Rajan[2] & D. K. Pandey[2]
[1]Department of Applied Geophysics, Indian School of Mines University, Dhanbad-826 004, India
[2]National Centre for Antarctic & Ocean Research, Vasco, Goa-403 804, India
*[Email:upendra_bhu1@rediffmail.com]

A high resolution satellite gravity and bathymetry data along two N-S trending profiles have been interpreted using gravity forward modeling technique off Prydz Bay, East Antarctica. The crustal density model indicates the oceanic crust has a distinctive character with a smooth upper surface and the Moho depth varies from ~20 km shoreward to <12 km offshore. The Moho shallows from~19 km to 15 km in between 60 and 80 km along the pfofile A-A'. It occurs around 13 km further offshore. The present study infers the presence of ~8 km thick sediments on the southern side while in the north the thickness is about 2 km. The shelf break occurs between 120-130 km from the beginning of the profile A-A' and between 40 and 70 km along the profile B-B'.

[**Keywords**: Prydz Bay, East Antarctica, Gravity modelling, Crustal Structure and Moho]

## Introduction

The area selected for study was in the Indian Antarctic Territory between Mac Robertson land and Davis station of Prydz Bay. The continental margin of Prydz Bay and Mac Robertson Landmass and the adjacent deep ocean basins occupy a key position for understanding of the continental margin of central Gondwana. A number of geophysical investigations (seismic reflection/refraction, gravity, magnetic and bathymetry) survey have been carried out in Prydz Bay and on the adjacent continental slope to define the continental margin over the Antarctic margin and southern Indian Ocean[1,2,4]. In 2000-02, Australian agencies[8] acquired more than 20,000 line-km new high quality multichannel seismic (MCS) dataset along the margin of East Antarctica. The main object of this work was to integrate seismic reflection and potential field data in models that illustrate the 2-D velocity structure at key locations on the margin. The satellite gravity and bathymetry data across the selected profiles using the GEOSAT/ERS-1-derived free-air gravity anomaly mosaic of Sandwell and Smith[5] had been analysed to understand the crustal structure off Prydz Bay.

## Geological Setting

The exposed geology along the coasts of Princess Elizabeth and Mac Robertson Lands extend at least 600 km south of Prydz Bay[3,6]. Most of the exposures consist of Precambrian Metamorphics, metasediments and intrusives, which do not provide good seismic reflection records. On the eastern side of Prydz Bay, mainly granulite facies metamorphic rocks ranging in age from Archaean to Mesoproterozoic are exposed in the Larsemann and Vestfold Hills and adjacent islands[7]. In the Enderby basin, the western offshore region of the Prydz bay, Ramana[4] interpreted the Mesozoic magnetic anomalies M1 through M0 (~130-118 Ma) and several oceanic fracture zones.

In the absence of basement samples from offshore, it is assumed here that basement rocks underlying the continental margin are also Archaean to Proterozoic gneisses that have been intruded by granitoid plutons and mafic dykes The Ocean Drilling Program (ODP) Leg 183 Site 1137 shows that Elan Bank is at least partly of continental origin[9,10]. One of the ODP site (742) is tied by the Japanese seismic survey, which is incorporated into a margin transects in this paper.

## Marine Geophysical Data

A bathymetric map of the oceans with a horizontal resolution of 1-12 kilometers was derived by combining available sounding depths with high resolution marine gravity information from the Geosat and ERS-1 spacecraft. The global gridded gravity anomaly data were derived from satellite altimeter measurements of sea surface[5] grid at 1 minute by 1 minute spacing, with an accuracy 3-7 mGal with a resolution limit of 20-25 km. According to Sandwell and Smith[5], the accuracy of these data is different due to differences in their acquisition and processing. In comparison with the shipboard gravity data, the accuracy of the satellite derived gravity data is about 4–7 mGal for random ship tracks. The accuracy improves to about 3 mGal, when the ship track follows a Geosat Exact Repeat Mission track line.

## Methodology

### Gravity Forward Modeling

The profiles taken for gravity study of the Prydz Bay are characterized by north–south trending linear gravity lows and a high. The gravity low extends from the Amery ice shelf. Towards the south there is small amplitude gravity high along the axis of the Lambert Glacier, representing the median gravity high which is also a characteristic of continental rift valleys[11]. The gradient between the central gravity low and the gravity highs along the profile is quite sharp up to Kerguelen plateau, indicating a faulted margin which is disturbed southward under the influence of cross tectonics.

A profile A-A' (Fig. 1) coinciding with seismic profile as discussed above is selected for modelling the subsurface structures (Fig. 2). This is modeled using forward modeling for 2-D bodies under seismic constraints of Stagg[3]. Figure 3 shows the azimuth of another gravity profile. This was also modeled to infer the crustal configuration. The initial gravity models are adopted from the seismic section and approximate estimate of density is based on the reported seismic velocities. However modifications wherever necessary are made to match the observed and computed fields. The observed and computed fields along with this profile are shown in Fig. 2, which shows a crustal thickness of about 14 km. The upper layer is bounded at its top by a rogue's basement surface with occasionally rugged topography that shallows northwards (Fig. 2 and Fig. 3). Normally and reversely magnetized blocks[3] in this layer have highly variable densities from 2.45-2.8 g/cm$^3$. The crust underlying the upper layer is modeled with density of 2.8 g/cm$^3$. Here four blocks are made by modeling in the lower layer with the boundary between L3 and L4 corresponding to the boundary between the seismically defined crust. Three of the four blocks have high densities (2.90 g/cm$^3$), the outermost block of the crust has a significantly lower density (L3: density = 2.75 g/cm$^3$). There is a significant variation in properties of the shallow basaltic layer. It is interpreted to reflect the widespread influence of hydrothermal alteration of the basalts around active faults through the oceanic crust[5]. The computed crustal models are checked with 2.5-D models and observed a similar density structure beneath the seafloor. The crustal density model indicates the oceanic crust has a distinctive character with a smooth upper surface, and the Moho depth varies from ~20 Km shoreward to <12 km offshore. Shallowing of Moho from ~19 km to 15 km can be seen between 60 and 80 km along the profile A-A', and further offshore it occurs around 13 km. The sediment thickens ~8 km on the southern side. In the north the thickness is about 2 km. The shelf break occurs between 120-130 km from the beginning of the profile, A-A'. It occurs around between 40 and 70 km along the profile B-B'.

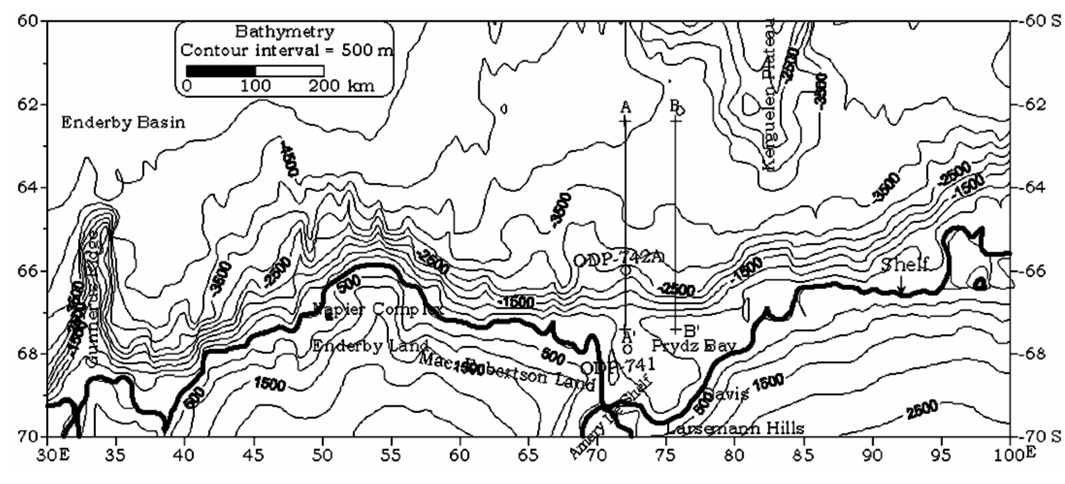


Fig. 1—Bathymetry (contour interval 500 m) map and selected profile location for gravity modeling of study area Prydz Bay, East Antarctica (after Sandwell and Smith 1997).

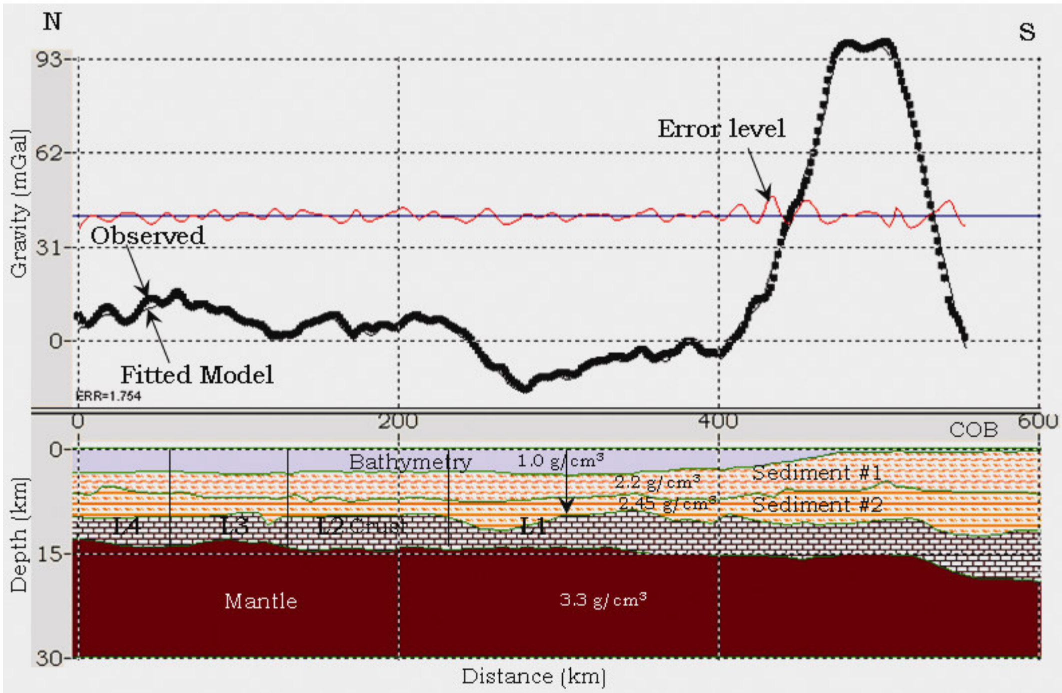


Fig. 2—Gravity field along profile A-A' (Latitude: 62.40 to 67.40 and longitude: 72.00) and the inferred crustal model. The computed gravity field due to this model is shown for comparison with the observed field. Crustai layers of the Pridz Bay, East Antarctica are marked along with their densities in g/cm3.

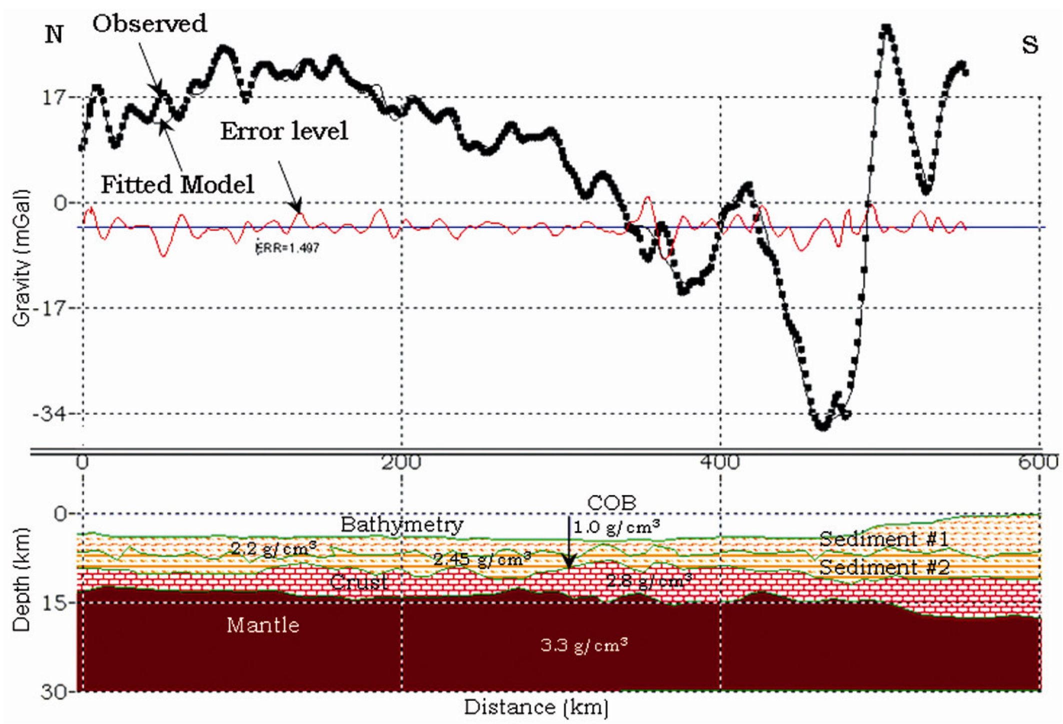


Fig. 3—Gravity field along profile P-B' (Latitude: 62.40 to 67.40 and longitude: 75.70) and the inferred crustal model. The computed gravity field due to this model is shown for comparison with the observed field; Crustal layers of the Pridz Bay, East Antarctica are marked along with their densities in g/cm3.

Based on the crustal thickness model (Figs 2 and 3) it is presumed that Continent Ocean Boundary (COB) in this part of the study area lies in the slope region. The interpreted continent boundary crust on the left of this profile is characterized by a basement surface. This appears to be down faulted oceanwards towards a basement depression. It may be due to the fracturing of basement and widespread intrusion of oceanic magma. In contrast, the interpreted oceanic crust on the right of the profile is essentially unbroken by faulting[1] and the crust is almost transparent. Almost in this sector, the change in density character from continental to oceanic crust appears to coincide with the zone of the deepest basement along the profile.

#### Determination of Continental Ocean Boundary and its Significance

In order to explore the hydrocarbon in deep sea and to evaluate the Indian plate with respect to the Enderby Land of east Antarctica in the geodynamic studies of eastern Gondwana land, the demarcation of COB is important. The marine magnetic and gravity data carried out from eastern continental margin of India revealed that the COB and Continental Ocean Transition (COT) occurs near the foot of the continental slope[12,13].

The magnetic survey is the lack of a consistent and well-defined magnetic signature of the COB along the continental margins of the oceans. The magnetic anomalies of the COB are generally weak and change sign randomly except the south coast of Australia, the Bay of Bengal, the Labrador Sea, and the east coast of North America[14].

The COB here is defined by gravity modeling constraint with published seismic data. Since the morphology and thickness of the sediments are well known from seismic data, it is not to be expected that gravity will contribute to a better definition of their geometry. Although gravity can contribute in better defining their densities, we take their geometry and density from seismic results. Therefore, the main contribution of the gravity modeling has been to allow us to infer the importance of the anomalous layer at the base of the crust.

## Discussion and Conclusion

The profiles A-A' (Fig. 2) and B-B' (Fig. 3) show the 2-D gravity modeling inferred crustal model. The computed gravity field due to this model is shown for comparison with the observed field. The above Crustal layers of the Pridz Bay, East Antarctica are marked along with their densities (g/cm3). The main aim of this study is to define deep-water margin of East Antarctica mainly offshore Pridz Bay. The shelf edge and upper slope of Pridz Bay are underlain by a major basin bounding fault system beyond which the crystalline basement underlying much of the shelf by at least 6 km. The thickness of sediments in this basin is approx 5-6 km and maximum thickness is at least 8 km north of Prydz Bay. The section thins gradually oceanwards, but is still greater than 2 km thick more than 500 km from the shelf edge.

The crustal density structure of COB zone of Prydz Bay constrained from seismic character and magnetic anomaly had been examined. Its location appears to coincide with the zone of deepest basement on the margin. The basement of the continental margin is characterized by seaward normal faults. By contrast, the basement of the oceanic crust displays strong seismic reflections. In between, the boundary shows a clear change from thick continental crust to thin oceanic crust. This is evidenced by a belt of high magnetic anomalies[3]. The analyses show that the COB is prominent, which is located at the distance approximately 300 km from the starting point A' and B' of the profiles AA' and BB' respectively (Fig. 1).

The crustal density structure is unusual. It gives a thickness of overlying crust of only 4 km. It is possible that these densities are from mantle, in which case the thin crust may be due to the presence of fracture zones or these densities may be coming from a lower crust that has been heavily tainted by the intrusion of mantle rocks. Oceanic crust in the eastern sector has a more typical oceanic density structure. It comprises a smooth upper surface underlain by short seaward-dipping reflectors. It had a transparent upper crustal layer probably correlating with a dyke complex, a lower crust dominated by dipping high amplitude reflections. This may reflect a strong reflection Moho confirmed by refraction modelling and prominent landward-dipping upper mantle reflections. The gravity modelling indicates that the gross margin structure is relatively simple. It also infers that both continental and oceanic crusts have behaved as a semi-rigid plate that has been depressed landwards by the thick sediment loading.

## Acknowledgements

The authors are grateful to Director, ISMU, Dhanbad for his kind permission to publish this paper.

We are thankful to reviewers for their critical suggestions, which improved present manuscript.

## References

1 Gandyukhin V, Gouseva Yu, Kudryavtsev G, Ivanov S & Leitchenkov G, Crustal structure, seismic stratigraphy and tectonic history of the Cosmonaut Sea sedimentary basin (Antarctica, southern Indian Ocean), *Explor. Protect. Mineral Resour.* 9 (2002) 27-31.

2 Joshima M, Ishihar T, Nakajima T, Sugiyama K, Tsuchida K, Kato A, Murakami F & Brown B, Preliminary results of the TH99 geological and geophysical survey in the Cooperation Sea and Prydz Bay area, *Polar Geosci.*, 14 (2001) 244-262.

3 Stagg H M J, The structure and origin of Prydz Bay and the Mac. Robertson Shelf, East Antarctica, Tectonophysics, 114 (1985) 315-340.

4 Ramana M V, Maria Desa & Ramprasad T, Seafloor spreading magnetic anomalies in the Enderby Basin, *East Antarctica, Earth & Planetary Science Letter,* 191 (2001) 241-255.

5 Sandwell D T & Smith W H F, Marine gravity anomaly from Geosat and ERS-1 satellite altimetry, *Journal of Geophysical Research* 102 (1997) pp. 10039-10054.

6 Tingey R J, The geology of Antarctica, (Oxford University Press) 1991, pp.680,

7 Mond A, The Permian sediments of the Beaver Lake area, Prince Charles Mountains, in: *Antarctic Geology and Geophysics*, edited by R J Adte, (Universitetsforlaget. Oslo.,) 1972, pp. 585-589.

8 Truswell E M, Dettmann M E & O'Brien P E, Mesozoic palynofloras from the Mac. Robertson shelf, East Antarctica: geological and phytogeographic implications, *Antarctic Science,* 11 (1999) 237-252.

9 Quilty P G, Truswell E M, O'Brien P E & Taylor F, Paleocene-Eocene biostratigraphy and palaeoenvironment of East Antarctica: new data from the Mac Robertson Shelf and western parts of Prydz Bay, AGSO *J. Austr. Geol. Geophys.,* 17(1999) 133-143.

10 Nicolaysen K, Bowring S, Frey F, Weis D, Ingle S, Pringle M & Coffin M F, Provenance of Proterozoic garnet-biotite gneiss recovered from Elan Bank, Kerguelen Plateau, *southern Indian Ocean, Geology,* 29 (2001) 235-238.

11 Weis D, Ingle S, Damasceno D, Frey F A, Nicolaysen K & Barling J, ,Origin of continental components in Indian Ocean basalts: evidence from Elan Bank (Kerguelen Plateau – ODP Leg 183, Site 1137), *Geology*, 29 (2001) 147-150.

12 Whittaker R C, Hamann N E, Pulvertaft T C R, A new frontier province offshore northwest greenland: structure, Basin Development and petroleum potential of the Melville Bay area, *AAPG Bulletin,* 81(1997) 978-998.

13 Murthy K S R, Rao T C S, Subrahmanyan A S, Malleswara Rao M M & Lakshminarayana S, Structural lineaments from marine magnetic anomaly maps of the eastern continental margin of India (ECMI) and NW Bengal Fan, *Marine Geology,* 114 (1993) 171-183.

14 Rao D, Gopala Krishna K S & Sar D, Crustal evolution and sedimentation history of the Bay of Bengal since the Cretaceous, *Journal of Geophysical Research,* 102 (1997) 17,747-17,768.