

Potential drilling target for solid earth sciences and IODP-Science Plan (2013-2023)

Estimating the rate of mantle flow- age transect of crust formed at the Chile ridge

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Abstract

Flows in the Earth's mantle, due to convection or rise of a plume, are potential driving mechanism of plate motion. The rate of mantle flow, however, has been hardly observed or directly estimated from natural examples. Orihashi et al. (1998) estimated dispersion rate of Afar plume by studying compositions and ages of volcanic products distributed along southern edge of Arabian peninsular (proposal to study the Afar system using IODP vessels was submitted: APL 727). Nevertheless, evidence for a rise of plume accelerating (or decelerating) plate motion has not been reported except for continental rift zones. MORB petrology revealed that the Indian Ocean-type MORBs are widely distributed in the Philippine Sea plate, southern Atlantic and in Southeast Pacific near the Chile ridge subduction zone. This implies a global heterogeneity in the mantle. Global plate motion models, on the other hand, suggests that the Chile ridge migrated eastward and subducted underneath the South American plate, having no evidence of kinematic interaction between internal, moving boundary of the heterogeneous mantle. MORBs in the Chile ridge system are variously enriched. Sherman et al. (1997) attributed the enriched MORB to sub-arc mantle that migrated through a slab window. In this case, transverse flow across the slab window and ridge axes can be expected. We therefore propose to drill a series of shallow holes that form age transects across the ridge axes, aiming to reveal the rate of circulation of the mantle marked by heterogeneity of MORB compositions, and if compositions of MORBs near the Chile ridge subduction zone was influenced by the deep mantle source or sub-ridge processes. Fundamental questions to be answered are: 1) is enriched MORB a fundamental component of a ridge subduction zone? and 2) what is the rate of mantle circulation just below the MOHO discontinuity?

Introduction

Petrological studies of MORBs revealed that the Indian Ocean-type MORBs are widely distributed in the Philippine Sea plate, the southern Atlantic and in the Southeast

Pacific near the Chile ridge subduction zone (Fig. 1). It seems to be possible to draw a boundary that separate the globe into two regions: N-MORB and Indian Ocean-type region. This implies a global heterogeneity of the mantle.

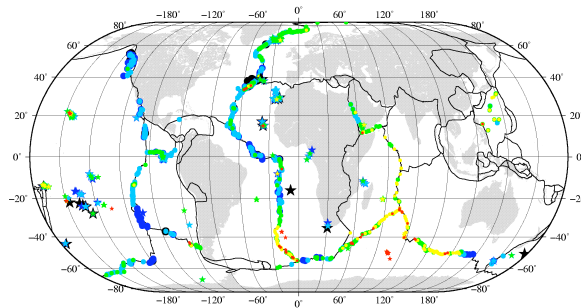


Figure 1: Distribution of MORB compositions compiled and analyzed by Iwamori et al (in prep). Yellow: Indian Ocean-type MORBs, blue: N-MORBs. A hypothesized global internal boundary of mantle is indicated as “front of enriched MORB (2)” in Fig. 5.

In closer view, MORBs near the Chile ridge subduction zone have variously enriched compositions (Klein and Karsten, 1995; Fig. 2). Sherman et al. (1997) attributed the enriched MORB composition to contaminated sub-arc mantle that migrated through a slab window (Fig. 3). In this case, transverse flow across the slab window and the ridge axis can be expected.

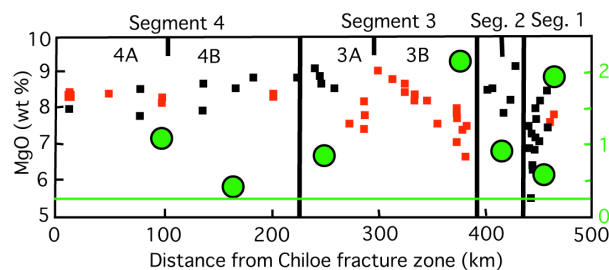


Fig. 2: Compositional variation of MORBs from the Chile ridge system (Sherman et al., 1997). Solid square: MgO contents of N-MORBs, red square: MgO contents of E-MORBs, green circles: Rb/Nb ratio.

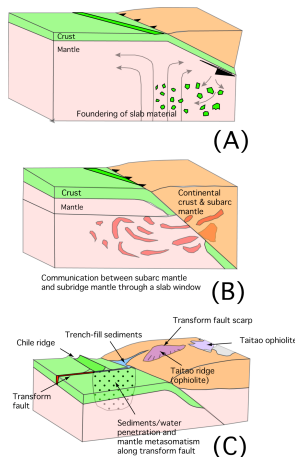
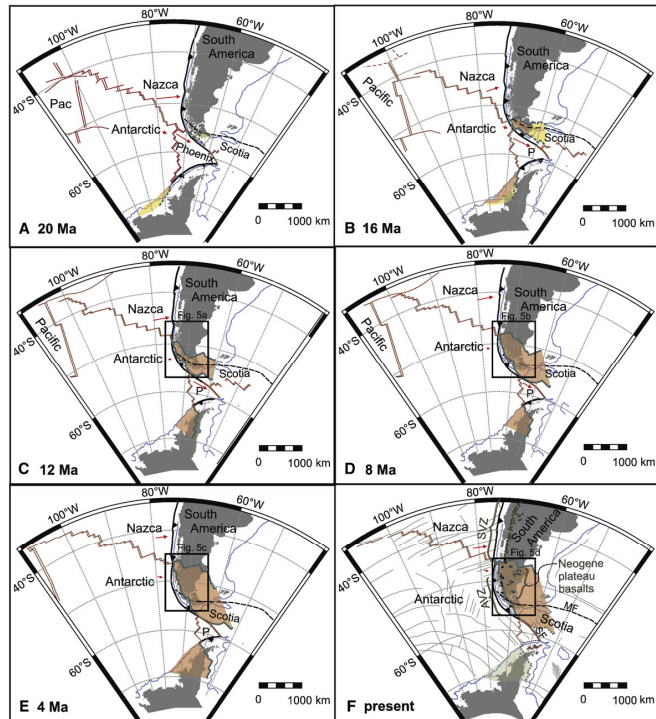


Fig. 3: Models account for the genesis of E-MORBs beneath the subducting ridge. (A) Foundering of slab materials contaminated sub-ridge mantle or (B) metasomatized sub-arc mantle migrated through a slab window (Sherman et al., 1997). Other possibility is (C) subduction of transform ridges. These influences must be restricted in an area indicated as front of enriched MORB (1) in Fig. 5.

Fig. 4: Migration of the Chile ridge illustrated by Breitsprecher & Thorkelson (2009)

Global plate motion models suggested that the Chile ridge migrated eastward and subducted underneath the South American plate (Fig. 4). During the ridge migration, the ridge system must have crossed the boundary between the enriched MORB and N-MORB. The Chile ridge spreading at a rate of 7 cm/y, and



moving eastward at a rate of 9 cm/y for the Nazca plate and 2 cm/y for the Antarctic plate, will provide an excellent opportunity to observe the compositional change of the MORBs underneath the ridge segments. Such spreading ridge with different migration velocities of plates in both sides can be used as a vernier when observing details of the compositional changes through time.

We therefore propose to drill a series of shallow holes that form age transects across several segments of the Chile ridge system aiming to reveal the rate of circulation of the mantle using heterogeneity of MORB compositions, and how any composition of MORBs near the Chile ridge subduction zone is influenced by the deep mantle source or sub-ridge processes. Fundamental questions to be answered are: 1) is enriched MORB a fundamental component of a ridge subduction zone? and 2) what is the rate of mantle circulation just below the MOHO discontinuity? Enriched MORBs are explained by

Testable hypothesis:

If distribution of enriched MORB was controlled by the patterns of global mantle compositions as shown by Iwamori (Fig. 1), then we can test the stability of global mantle circulation system (or how fast the front of the enriched MORB migrated through time) using the age transect strategy and using the samples of the basement

rocks formed at the Segment 3 and/or 4 (Fig. 5). Since the Chile ridge system is approaching to the South American continent through time, the change in composition through time is expected even if the enriched MORB front was not moving at all. Enriched MORB front likely move outward (Fig. 5). The migration rate (if any) would be determined with better resolution at the Chile ridge system than other possible ridges within a fixed time interval. If there was no compositional change through time, then enriched MORB is characteristic of the corresponding ridge segment. A series of drill hole of the crust formed at the Segment 1 (eastward-most subducting ridge segment) would reveal whether enrichment is a fundamental phenomenon in ridge subduction zone or it is characteristic of the corresponding ridge segment.

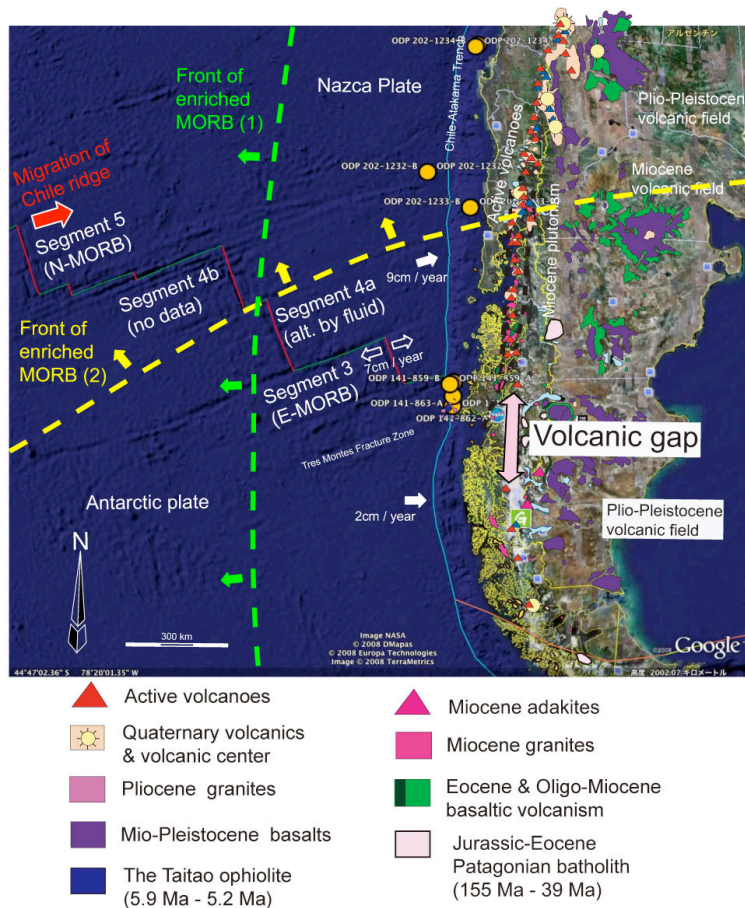


Fig. 5: Tectono-magmatic map near the Chile ridge subduction zone. MORBs from the Segments 1 ~ 3 have variously enriched or contaminated compositions (Klein and Karsten, 1995) and those from the Segment 4a have compositions influenced by fluid (Iwamori, unpublished data). Segment 5 has N-MORB composition. There is no recovery from the Segment 4b. Whether front of the enriched mantle extends toward NS direction (green line) or EW direction (yellow line) is not certain. Compositional variation of the rocks from the Andean volcanoes and/or the Patagonian volcanic field may provide a clue to understand this (study in progress).

Holes along the Tres Montes fracture zone focus on the comparison with the Chile Margin Unit of the Taitao ophiolite (Anma et al., 2006) to understand processes of alteration or contamination along a transform fault zone. This is to test whether a transform fault has significant influence on metasomatism of the sub-arc mantle (Fig. 3).

Drilling strategy:

Drill a series of shallow holes to 200 m-deep of the basement penetration through sediments, along a profile of crust that were formed in the Segment 1 (subducting segment), Segment 3 and Segment 4 of the Chile ridge at 3, 5.6, 9, 12 and 15 Ma. Also drill a shallow hole through 3 Ma and 5.7 to 5.2 Ma crusts along the Tres Montes fracture zone. Data of 5.7 Ma holes are directly comparable with the data for the 5.7 Ma Taitao ophiolite.

Requirement:

There is no data from the Segment 4b. It is most important to fill this gap to proceed this potential proposal. Also seismic profiles that across crusts formed at the Segments 1, 3 and 4 are required.

References

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