Mantle heterogeneity beneath the Antarctic-Phoenix Ridge in the Drake Passage, Antarctica

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Summary We determined Sr, Nd and Pb isotopic compositions for basalts recovered from the fossilized Antarctic-Phoenix Ridge (APR) in the Drake Passage, Antarctica, in order to understand the nature of sub-ridge mantle source. Enriched (E-type) mid-ocean ridge basalts (MORB) coexist with the normal (N-type) MORBs in the axial region of the APR, being far from any known hotspots. The E-type basalts are relatively young in comparison with the N-type samples, and erupted after the extinction of the APR. Extent of enrichment in incompatible elements in the basalts correlates positively with isotopic ratios of Sr and Pb, and negatively with Nd. The E-type melts have been generated by low-degree of partial melting of an enriched mantle source. Extinction of the APR is likely to lead the extent of partial melting in this region to decrease. We interpret that the geochemically enriched materials might exist as a form of highly localized spots or veins in ambient depleted mantle of this region, and have been the first fraction to melt for generating the E-type basalts studied.

Citation: Choi, S.H., J.I. Lee, and W.H. Choe (2007), Mantle heterogeneity beneath the Antarctic-Phoenix Ridge in the Drake Passage, Antarctica, *in* Antarctica: A Keystone in a Changing World – Online Proceedings of 10th ISAES, edited by A.K. Cooper and C.R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 160, 3 p.

Introduction

The origin of E-MORB has been generally invoked as plume-ridge interactions, based on compositional variations toward on- and near-ridge hotspots. However, the occurrence of E-MORB far from hot spots is not readily explained by interaction of enriched plumes from the deep mantle with the dominantly depleted mid-ocean ridge basalts (N-MORB) mantle source. The Antarctic-Phoenix Ridge (APR), the last remnant of the once-extensive spreading center in the Drake Passage between South America and Antarctica, is remote from the influence of hotspots. Normal (N)- and enriched (E)-MORB coexist in this area. The APR is thus an excellent place to examine the intrinsic isotopic heterogeneity in the oceanic upper mantle. Here, we present Sr-Nd-Pb isotopic compositions for 17 axial MORB samples from the APR. Our data provide insights into the nature and distribution of mantle source heterogeneity.

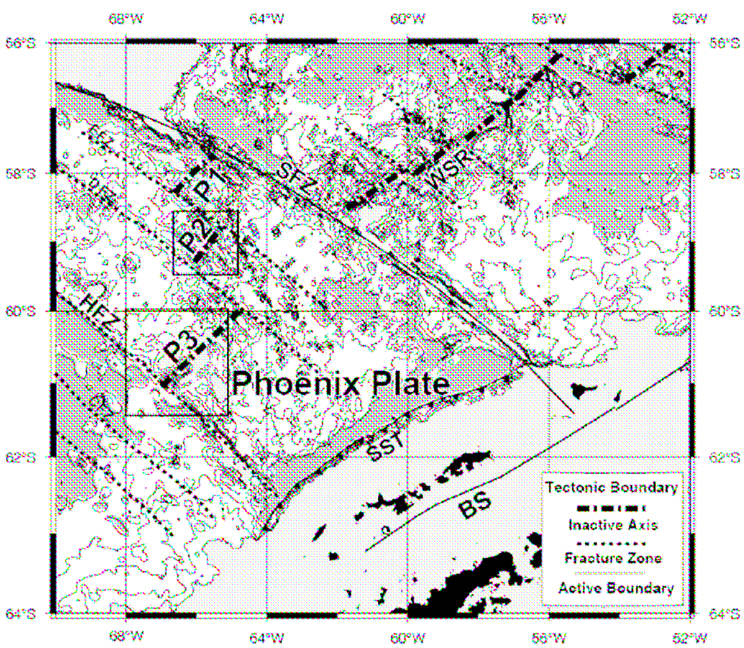

Figure 1. (a) Tectonic boundary map over the bathymetry using satellite altimetry in the Drake Passage (modified from Smith and Sandwell, 1994). Contours are depths. Abbreviations: P1, P2, P3, Antarctic-Phoenix Ridges; SFZ, Shackleton Fracture Zone; HFZ, Hero Fracture Zone; SST, South Shetland Trench; WSR, West Scotia Ridge; BS, Bransfield Strait; DFZ, D Fracture Zone; EFZ, E Fracture Zone.

Geological setting and sampling

The APR consists of three inactive segments (P1, P2 and P3; Fig. 1) between the Shackleton and Hero Fracture Zones. Spreading of the APR slowed abruptly at the time of magnetic chron C4A (~7.8 Ma), probably as a result of extinction of the West Scotia Ridge (Fig. 1), and became extinct at chron C2A (~3.3 Ma) (Larter and Barker, 1991; Livermore et al., 2000). Estimated spreading rates were from >30 mm/y prior to chron C4A to 13 mm/y just before extinction (Livermore et al., 2000).

The samples named as PR2- have been collected from the inner wall of the northwest flank in the P2 segment. The K-Ar whole-rock ages for the basalts range from 2.1 to 1.4 Ma. The samples named as SPR have been collected from the seamount in the P3 segment, which dated to 3.1-1.4 Ma. The samples named as PR3- have been collected from the southeastern ridge in the P3 segment, which dated to 3.5 - 6.4 Ma.

Geochemistry

Major and trace element chemistry of the PR3-basalts are N-MORB type, whereas those for the

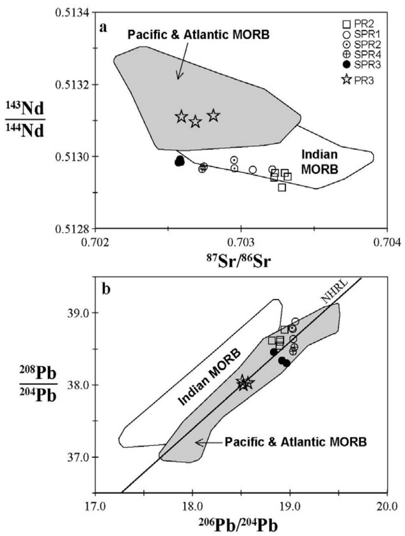

Figure 2. Sr, Nd and Pb isotopic compositions of the basalts from the Antarctic-Phoenix Ridge.

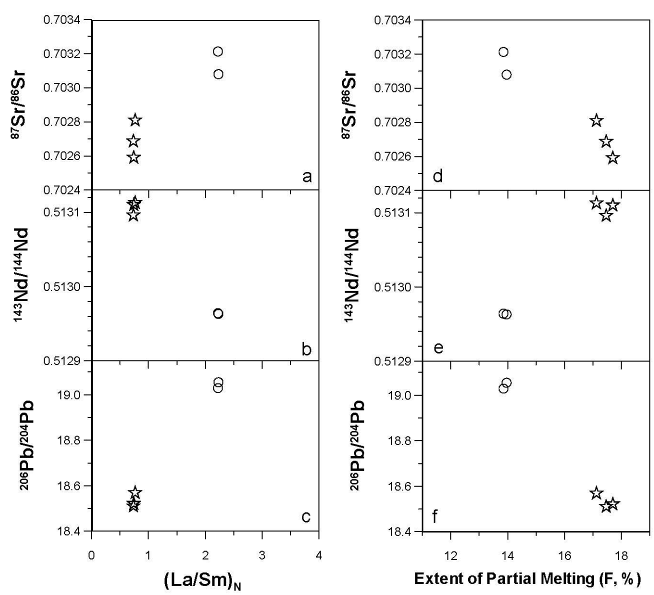

Figure 3. Isotopic systematics and incompatible element ratios versus $(La/Sm)_N$, normalized to composition of chondritic meteorites (a-c), and extent of partial melting (d-f). Symbols as in Fig. 2.

axial seamount (SPR) and PR2- basalts are E-MORB type. That is, the N-MORB type PR3- basalts are low-K tholeiites, and have lower Zr/Y (<4) and slightly light rare earth element (LREE)-depleted pattern on the chondrite-normalized REE plot, whereas the E-MORB type SPR and PR2- samples are medium-K mildly alkaline basalts, and have higher Zr/Y (5-12) and strongly LREE-enriched pattern. We address that the E-type basalts are relatively young in comparison with the N-type samples, and erupted after the extinction of the APR.

On the $^{87}Sr/^{86}Sr$ vs. $^{143}Nd/^{144}Nd$ isotopic correlation diagram (Fig. 2a), the N-type basalts plot within the field of Pacific/Atlantic MORB, meanwhile the E-type samples plot off the field, showing radiogenically enriched Indian MORB-like signature. Notably, well-separated bimordal Pb isotope ratios, which show high values for E-type and low values for N-type basalts, are apparent in Fig. 2b.

The $(La/Sm)_N$, normalized to the chondrite, has been considered as a good indicator of the enrichment of the source, with greater values corresponding to more fertile mantle. The E-type APR basalts are characterized by elevated $(La/Sm)_N$ ratios, ranging from 2.2 to 3.4, relative to the N-type having the values of ~0.7. In Fig. 3a-c, we have compared the Sr-Nd-Pb isotopic compositions with the $(La/Sm)_N$ ratios. Relatively primitive basalts (SPR and PR3-) have been used in this approach. It is clear that the highly incompatible element ratios are strongly coupled with the isotopic compositions, supporting the notion that mantle source beneath the APR is quite heterogeneous with respect to incompatible trace elements and Sr-Nd-Pb isotopic compositions. The most important implication is that these correlations between incompatible trace element and isotopic ratios reveal an existence of two end-member components: one enriched component with more radiogenic Sr and Pb and less radiogenic Nd and another depleted end-member.

In order to evaluate if the processes of mantle melting is related with the mantle source heterogeneity, we estimated the extent of melting following the method of Niu and Batiza (1991) based on major element compositions, after normalization to a constant MgO content of 8 wt% to correct for crustal-level crystal fractionation. The determined extent of melting (F) of the APR basalts is variable from 12 to 18 wt%, and illustrated in Fig. 3d-f graphically with respect to isotopic compositions. It is clear that the E-type basalts, having more radiogenic Sr and Pb, and less radiogenic Nd, and elevated $(La/Sm)_N$ ratios, represent a relatively small degree of melt in comparison with the N-type basalts.

Discussion

It should be stressed that this region is distant from any known hotspots. If enriched mantle is associated with higher potential temperatures by analogy with hotspots, higher upwelling temperatures should lead to greater degree of melting. However, this is clearly not the case (Fig. 3d-f). The E-type basalts represent relatively low degree of melts relative to the N-type basalts, reflecting that invasion of plume materials from deep mantle into the ambient N-MORB mantle source can not be the source of the enriched materials beneath the APR. Therefore, it is considered that the sub-ridge mantle is geochemically heterogeneous at shallow level in the asthenosphere. In order to explain the nearby coexistence of distinct E-MORB and N-MORB in the APR, it seems reasonable to expect that the scale of heterogeneities may be small. That is, the enriched component must exist as a form of highly localized spots or veins.

The sub-ridge passive upwelling rate is proportional to the spreading rate. The apparent absence of extensive recent volcanic activity along this axial regions of the APR, inferred from the very poorly defined central magnetic anomaly, suggests that the final stage of volcanic activity, responsible for the E-type basalts, has occurred prior to the magma supply shutting down following the extinction of the Antarctic-Phoenix Spreading Ridge. It is reasonable to expect that the extent of melting decreases during periods of the final stage since slower upwelling gives more time for mantle to lose heat to the surface. Compared to the ambient depleted matrix, the enriched materials have high abundance of incompatible elements, and possibly high volatile contents (Asimow and Langmuir, 2003). Enriched component is thus the first fraction to enter the melt. Derivation of the E-type APR basalts represented by relatively small extent of melt of radiogenically enriched mantle source after extinction of the APR can be explained like this.

Conclusions

(1) The E-MORB coexists with the N-MORB in the axial region of the Antarctic-Phoenix Ridge, being far from any known hotspots. (2) The extent of enrichment in incompatible elements in the basalts correlates positively with isotopic ratios of Sr and Pb, and negatively with Nd. (3) The E-type melt compositions have been generated by low-degree of partial melting of an enriched mantle source, after the extinction of the APR. (4) Sub-ridge mantle is not geochemically uniform at shallow level in the asthenosphere. (5) The enriched components in the ambient N-MORB mantle source may exist as a form of highly localized spots or veins.

Acknowledgments. We would like to thank Phillip Kyle for handing this extended abstract.

References

Asimow, P. D., and C. H. Langmuir (2003), The importance of water to oceanic mantle melting regimes, Nature 421, 815-820.

Larter, R. D., and P. F. Barker (1991), Effects of ridge crest trench interaction on Antarctic Phoenix spreading-Forces on a young subducting plate, J. Geophys. Res., 96, 19583-19607.

Livermore, R., J. C. Balanyá, A. Maldonado, J. M. Martínez, J. Rodriguez-Fernández, C. S. de Galdeano, J. G. Zaldívar, A. Jabaloy, A. Barnolas, L. Somoza, J. Hernández-Molina, E. Suriñach, and C. Viseras (2000), Autopsy on a dead spreading center: The Phoenix Ridge, Drake Passage, Antarctica, Geology 28, 607-610.

Niu Y., and R. Batiza (1991), An empirical method for calculating melt compositions produced beneath mid-ocean ridges: Application for axis and off-axis (seamounts) melting, J. Geophys. Res., 96, 21753-21777.

Smith W. H. F., and D. T. Sandwell (1994), Bathymetric prediction from dense satellite altimetry and sparse shipboard bathymetry, J. Geophys. Res., 99, 21803-21824.