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Geophysical investigations of P3 segment of the Phoenix Ridge in Drake Passage, Antarctica

Y. K. Jin,[1] K. J. Kim,[2] J. K. Hong,[1] M. Park,[1] S. H. Nam,[1] J. H. Lee,[1] and Y. D. Kim[1]

[1]Korea Polar Research Institute, KORDI, 503 Get-Pearl Tower, Songdo Techno Park, 7-50 Songdo-dong, Yeonsu-gu Incheon, 406-840, Kore1a (ykjin@kopri.re.kr)
[2]AAT, Sungnam, Kyeounggi Province, Korea

Summary During the KARP 99/00 cruise, new swath bathymetry, gravity, and magnetic data were obtained in the P3 segment of the Phoenix Ridge in Drake Passage, Antarctica. The detailed bathymetry (including a deep valley, a 2500 m-high seamount, seabed faults and depressions) suggests that spreading rates in P3 varied with time, from an intermediate rate off the ridge axis to a slow rate when spreading ceased. Mantle Bouger anomalies reveal that several gravity lows are associated with the seamount and both flanks of the P3 axial valley, and that highs are found at the junction of the ridge axis and the Hero Fracture Zone. A synthetic magnetic model indicates that the positive anomaly on the axial seamount probably results from the seamount eruption and that it post-dates spreading. By removing the seamount effect, the cessation of P3 spreading is interpreted at about 3.6 Ma, earlier than the 3.3 Ma of previous studies.

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Introduction

Drake Passage between the South America and Antarctic Peninsular opened during the development of the Scotia Arc from 41 Ma (Barker et al., 1991). In Drake Passage, the Phoenix Ridge has three extinct spreading ridge segments (P1, P2 and P3 in Fig. 1). These segments separated the Phoenix plate from Antarctic plate. Previous magnetic studies suggested that the seafloor spreading in each of the ridge segments stopped synchronously at 3.3 Ma (Larter and Barker, 1991; Livermore et al., 2000; Eagles, 2003).

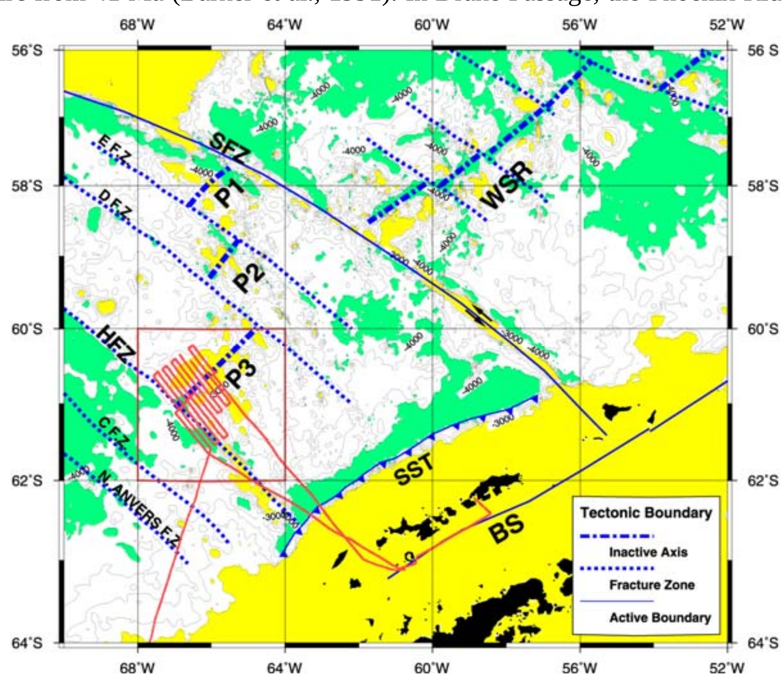

Figure 1. Tectonic boundary map and survey lines along which multibeam bathymetry, gravity and magnetic data were recorded.

This study presents the results of bathymetric, gravity and magnetic surveys in the P3 segment and at the intersection with the Hero Fracture Zone. The main objectives of this work are to understand the tectonics and the oceanic crustal structure of the Phoenix Plate, to examine the geophysical signature with respect to various proposed accretionary models, and to explain the extinction process of Phoenix Ridge.

Data acquisition and processing

As part of the KARP 1999/2000 cruise, geophysical surveys that included the acquisition of swath multibeam bathymetry, gravity, and magnetic data were conducted onboard the Korean vessel R/V *Onnuri*. The track lines separation was 7 km and the survey covered the western half of the P3 segment and the intersection of the Hero Fracture Zone (HFZ) (Fig. 1). The bathymetry data were acquired using the SeaBeam 2000 system. Generic Mapping Tools (GMT) (Wessel and Smith, 1998) and the MB system (Caress and Chayes, 1996) were utilized for processing and plotting the data. Gravity data were obtained from a Lacoste and Romberg shipborne gravity meter (S-118) and these data were corrected with Eötvös and standard corrections. Mantle Bouguer anomalies (MBA) and residual mantle Bouguer anomalies (RMBA) were computed according to the procedure developed by Prince and Forsyth (1988) and Kuo and Forsyth (1988), following the results of best-fit modeling. Marine magnetic data were obtained using the Geometrics G-886 magnetometer. Raw magnetic data included noise due to sensor motion and due to ionospheric effects (Lee, *et al.*, 1996). To reduce the noise, we used a moving average with a 30-second window.

Diurnal corrections were carried out by using base station magnetic data recorded at King Sejong Station. Magnetic anomalies were finally calculated relative to the 2000–2005 International Geomagnetic Reference Field (Mandea et al., 2000).

Results and discussion

Topographic feature

Bathymetric data in the P3 segment show a deep valley, a nodal basin, and a prominent seamount. These morphological characteristics are typical features of the slow-spreading ridges (Fig. 2). Also, the HFZ is characterized by linear, axis-parallel high ridges, and depressions with an *en echelon* distribution. These morphological features exhibit both slow-spreading and intermediate-spreading characteristics, implying a significant change in the spreading rate. This is well-correlated with results obtained from the seafloor magnetic modeling showing a decrease in the spreading rate from 25 km/m.y. to 10 km/m.y. at the last phase of spreading.

A notable structure is an anomalous seamount (called ‘Phoenix seamount’ in this study) on the axis of the P3 ridge, which has 2500 m relief above the seafloor. The morphology of this seamount, together with other smaller volcanoes, suggests that the magma may have been high viscosity material. The Phoenix seamount could have been emplaced during the terminal activity of the ridge. Occurrence of such an axial seamount is very unusual at a spreading center with an ultra-slow spreading rate in which the magma supply would be expected to be low.

The lineaments of the fabrics and the direction of the structures imply the possibility of oblique extensional stresses. The decrease in the spreading rate may produce a relative increase in extensional stress, and at the end of spreading, the brittle oceanic crust would be deformed and fragmented by the oblique extension.

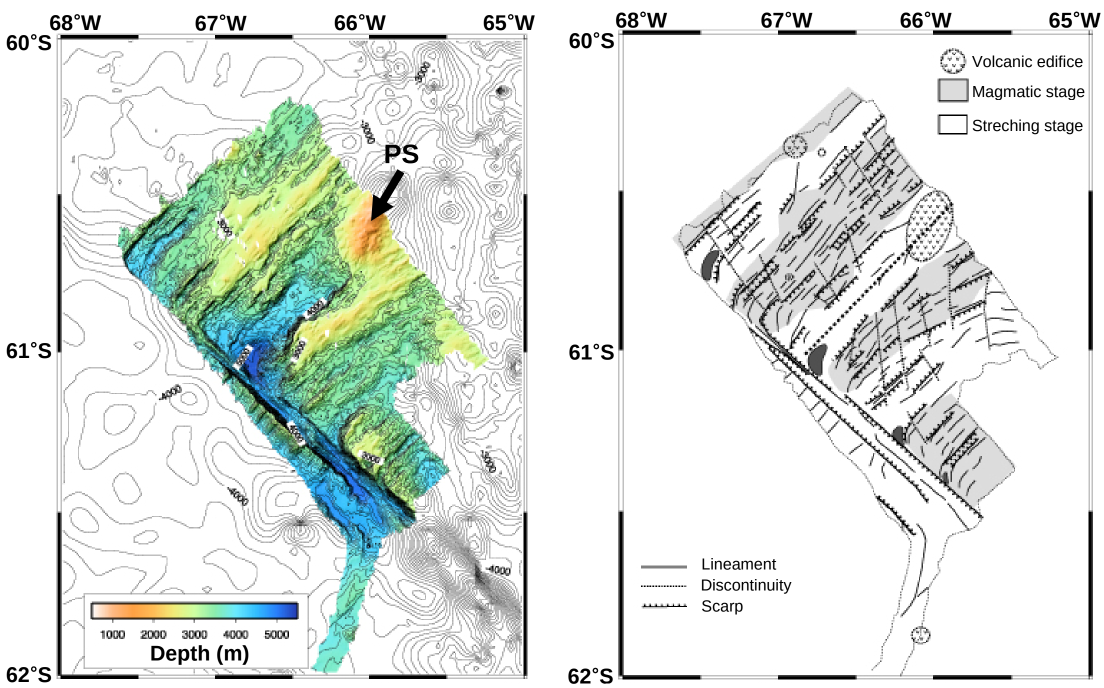

Figure 2. Bathymetric map (left) and interpreted line drawing of the study area (right). PS – Phoenix seamount.

Gravity

The free-air (FA) gravity anomalies directly reflect the seafloor topography of the P3 segment and the HFZ. Large positive anomalies are associated with the high rift flanks of the P3 axis, with the Phoenix seamount and with the southernmost end of the area.

Mantle Bouguer anomalies derived from the FA anomalies reveal that several gravity lows are associated with the Phoenix seamount and both flanks of the P3 axial valley, and that gravity highs are found at the intersection of the ridge axis and the Hero Fracture Zone (Fig. 3). A prominent, sub-circular gravity low coincident with the Phoenix seamount indicates the existence of thick crust (up to 10 km in thickness) beneath the seamount. This thick crust would correspond to gabbroic roots beneath similar structures in other extinct spreading centers. The crustal thickness rapidly decreases to 5.5 km beneath the intersection of the ridge axis and the Hero fracture zone as reflected by positive Mantle Bouguer anomalies.

Using a simple cooling half-space model incorporating only vertical conduction of heat transfer, we can compute the variation in the gravity field caused by the thermal cooling effect after spreading ceased. Cooling is dominant beneath the spreading center and slowly propagates outward from that center. The change in gravity due to cooling near the spreading axis after spreading ceased (about 3 million years) is about 5 mgal and thermal equilibrium is restored after about 10 million years. The residual gravity anomaly is obtained by removing the cooling effect from the Mantle Bouguer anomaly. In this study area, the variation of gravity by cooling effect is negligible because its magnitude is much smaller than that that of the gravity anomalies.

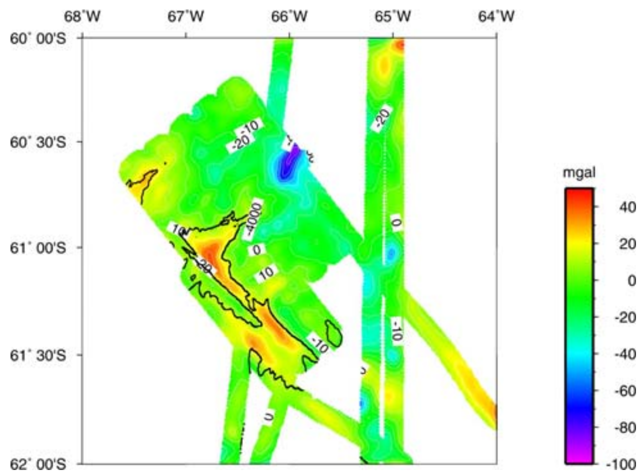

Figure 3. Mantle Bouguer anomaly map derived after correction of the gravitational attraction of the two different layer interfaces. The solid lines are the 4000 m bathymetric contour.

Magnetics

We have modeled the magnetic anomalies using a smoothed version of the observed bathymetry and a 1 km-thick source layer with a susceptibility of 0.005 SI, and ignoring the sedimentary layer. Forward modeling was carried out using the HYPERMAG program of Saltus and Blakely (1993). We used the same field parameters that were used by Larter and Barker (1991) – that is, an inclination of -74° and a declination of 0°. The magnetic modeling profiles can be divided into two groups, western and eastern, that show different anomaly patterns about the spreading axis. The eastern group crosses near or over the Phoenix seamount, while the western group crosses the deep central valley.

The eastern profiles show positive anomalies on the axis due to the effect of the Phoenix seamount, whereas the western profiles are characterized by negative anomalies on the axis as shown in Fig. 4. Negative anomalies on the P3 ridge axis have not previously been reported. In contrast, only positive magnetic anomalies occur on the axis of the

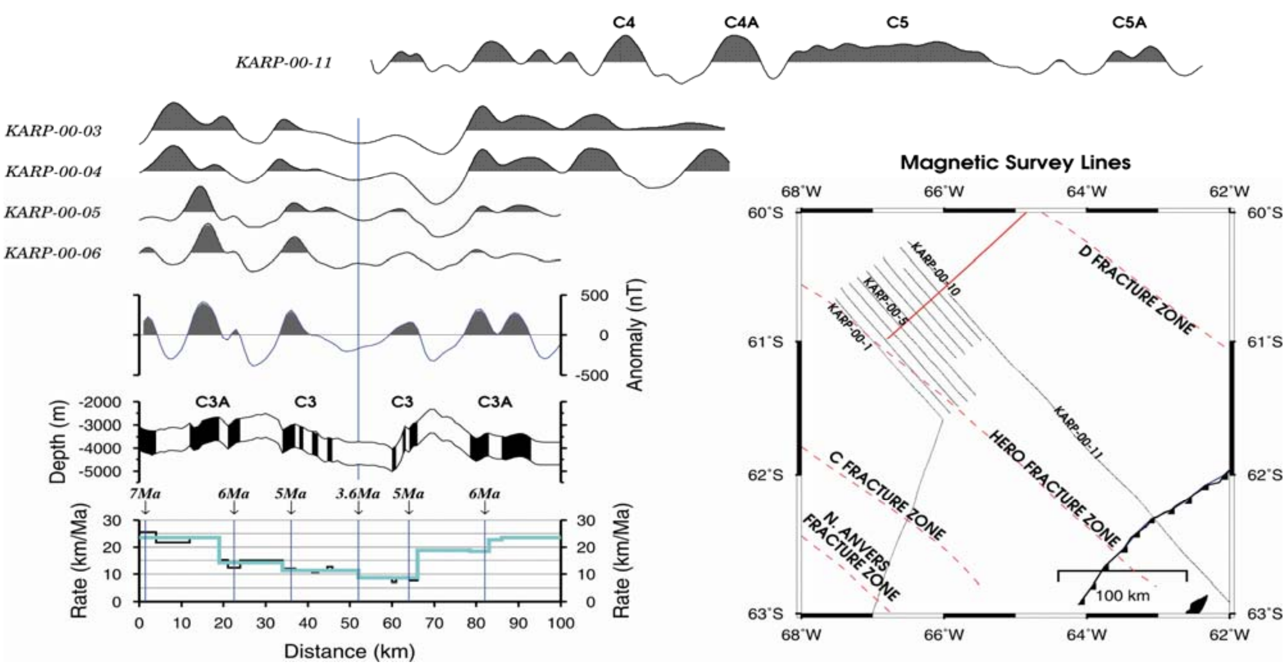

Figure 4. Modeled magnetic anomaly profiles over the P3 segment and the intersection of the Hero Fracture Zone.

Phoenix Ridge in the P1 and P2 segments. We believe that the positive magnetic anomalies on the Phoenix Seamount were formed due to volcanic eruption after the cessation of spreading in the P3 segment, and not during the spreading stage. By removal of the Phoenix Seamount effect, the spreading in the P3 segment is interpreted to have ceased at about 3.6 Ma; this is slightly earlier than spreading ceased in the P1 and P2 segments.

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