Geological and Geophysical Survey in the Bellingshausen Basin, off Antarctica

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ベリングスハウゼン・ベースンにおける地質学的，地球物理学的調査

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要旨: 海洋底磁気異常から推定できる古海溝の存在が，3重合反射法地震探査記録断面で確認できた．また，海洋基盤上の古海溝下部斜面堆積層，大陸基盤上の古前弧堆積盆堆積層，古島弧と古背弧堆積盆堆積層も確認できた．この古海溝-島弧システムは白亜紀以来存在していた．白亜紀～古第三紀のアンデス火成岩類はこの古システムの背弧火成活動に当たる．

海嶺の沈み込みはこの古海溝-島弧システム全体の隆起と加熱を引き起こした．海洋底磁気異常は，この海嶺の沈み込みが南極大陸にそって南西から北東へと順に起こっていったことを示す．この海嶺の沈み込み後，この古海溝-島弧システムは非活動縁辺域に転化した．古海溝と古島弧間では中期中新世になって沈降と堆積が始まった．この沈降は南極大陸氷の進出によるものであろう．全堆積層は古海溝下部斜面堆積層のところで最も厚く，その海側と陸側で薄くなる．

Abstract: The continental margin in the Bellingshausen Basin off West Antarctica was geologically and geophysically surveyed.

The paleo-trench, which has been inferred from the seafloor magnetic anomalies, is found out in the 3-fold seismic reflection profiles. In addition, the paleo-trench-lower-slope-sedimentary-complex on the oceanic basement, sediments of paleo-fore-arc-basin on the continental basement, paleo-island-arc and sediments of paleo-back-arc-basin are recognized. This paleo-trench-arc-system may have existed since Cretaceous time. The Cretaceous to Early Tertiary Andean igneous rocks correspond to this back-arc igneous activity.

Ridge subduction caused the uplift and heating of the whole paleo-trench-arc-system. Seafloor magnetic anomalies show that the ridge subduction has progressively occurred in a northeasterly direction along the Antarctic margin. After the ridge subduction, this paleo-trench-arc-system has been transformed into a passive margin. Between the paleo-trench and the paleo-island-arc, subsidence and deposition began in the Middle Miocene. This may be due to advance of ice sheet. Total sediment thickness is the largest in the site of the paleo-trench-lower-slope-sedimentary complex, and decreases both seaward and landward.

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1. Introduction

Recent deep-sea drilling on Leg 35 in the Bellingshausen Basin stimulated interest in the tectonic and sedimentary evolution of the continental margin. The Ministry of International Trade and Industry planned geological and geophysical surveys in this area, and the Technology Research Center of the Japan National Oil Corporation conducted them. The R/V HAKUREI-MARU was used for the survey in December 1980 through February 1981. The purposes of this survey were to outline the general features of the continental margin in the Bellingshausen Basin, and to study the tectonic and sedimentary evolution of this area.

This area has been studied by geophysical measurements (HOUTZ *et al.*, 1973; HOUTZ, 1974), by deep-sea drilling augmented by the updated reviews and discussions (HOLLISTER *et al.*, 1976), and by plate tectonics synthesis (WEISSEL *et al.*, 1977).

2. Vessel and Scientific Instrumentation

The R/V HAKUREI-MARU having no ice-class — overall length 86.95 m, 1821.6 G.T., engine rating 3800 ps $\times$ 230 rpm $\times$ 1 — was chartered from the Metal Mining Agency of Japan and the Nippon Marine Service and Engineering Co., Ltd.

The vessel was equipped with a digital seismic reflection recording system consisting of a digital data acquisition unit of the NE127–129, Nippon Electric Co., Ltd., a 12-channel SEC mini-streamer cable, 600 m long, a Norwalk APS-120 compressor, and 2 airguns having a total volume of 11.5 *l*. Sonobuoys, OC-01 Oki Electric Industry Co., Ltd. and a NRE-8A receiver, Japan Radio Co., Ltd. were used for seismic refraction measurements. A proton precession magnetometer, Geometrics G-801, a gravity meter, La Coste and Romberg S-79, a 12-kHz precision depth recorder, NS-16, Nippon Electric Co., Ltd., and a 3.5-kHz subbottom profiler, Raytheon were provided. For heat flow measurements, a GSJ-type piston corer with thermistors and recording apparatus, Nippon Oil and Fats Co., Ltd., and a thermal conductivity meter, QTM-DII, Showa Denko Co., Ltd. were used. Bottom sampling was done with a GSJ-type piston corer and a GSJ-type, chain-bag and cylinder dredger. Positioning was made with the Navy Navigation Satellite System, Magnavox model 200, consisting of navigation and data acquisition units. A meteorological satellite image receiver, JAA-2N, Japan Radio Co., Ltd. was used for weather forecast and ice-edge detection.

3. Survey

The survey was carried out for 30 days on the continental margin of the Bellingshausen Basin to the north of the pack ice (Fig. 1).

Ice conditions in this area are variable according to time and location, and are difficult to forecast. A scientific survey program in the south of 66°S is virtually impossible to predetermine. Actually, the program was designed based on the prevailing ice edge, which was caught with a meteorological satellite image receiver. Ice conditions, weather and visibility during the survey were exceptionally good. The lowest temperature was −3.8°C for air and −1.9°C for water. Icebergs of various sizes were often encountered.

We obtained 14 lines of 3-fold seismic reflection data with a total length of 3280 km, and 5 seismic refraction data. Also 5600 km length of magnetic survey, 6300 km length of gravity survey, 8 core samples, 7 dredge samples and 7 heat flow data were taken (Fig. 1). Positioning by satellite fixes was made 24 times per day on the average, and navigation between satellite fixes was water track mode. Shot interval of seismic reflection survey was 22 seconds, which approximately corresponds to 50 m. The pressure for airgun was 138 bars.

4. Results

Seafloor magnetic anomalies reveal the tectonic history of the seafloor and the type of the continental margin. These are discussed in detail by HERRON and TUCHOLKE (1976) and WEISSEL *et al.* (1977), and are summarized here as a framework for subsequent discussions, including our results. Magnetic anomalies (Fig. 2) show that most of the oceanic basement in the Bellingshausen Basin was formed at the Aluk Ridge which once trended northeast, but which has been subducted beneath the Antarctic margin. Magnetic anomalies over the flank of the Aluk Ridge become younger toward the continent, and three discrete ridge-flank segments are separated by fracture zones. Southwest of the Peter I Fracture Zone, the magnetic anomalies show that the ridge crest was diagonal to the continent, and was subducted during the period from Latest Cretaceous to Early Eocene. The magnetic anomalies between the Peter I and Tula Fracture Zones indicate that the ridge was subducted in the Middle to Late Eocene period. However, the magnetic anomalies northeast of the Tula Fracture Zone point out that the ridge continued to generate the oceanic basement until it was consumed in the Early Miocene time. Subduction ceased when each ridge-crest segment was consumed.

A paleo-trench, which has been inferred from the seafloor magnetic anomalies, is found out in the 3-fold seismic reflection lines 7, 8, 9 (Fig. 3) and 10. The trench lower slope sedimentary complex on the oceanic basement, and sediments of a fore-arc basin on the continental basement are also recognized. In the continental shelf of the lines 9 (Fig. 4) and 10, the paleo-island-arc and sediments of a back-arc basin are observed. The morphologic expression and larger negative free-air gravity anomaly of the paleo-trench deteriorated through isostatic rebound (Figs. 3 and 5). The

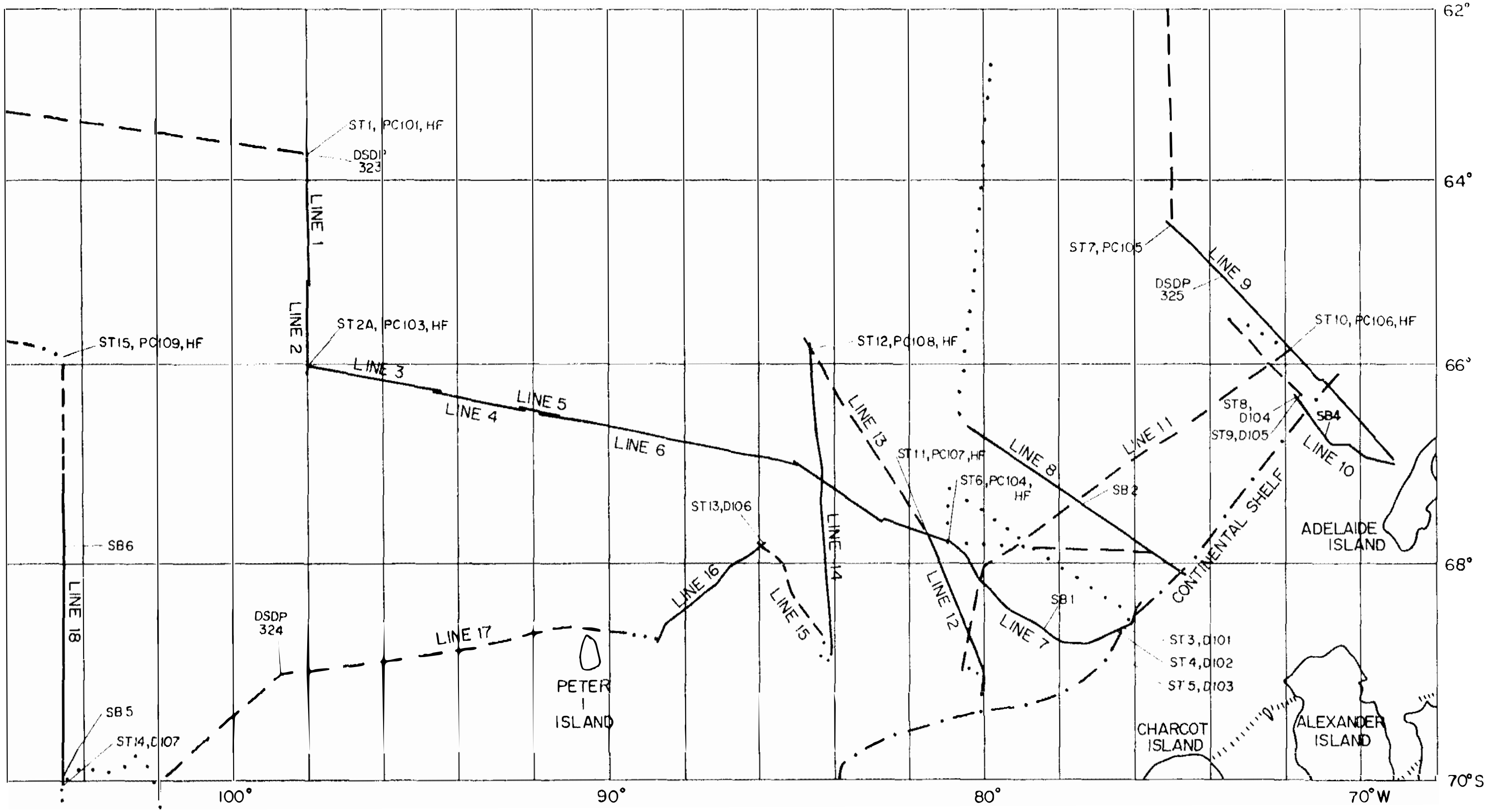

Fig. 1a. Locations of profiles and stations in the Bellingshausen Basin. Dotted lines represent depth and gravity-field profiles, dashed lines represent depth, gravity-field and magnetic-field profiles, and full lines represent depth, gravity-field, magnetic-field and seismic reflection profiles. ST: station, PC: piston core, D: dredge, HF: heat flow, SB: sonobuoy launch position. A chain line represents the edge of continental shelf.

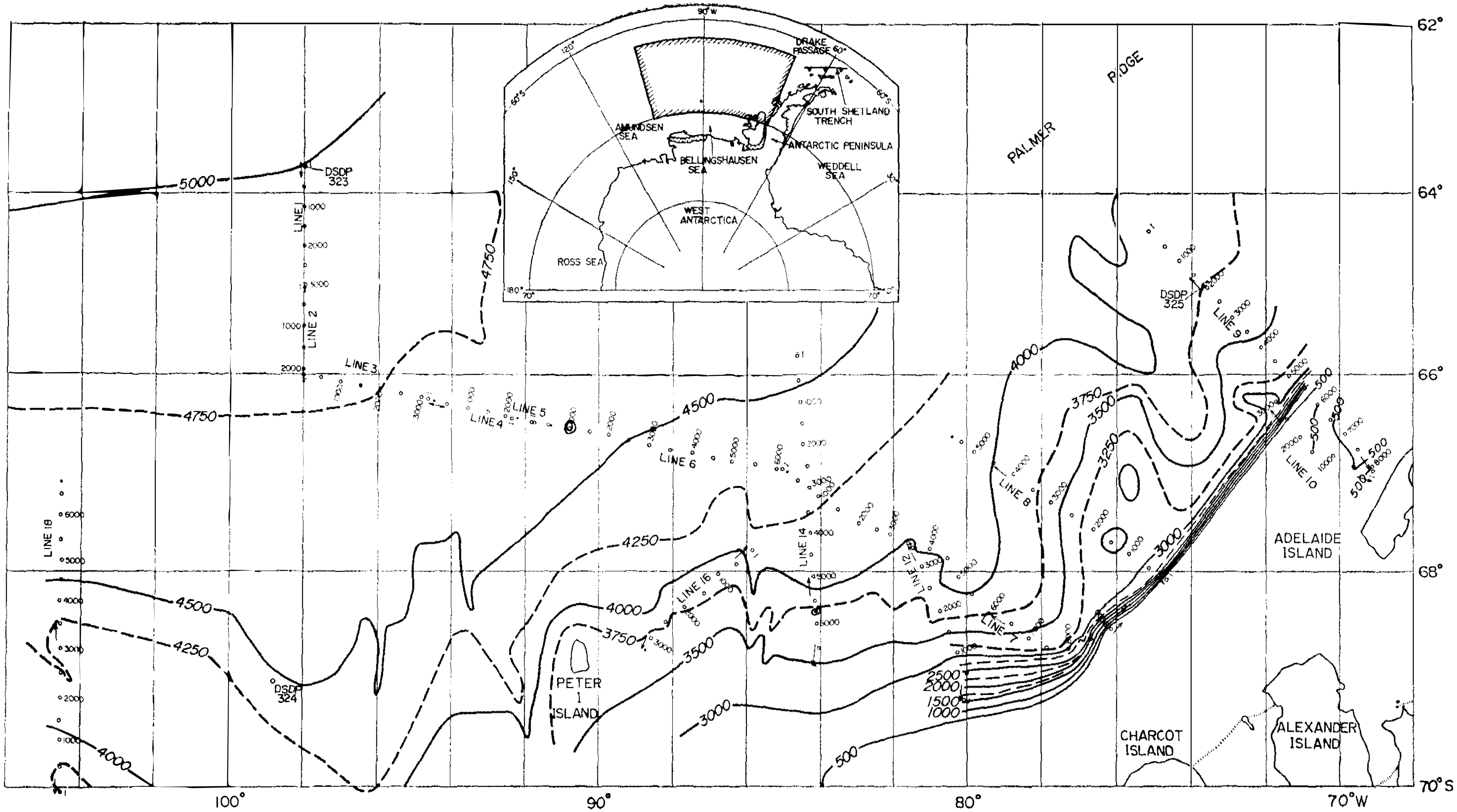

Fig. 1b. Outlined bathymetric and shotpoint map of seismic reflection survey in the Bellingshausen Basin. Bathymetric map of TUCHOLKE *and* HOUTZ *(1976) was referred to. 2 seconds in two-way reflection time=1495 m. Contour interval is 500 m with 250-m contours dashed. Arrows show data-processed profiles of seismic reflection survey. Hatching on the inset outline of West Antarctica shows location of the surveyed area.*

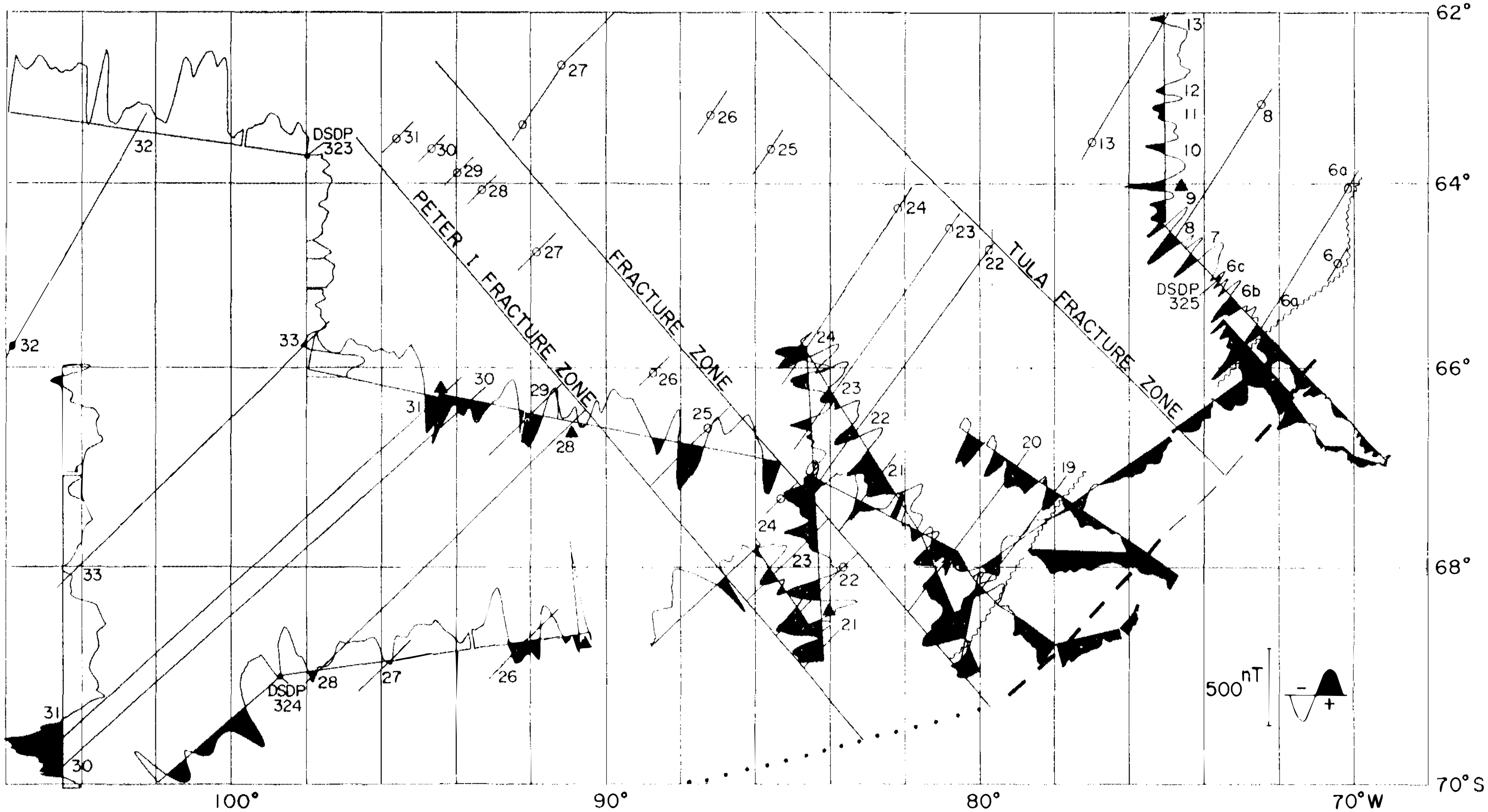

Fig. 2. Magnetic anomalies along ship-tracks in the Bellingshausen Basin. Circles indicate the magnetic anomalies identified by HERRON *and* TUCHOLKE *(1976) and* WEISSEL *et al. (1977). Magnetic lineations have been identified according to the numbering scheme of* LABRECQUE *et al. (1977). Wavy lines represent the boundary of seafloor magnetic anomalies and low-amplitude magnetic anomalies. Dashed line represents the location of the paleo-trench, and dotted line represents the inferred location of the paleo-trench. Solid triangles represent seamounts. The Tula Fracture Zone was located by* HERRON *and* TUCHOLKE *(1976).*

trench lower slope sedimentary complex indicates a chaotic reflection configuration, and is unconformably covered by the seismic units B and C. The sediments of the fore-arc basin are unconformably overlain by unit B. The paleo-island-arc shows a truncated basement-high under the sea bed, and is unconformably covered by unit B. The sediments of the back-arc basin are truncated by the sea bed. The paleo-island-arc and the paleo-back-arc-basin are correlated with the South Shetland Islands and the Bransfield Trough, respectively, in the extant South Shetland trench-arc system.

Ridge subduction, which is concluded from the seafloor magnetic anomalies, caused the uplift and heating of the whole trench-arc system. The seismic unit C could not be deposited on the system (Figs. 3 and 4) because of the uplift, and the magnetic anomalies on the system became less significant (Fig. 2) because of the heating.

After the ridge subduction, this trench-arc system was transformed into a passive margin (Figs. 3 and 4), and the upper part of unit C began to be deposited. Seismic units A, B and C in Figs. 3 and 4 can be traced to DSDP site 325 (Fig. 6a). According to HOLLISTER *et al.* (1976), unit A is terrigenous turbidite and ice-rafted detritus of Pliocene to Pleistocene, unit B is terrigenous turbidite and ice-rafted detritus of Middle

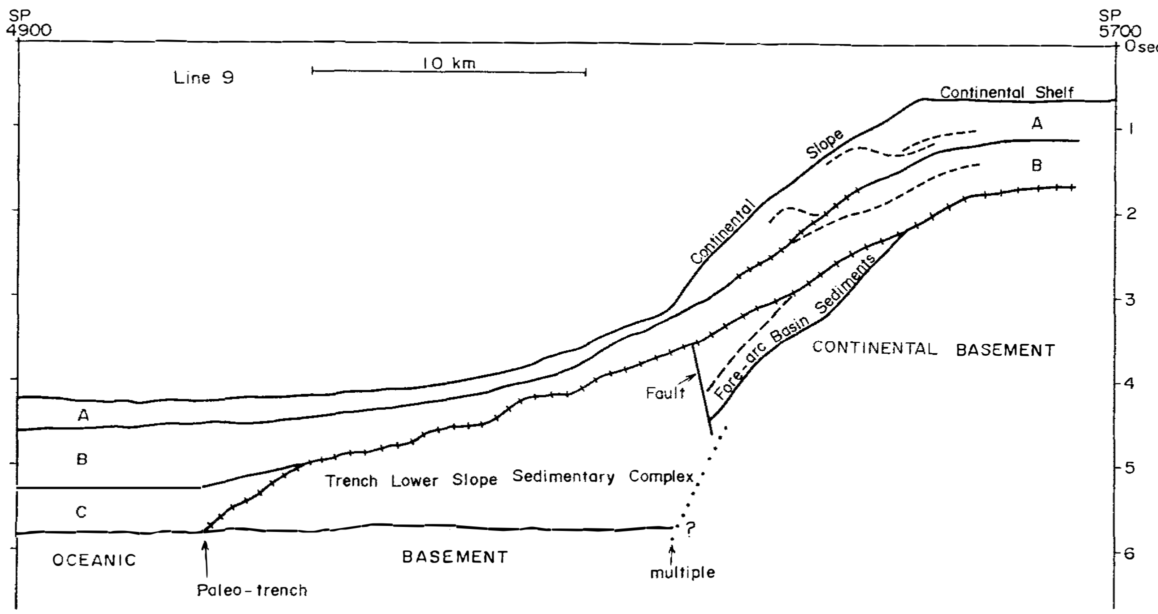

Fig. 3. Interpreted seismic reflection profile across the Bellingshausen paleo-trench. Two-way reflection time in seconds is shown on the right side of the figure. Location is shown in Fig. 1b. SP: shotpoint. The morphologic expression of the paleo-trench deteriorated through isostatic rebound. The trench lower slope sedimentary complex and fore-arc basin sediments are recognized. A, B and C represent seismic unit A, B and C. Units A, B and the upper part of unit C were deposited after subduction ceased, and the lower part of unit C was deposited while subduction persisted. Barred lines represent unconformities. Dashed lines represent the part of reflectors.

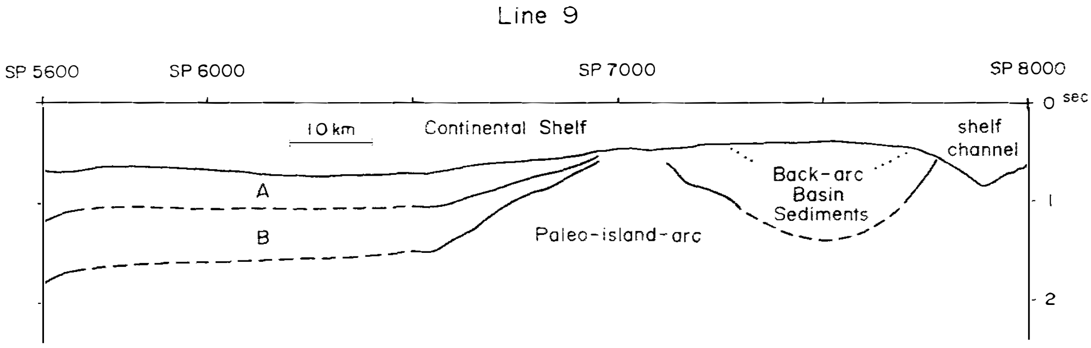

Fig. 4. Interpreted seismic reflection profile across the Bellingshausen paleo-island-arc and paleo-back-arc-basin. Two-way reflection time in seconds is shown on the right side of the figure. Location is shown in Fig. 1b. SP: shotpoint. The paleo-island-arc shows a truncated basement-high under the sea bed. The paleo-back-arc-basin is shown by the truncated sedimentary basin. A and B represent seismic units A and B. Dashed lines represent the inferred reflectors. Dotted lines represent the part of reflectors.

to Late Miocene, and the upper part of unit C is Early Miocene terrigenous turbidite. In DSDP site 323 of HOLLISTER *et al.* (1976), unit A is terrigenous turbidite, ice-rafted detritus and pelagic sediments of Pliocene to Pleistocene, unit B is terrigenous turbidite and ice-rafted detritus of Middle to Late Miocene, the upper part of unit C is Early Miocene terrigenous, hemipelagic sediments, and the lower part of unit C is Cretaceous to Paleocene pelagic sediments (Fig. 6b). These indicate that the upper part of unit C was deposited after subduction ceased, and the lower part of unit C is pelagic sediments which were deposited while the trench and ridge blocked the influx of Antarctic detritus before subduction ceased.

Northeast of the Tula Fracture Zone, Horizon S of TUCHOLKE and HOUTZ (1976) corresponds to the top of the oceanic basement. Southwest of the Tula Fracture Zone, Horizons R and S of TUCHOLKE and HOUTZ (1976) do not always correlate with the unit A/B and B/C boundaries, respectively.

Between the paleo-trench and the paleo-island-arc, subsidence began in the Middle Miocene, and unit B was deposited (Figs. 3 and 4). This may be due to advance of ice sheet. Advance of ice sheet is indicated by the first occurrence of ice-rafted debris in the earliest Middle Miocene at DSDP sites 323 and 325 (HOLLISTER *et al.*, 1976).

East of 80°W, the construction of the continental-rise prism shows seaward progradation (A and B of Fig. 6a), the continental slope is steep (Fig. 1b), and the progradation of the shelf edge is small (Fig. 3). In contrast, west of 80°W, the progradation of the rise prism is not observed (Fig. 6b), the slope is gentler (Fig. 1b; VANNEY

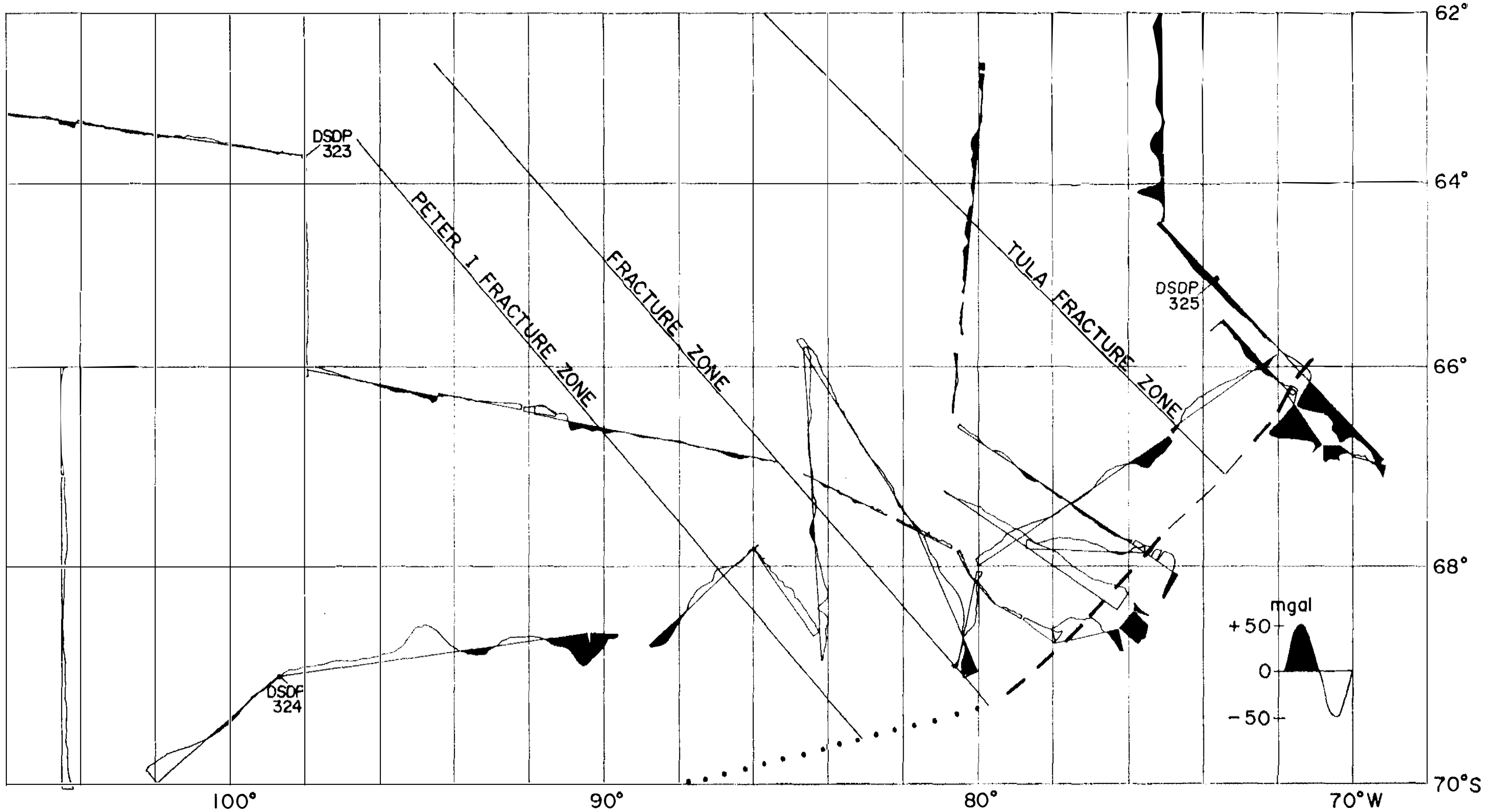

Fig. 5. Free-air gravity anomalies along ship-tracks in the Bellingshausen Basin. Dashed line represents the location of the paleo-trench, and dotted line represents the inferred location of the paleo-trench. The larger negative free-air gravity anomaly of the paleo-trench deteriorated through isostatic rebound.

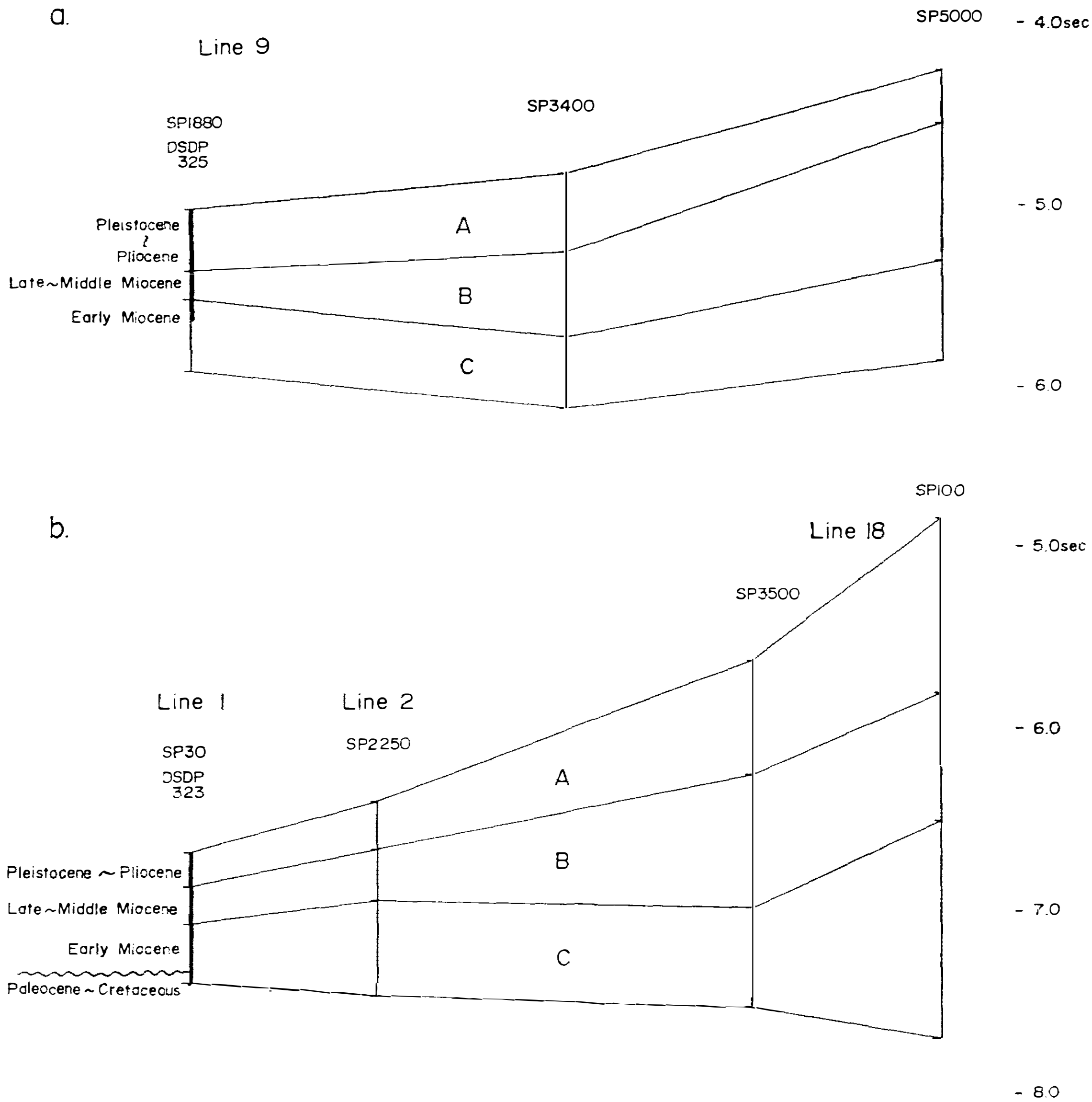

Fig. 6. Interpreted outlines across the Bellingshausen continental rise and abyssal plain. Two-way reflection time in seconds is shown on the right side of the figure. Location is shown in Fig. 1b. SP: shotpoint. A, B and C represent seismic units A, B and C. Heavy line segments indicate the penetrated sections of DSDP sites 323 and 325 (HOLLISTER et al., 1976).

and JOHNSON, 1976), and the progradation of the shelf edge is probably larger. In the steep slope east of 80°W, unit A unconformably covers unit B, and indicates anomalous sedimentation (Fig. 3). This is due to Antarctic glaciation maximum.

Total sediment thickness (Fig. 7) is about 3 seconds of two-way reflection time in the site of the trench lower slope sedimentary complex, and decreases both seaward and landward. Isopachs show that the provenance of sediments is mostly the Ant-

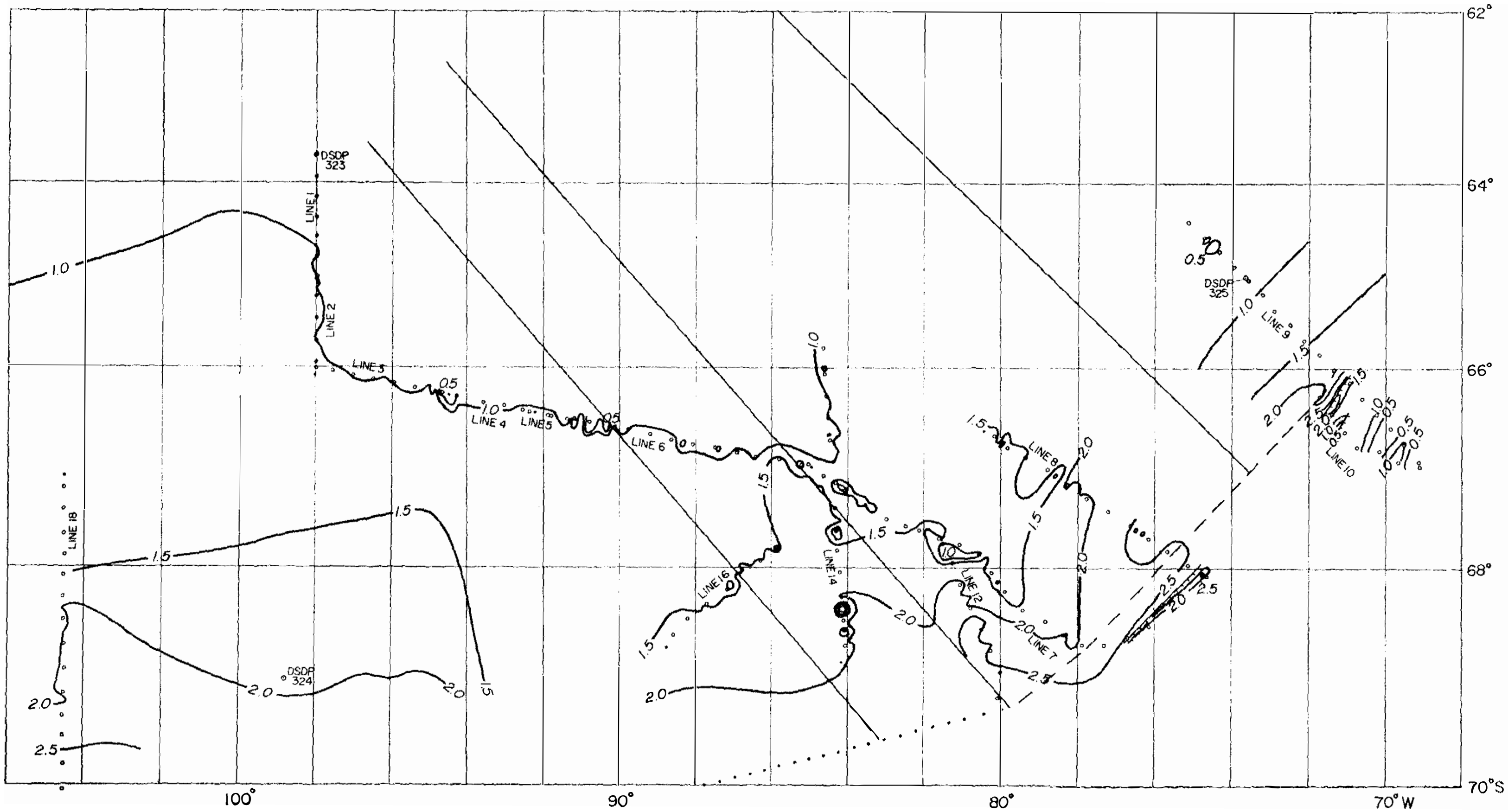

Fig. 7. Total sediment thickness in the Bellingshausen Basin. Seismic profiles of TUCHOLKE *and* HOUTZ *(1976) were referred to. Contour interval is 0.5 seconds of two-way reflection time. Full lines represent fracture zones. Dashed line represents the location of the paleo-trench, and dotted line represents the inferred location of the paleo-trench. Barbed lines represent faults.*

arctic continent and the paleo-island-arc. Most of thickness anomalies are clearly related to the age and morphology of the basement. Thicker sediments are found southwest of the Tula Fracture Zone, and thinner sediments are observed northeast of the Tula Fracture Zone. Morphologic highs have relatively thin sediment covers. Fracture zones have also influenced sediment thickness.

5. Bellingshausen Paleo-Trench-Arc-System

The Bellingshausen paleo-trench west of 80°W extends probably along the continental slope. Based on the bathymetry (VANNEY and JOHNSON, 1976) and the pattern of seafloor magnetic anomalies (WEISSEL *et al.*, 1977), its western extreme is thought to be at 120°W, 70°S in the Amundsen Ridge.

WEISSEL *et al.* (1977) suggested that after anomaly-32 time southwest of the unnamed fracture zone in Fig. 2 and after anomaly-29 time for the next ridge segment to the north, segments of the Pacific-Antarctic and Aluk spreading systems migrated away from each other in a manner similar to segments of the Chile and Pacific-Antarctic Ridges at the present time. It is considered that before the oceanic basement formed at the Aluk Ridge was subducted, the oceanic basement which possibly is the Phoenix plate had been consumed in the Antarctic margin, and that the paleo-trench-arc-system had existed since Cretaceous time.

Cretaceous to Early Tertiary Andean igneous rocks correspond to the back-arc igneous activity. WEISSEL *et al.* (1977) discussed that we have weak evidences for progressive cessation of subduction in a northeasterly direction along the Antarctic margin from radiometric ages determined on rocks from Antarctica. DELONG and FOX (1977) suggested that this may be due to decrease or cessation of subduction-related magmatism when progressively younger and hotter oceanic basement is subducted.

The continental basement is thought to be mostly the upper Paleozoic to lower Mesozoic Gondwanian Orogen (ELLIOT, 1975) and partly the plutons and volcanics of the Andean Orogen.

Acknowledgments

I thank the Agency of Natural Resources and Energy, Ministry of International Trade and Industry for permitting me to publish this paper. I also thank Captain H. OKUMURA and the crew, and Dr. Y. ISHIWADA, chief scientist, and the scientific party of the R/V HAKUREI-MARU for the effective execution of our survey.

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(*Received December 2, 1981; Revised manuscript received January 6, 1982*)