The Antarctic Region: Geological Evolution and Processes
1997, 719-723

Tectonic and Sedimentary Architecture of the Bellingshausen and Amundsen Sea Basins, SE Pacific, by Seismic Profiling

K. GOHL[1,3], F.-O. NITSCHE[1], K. VANNESTE[2,4], H. MILLER[1], N. FECHNER[1,5], L. OSZKO[1], C. HÜBSCHER[1,5], E. WEIGELT[1] & A. LAMBRECHT[1]

[1]Alfred Wegener Institute for Polar and Marine Research, P.O. Box 120161, D-27515 Bremerhaven - Germany
[2]Renard Centre of Marine Geology, University of Gent, B-9000 Gent - Belgium
[3]Macquarie University, School of Earth Sciences, Sydney NSW 2109 - Australia
[4]Royal Observatory of Belgium, B-1180 Brussels - Belgium
[5]Dept. of Geosciences, University of Bremen, D-28359 Bremen - Germany

Received 30 November 1995; *accepted* 27 November 1996

Abstract - The basins of the Bellingshausen and Amundsen Sea, Southeast Pacific, play a key role in reconstructing the glacial history of West Antarctica by identifying traces of glaciation and deglaciation in the sedimentary sequences of the shelf, slope and continental rise. Recent multichannel seismic surveys of *RV Polarstern* across the shelf, slopes and parts of the continental rise and abyssal plains have yielded valuable data to help contrain the glacial-marine deposition as well as provide new models of the tectonic development of that SE Pacific sector. A characteristic feature of the Bellingshausen Sea margin is the dominant sequence of alternating prograding and aggrading sedimentary layers on the outer shelf and slope. A distinct unconformity onto which the upper sediments downlap extends from the upper slope to the continental rise and separates the sedimentary sequences into two basic units. Continuous series of sediment drift systems are found on the continental rise along the margin of the Antarctic Peninsula and the Bellingshausen Sea. Two seismic profiles across an elevated drift with more than 700 m relief show evidence for tectonic control of the initial location of the drift. Compressional tectonic forces caused eastward-directed interplate subduction, forming a large basement step within the Bellingshausen Sea basin, which focussed subsequent drift deposits. The seismic observation of this tectonic event has far-reaching consequences for the Neogene crustal evolution of the SE Pacific. Data from the Amundsen Sea basin also reveal evidence for tectonic activity until Quaternary times.

Keywords: *West Antarctic margin, multichannel seismics, glacial-marine deposition, oceanic crust*

INTRODUCTION

The continental margins of Antarctica play a key role in unveiling the glacial and climatic history of the southern hemisphere. A major task is to resolve and identify sequences of glacial-marine deposition and glacial erosion on the shelf and its slopes and to correlate sedimentation sequences and cycles with tectonic events in a larger regional aspect. The basins of the Bellingshausen and Amundsen Seas have recently become areas of interest for geophysical investigations (e.g. Kimura, 1984; Anderson et al., 1991; Cunningham et al., 1994; Rebesco et al., 1996). Enhancing the knowledge of the sedimentary and tectonic composition and structure of the shelf, slope and continental rise along the poorly explored Pacific Antarctic margin is necessary for completing a future integrating glaciological/climatic model of Antarctica.

During two expeditions of the *RV Polarstern* in 1994 and 1995, more than 4000 km of multichannel seismic (MCS) and refraction data were recorded on the shelf, the continental rise and the abyssal plains of the Bellingshausen and Amundsen Seas (Fig. 1). In four complete and two incomplete profiles across the shelf and slope, the architecture of the formerly ice-covered shelf is imaged and can be analysed. Seismic profiles across major gravity field lineations of the continental rise and abyssal plain provide new constraints on the tectonic evolution of this SE Pacific sector. In this paper, we present an overview of a tectonic and sedimentary study of the basins of the Bellingshausen and Amundsen Seas based on a selection of our MCS dataset.

SEISMIC DATA

We applied several configurations for the seismic acquisition system ranging from low to intermediate resolution (10-150 Hz). The eastern profiles AWI-94002, AWI-94003 and AWI-94020 as well as all of the AWI-95-profiles (Fig. 1) were shot with an array of eight airguns of 3 liters volume each (20-100 Hz) and recorded with a 2400 m long active streamer of 96 channels. Because of a heavily damaged streamer at the end of profile AWI-94020, the subsequent western profiles were recorded with a 600 m long streamer of 96 channels and the same airgun array. We used a cluster of three 4.2-liter generator-injector (GI) airguns (30-150 Hz) for profile AWI-94030. Because of ice-conditions, only profiles AWI-94002, AWI-94003, AWI-94030 and AWI-94042 reach onto the shelf, while the others ended on the upper shelf slope.

In addition to the reflection profiles, we recorded two profiles of seismic wide-angle and refraction data west of

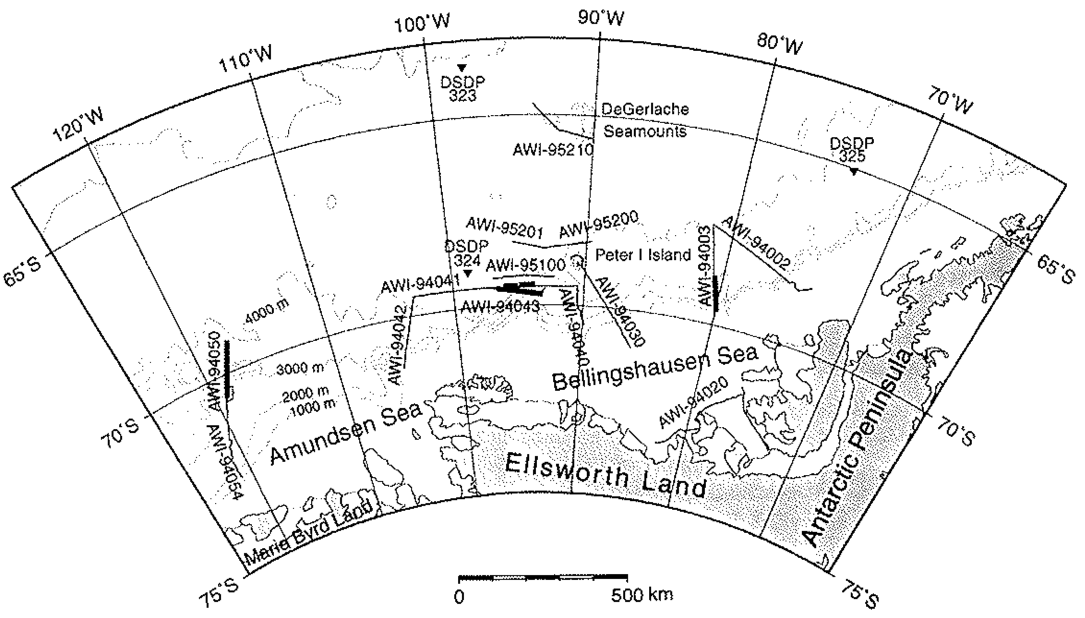

Fig. 1 - Location map of seismic profiles in the Bellingshausen and Amundsen Seas, aquired during cruises ANT-XI/3 (1994) and ANT-XII/4 (1995) of RV Polarstern. Bold profile lines indicate the seismic sections shown and described in this paper. Triangles mark locations of DSDP sites.

Peter I Island with ocean-bottom hydrophones (OBH) by using a 32-liter Bolt gun as source. Unlike in other areas, the energy of a single 32-l airgun in the Bellingshausen Sea did not provide the energy for offsets of more than 20 km. Harsh weather conditions during recording profile AWI-95100 did not permit us to activate a second 32-liter Bolt gun. Thus the data of both refraction profiles turned out to be of rather poor quality.

We applied standard data processing procedures to the MCS data after demultiplexing, including CDP sorting, spherical divergence, NMO-correction, stacking and bandpass filtering. A prestack frequency-wavenumber (FK) filter appeared to be the most successful method for suppressing primary and secondary multiples of the data across the shelf area, although traces of suppressed multiples remain.

SHELF AND SLOPE SEDIMENTS

Although the MCS profiles across the shelf and slope are located several hundred kilometers apart (Fig. 1) in different regions along the Bellingshausen Sea margin, we observe common characteristic sedimentary features on all profiles, such as prograding sequences at the shelf edge as well as a distinct unconformity on the slope. All profiles covering the shelf break show pattern of progradation, aggradation and erosion. An example of such sequences is illustrated in profile AWI-94003 (Fig. 2). This line shows a slope gradient of about 3° and a progradation of the palaeo shelf edge of about 20 km. The other profiles show a similar slope gradient between 3° and 5°, except for line AWI-94002 which has a gradient of about 11°. The amounts of progradation range from 10 km to 30 km. The difference in slope gradients could be caused by a variation in sediment supply from alternating feeding areas as well as changes in the ice stream direction and distance to the coast. There is, however, only sparse information about the ice dynamics along the coasts of Ellsworth and Marie Byrd Lands (Drewry, 1983).

All profiles show horizontally layered sequences on the outer shelf which turn into gently dipping prograding sequences near the shelf edge. These layers are overlaid by steeply dipping prograding sequences, often truncated at the top. The uppermost part again is built of horizontal layers parallel to the sea bottom. This observation is consistent with that of recent British seismic profiling across the shelf and slope of the Bellingshausen Sea (Cunningham et al., 1994). An outstanding feature of the shelf and shelf slope data is a distinct unconformity which can be identified on most profiles and onto which the prograding sequences downlap (Fig. 2). This unconformity begins on the shelf at the top of the gently dipping, mostly aggrading sequence. It is partially hidden by multiple reflections, but on some profiles (i.e. AWI-94003) it can be followed down the slope onto the continental rise. On AWI-94030 and AWI-94040, a strong undulation of basement structures beneath the continental slope makes a clear identification of this horizon difficult. As we observe on the lower slope along profile AWI-94003, this unconformity is not characterised by a linear reflector, but by a topography indicating bottom current activity. The younger sediment layers of the prograding outer shelf downlap against the unconformity. The origin of this erosional surface is not clear yet. One reason could be a change in the current pattern due to the opening of the Drake Passage (Barker & Burrell, 1977). Alternatively, we suggest that the reflection horizon might represent a time of starvation of sediment supply along the slope during the initial build-up of the West Antarctic ice sheet on the inner shelf area.

The similar pattern of all profiles indicate to us a consistent long-term glacial development along the margins of the Bellingshausen and Amundsen Seas. However, no sufficient drilling information is available yet. The only Deep Sea Drilling Project hole, DSDP Site 324, which is in the vicinity of our investigation area,

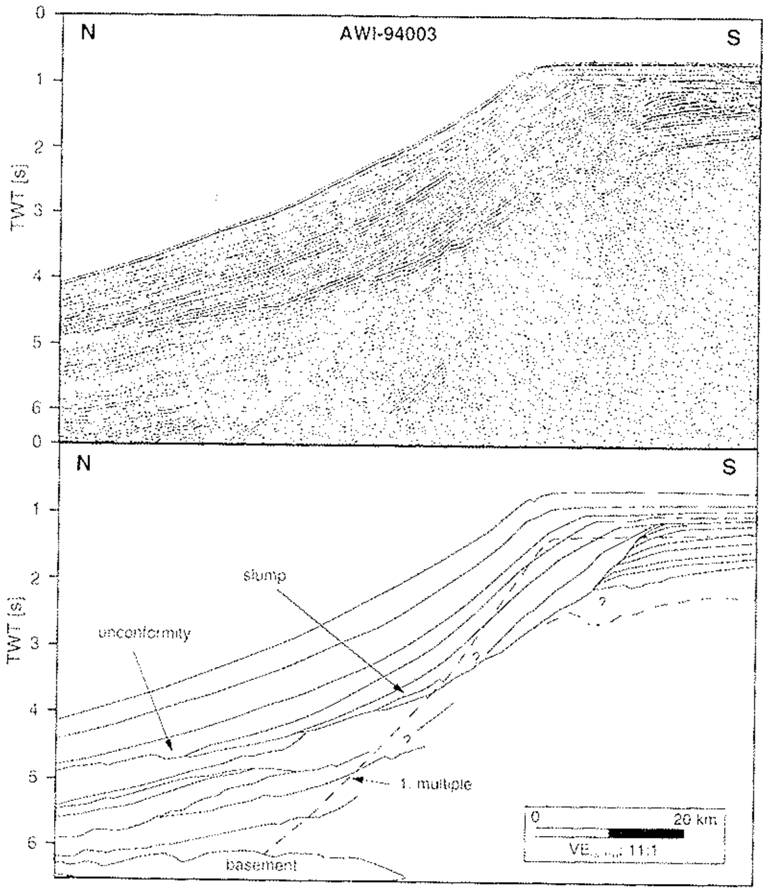

Fig. 2 - Seismic section and corresponding line drawing of the southern part of profile AWI-94003. This section shows pronounced prograding sequences at the shelf edge. An erosional unconformity is clearly identified.

reached only the early Pliocene at its maximum depth of 218 m (Tucholke & Houtz, 1976). Hence, we can only assume with a large uncertainty that the unconformities along all seismic shelf and slope profiles were formed by the same event.

CONTINENTAL RISE AND ABYSSAL PLAIN

The continental rise of the Bellingshausen Sea is dominated by parallel and subparallel sediment sequences. Some of the horizontal and subhorizontal reflectors are traced onto the slope and shelf. The average sediment thickness is between 2 and 3 km (1.5 s and 2.0 s). As an outstanding topographic rise in the Bellingshausen Sea, a large sediment drift body is observed on profiles AWI-94041 (Fig. 3) and AWI-94043 (Fig. 4). It is elevated more than 700 m above the surrounding seafloor and measures a width of about 70 km. The dimensions and the seismic character of the drift are comparable to sediment drifts along the continental rise of the Antarctic Peninsula (Rebesco et al., 1996). Parallel reflectors of weak

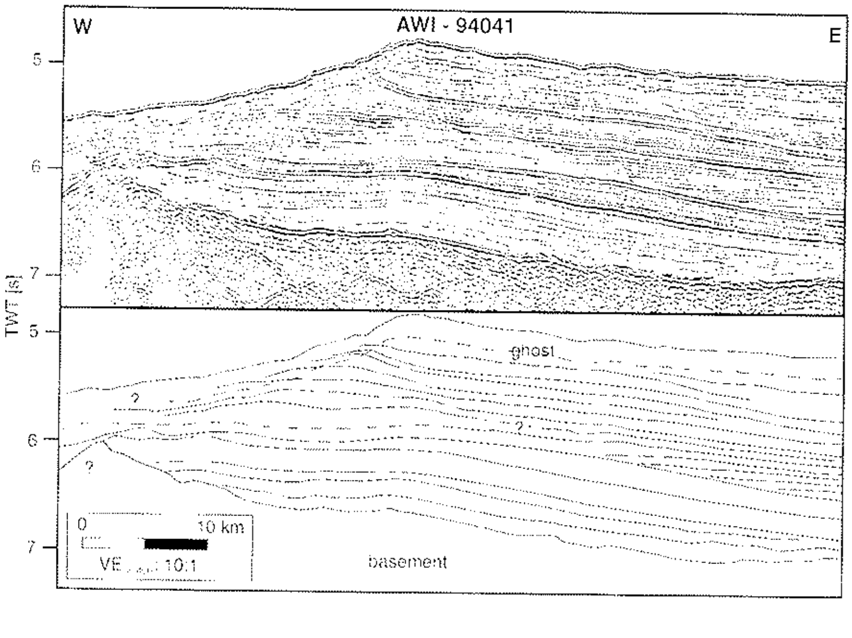

Fig. 3 - Seismic section and corresponding line drawing across a large sediment drift system in the center along profile AWI-94041. This drift shows a similar architecture as those observed along the Antarctic Peninsula by Rebesco et al. (1996).

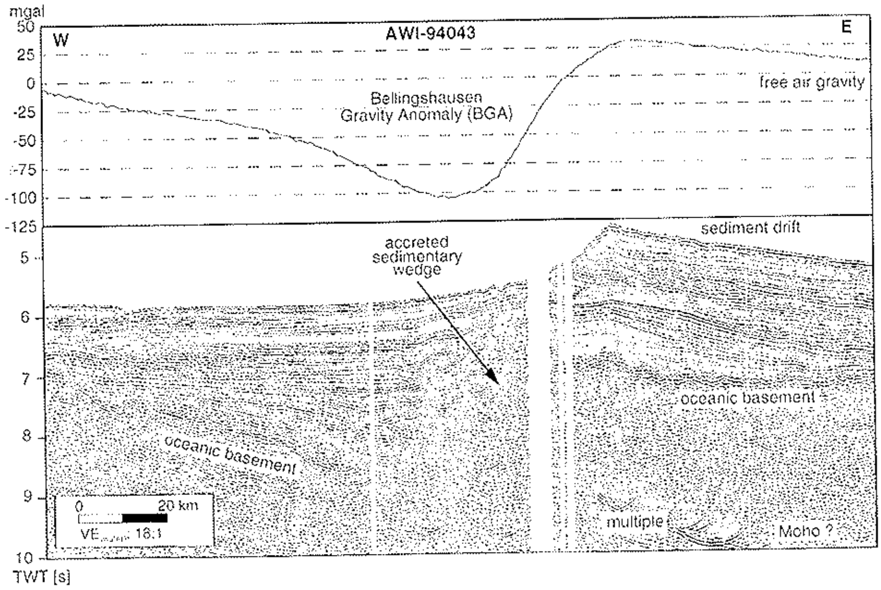

Fig. 4 - Seismic section and shipborne gravity profile AWI-94043 across the large-amplitude, north-south striking Bellingshausen Gravity Anomaly (BGA) as observed from satellite altimetry data (Sandwell and Smith, 1992).

reflectivity are characteristic for these drifts. Other, smaller drifts or mounds occur along parts of profiles AWI-94002, AWI-94003 and AWI-94041 not shown in present figures. Recent studies of the sedimentation pattern, deposition rates and measurements of the present sea-bottom current systems suggest that the drifts on the continental rise along the Antarctic Peninsula are generated by a suspension of turbidity sediments that are directed westward by bottom currents (Rebesco et al., 1996).

Satellite-derived gravity data (Sandwell and Smith, 1992) reveal large north-south-striking anomaly systems in the Bellingshausen Sea that are oriented obliquely to existing fracture zones and span from the shelf to an area northwest of Peter I Island and from Peter I Island across the De Gerlache Seamounts to about 60° S. Our seismic data in conjunction with models of shipborne gravity data across the western anomaly (named Bellingshausen Gravity Anomaly) show an accreted sedimentary wedge on top of an eastward dipping oceanic basement slab. We interpret this tectonic feature as a regional strike-slip regime with a strong compressional component forcing an interplate subduction (Gohl et al., in press). Profiles AWI-94041 and AWI-94043 illustrate clearly that the location or, more accurately, the sedimentary driftal deposition onset occured over an uplifted structure of the basement and its overlying pre-drift sedimentary sequence. The transpressional tectonic motion might be linked to the volcanism of Peter I Island at around 13 Ma (Bastien et al., 1976) which also places the onset of a sediment drift nucleus at about the same age, assuming similar bottom current conditions since that time until present.

With the exception of drift areas, there is no significant difference in the sedimentary architecture among the seismic profiles on the continental rise of the Bellingshausen Sea, whereas strong basement undulations and faults result in a less homogeneous sediment sequence structure in the central Amundsen Sea. Along profiles AWI-94050 (Fig. 5) to AWI-95054, the seafloor topography varies, basement uplifts are frequent and the sediment cover reaches thicknesses of up to 3 km in between. The seismic image shows numerous unconformities through the entire sedimentary sequence that may be associated in parts to the basement and fault geometry. The almost chaotic sediment and basement behaviour lead us to the suggestion that the continental margin of the Amundsen Sea underwent intense tectonic activity, probably in several phases since the separation of the Campbell Plateau from Marie Byrd Land at about 80 Ma (i.e. Bradshaw, 1989)

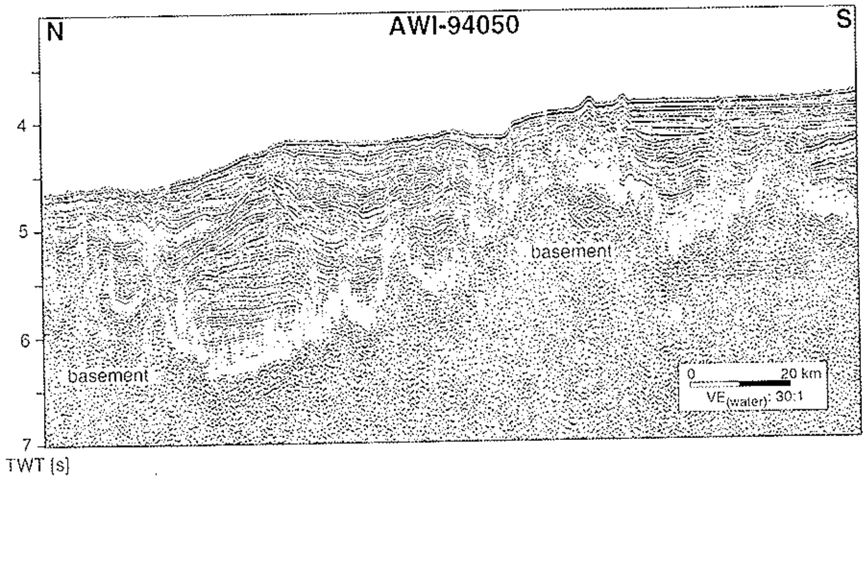

Fig. 5 - Seismic section across an undulating basement topography in the central Amundsen Sea (profile AWI-95050)

until Quaternary times. A large concentrated area of basement uplifts and seamounts (Marie Byrd Seamounts) in the central part of the Amundsen Sea continental margin, as observed from satellite-derived gravity data (Sandwell and Smith, 1992), indicate magmatism and volcanism and might be associated with the basement undulations along the entire profiles AWI-94050 to AWI-94054. Stock and Molnar (1987) indicated the possibility of a plate boundary in the vicinity of the Marie Byrd Seamounts. However, the determination of the exact timing and the reconstruction of tectonics events in the Amundsen Sea will remain a challenge with regard to the limited surface-geophysical information available at this time.

CONCLUSIONS

More than 4000 km of MCS seismic data in the Bellingshausen Sea from RV Polarstern cruises in 1994 and 1995 contribute to an increasing understanding of the sedimentary architecture and tectonic framework of the Bellingshausen and Amundsen Sea basins. This paper presents a selection of seismic observation highlights:

Similar to observations of shelf areas around the Antarctic continent (i.e. Anderson et al., 1991; Cooper et al., 1991), the Bellingshausen Sea outer shelf and slope is characterized by alternating prograding and aggrading sedimentary sequences. A seismically distinct unconformity extends from the upper slope to the continental rise. The younger layers on top downlap against the unconformity. An age constraint of the unconformity is speculative at this stage. It might be correlated with the tectonic activity associated with the opening of the Drake Passage. Another possibility is that a starvation of sediment supply during the initial build-up of the West Antarctic ice sheet on the inner shelf area created the reflection horizon.

Seismic profiles across major north-south-striking gravity anomalies in the western Bellingshausen Sea reveal a compressional tectonic feature with a significant basement step. It is likely that such a basement step served as the location nucleus for building up a large sediment drift system by a bottom-current controlled westward deflection of sediment suspensions from turbidity streams as observed along the Antarctic Peninsula by Rebesco et al. (1996).

The continental rise and the abyssal plain of the central Amundsen Sea basin are characterized by intense basement undulations and faults. The sedimentary sequences on top are heavily deformed and faulted, indicating wide-spanned tectonic activity since the separation of the Campbell Plateau from Marie Byrd Land until Quaternary times.

ACKNOWLEDGEMENTS

We are grateful to the crew of RV Polarstern for their support during cruises ANT-XI/3 and ANT-XII/4. Many thanks to the additional members of the geophysics group on board: Hartmut Martens, Conrad Kopsch, Eric Maes, Manfred B°ckmann, Michael K°sters, Ari Tryggvason, Anke Sellhorn-Timm, Sven Frehers and Olaf Haase. The review comments and suggestions by Alan Cooper and Carol Raymond helped improve the manuscript. The Belgian participation in this study took place in the framework of the Scientific Research Programme on Antarctica (Phase III) supported by the Belgian Federal Office for Scientific, Technical and Cultural Affairs. Kris Vanneste participated as a research assistent of the Belgian National Fund for Scientific Research. This is AWI publication no. 1164.

REFERENCES

Anderson, J.B., Bartek, L.R. & Thomas, M.A., 1991. Seismic and Sedimentological Record of Glacial Events on the Antarctic Peninsula Shelf. In: Thomson M.R.A., Crame J.A. & Thomson J.W. (eds.), *Geological Evolution of Antarctica*, Cambridge University Press, Cambridge, 687-691.

Barker P.F., & Burrell J., 1977. The Opening of the Drake Passage. *Marine Geology*, **25**, 15-34.

Bastien T.W., Lehmann E.K. & Craddock C., 1976. The Geology of Peter I Island. In: Hollister, C.D. et al. (eds.), *Initial Reports of the Deep Sea Drilling Project*, Vol. **35**, Washington, D.C., 341-357.

Bradshaw J.D., 1989. Cretaceous Geotectonic Patterns in the New Zealand Region. *Tectonics*, **8**, 803-820.

Cooper A.K., Barrett P.J., Hinz K., Traube V., Leitchenkov G. & Stagg H.M.J., 1991. Cenozoic Prograding Sequences of the Antarctic Continental Margin: A Record of Glacio-Eustatic and Tectonic Events. *Marine Geology*, **102**, 175-213.

Cunningham A.P., Larter R.D. & Barker P.F., 1994. Glacially Prograded Sequences on the Bellingshausen Sea Continental Margin Near 90° W. *Terra Antartica*, **1(2)**, 267-268.

Drewry D.J., 1983. *Antarctica: Glaciological and Geophysical Folio*. Scott Polar Research Institute, Cambridge, 9 Sheets.

Gohl K., Nitsche F. & Miller H., in press. Seismic and Gravity Data Reveal Tertiary Intra-Plate Subduction in the Bellingshausen Sea, South-East Pacific, *Geology*.

Kimura K., 1982. Geological and Geophysical Survey in the Bellingshausen Basin, off Antarctica. *Antarctic Record*, **75**, 12-24, 1982.

Rebesco M., Larter R.D., Camerlenghi A. & Barker P.F., 1996. Giant Sediment Drifts on the Continental Rise West of the Antarctic Peninsula. *Geo-Marine Letters*, **16**, 65-75.

Sandwell, D.T. & Smith, W.H.F., 1992. Global Marine Gravity from ERS-1, Geosat and Seasat Reveals New Tectonic Fabric. *EOS Trans. AGU*, **73**, 133.

Stock J. & Molnar P., 1987. Revised History of Early Tertiary Plate Motion in the South-West Pacific. *Nature*, **325**, 495-499.

Tucholke E. & Houtz R.E., 1976. Sedimentary Framework of the Bellingshausen Basin From Seismic Profiler Data. In: Hollister C.D. et al. (eds.), *Initial Reports of the Deep Sea Drilling Project*, Vol. **35**, Washington, D.C., 197-227.