



Mantle dynamics and generation of a geochemical mantle boundary along the East Pacific Rise – Pacific/Antarctic ridge



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ABSTRACT

A large-scale mantle compositional discontinuity was identified along the East Pacific Rise (EPR) and the Pacific–Antarctic Ridge (PAR) with an inferred transition located at the EPR 23°S–32°S. Because of the EPR–Easter hotspot interactions in this area, the nature of this geochemical discontinuity remains unclear. IODP Sites U1367 and U1368 drilled into the ocean crust that was accreted at ~33.5 Ma and ~13.5 Ma, respectively, between 28°S and 30°S on the EPR. We use lavas from Sites U1367 and U1368 to track this mantle discontinuity away from the EPR. The mantle sources for basalts at Sites U1367 and U1368 represent, respectively, northern and southern Pacific mantle sub-domains in terms of Sr–Nd–Pb–Hf isotopes. The significant isotopic differences between the two IODP sites are consistent with addition of ancient subduction-processed ocean crust to the south Pacific mantle sub-domain. Our modeling result shows that a trace element pattern similar to that of U1368 E-MORB can be formed by melting a subduction-processed typical N-MORB. The trace element and isotope compositions for Site U1368 MORBs can be formed by mixing a HIMU mantle end-member with Site U1367 MORBs. Comparison of our data with those from the EPR–PAR shows a geochemical mantle boundary near the Easter microplate that separates the Pacific upper mantle into northern and southern sub-domains. On the basis of reconstruction of initial locations of the ocean crust at the two sites, we find that the mantle boundary has moved northward to the Easter microplate since before 33.5 Ma. A model, in which along-axis asthenospheric flow to where asthenosphere consumption is strongest, explains the movement of the apparent mantle boundary.

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1. Introduction

Based on radiogenic isotopes for basalts from the northern East Pacific Rise (EPR), the Pacific mantle was previously considered as a well-mixed mantle reservoir (e.g. Cohen and O'Nions, 1982). However, as the more data became available for the northern EPR (Zindler and Hart, 1986; Prinzhofer et al., 1989; Regelous et al., 1999; Niu et al., 1999; Goss et al., 2010), the southern EPR (Hanan and Schilling, 1989; Bach et al., 1994; Mahoney et al., 1994; Niu et al., 1996; Haase, 2002) and the Pacific–Antarctic ridge (PAR) (Ferguson and Klein, 1993; Castillo et al., 1998; Vlastélic et al., 1999; Hamelin et al., 2010, 2011), it has become clear that the Pacific mantle is compositionally heterogeneous with varying amplitude on all scales. Based on the data from the PAR 66°S–53°S and the EPR, Vlastélic et al. (1999) first suggested the presence of two sub-Pacific mantle domains with a sharp geochemical transition near the Easter island (~25°S). Despite the possible influence of

the Easter hotspot on the East Rift of the Easter Microplate (Haase, 2002; Kingsley et al., 2002), the data on the most depleted basalts (the least hotspot-influenced basalts) from the West Rift and East Rift indicate the presence of northern and southern sub-Pacific domains (Haase, 2002), respectively, as defined by Vlastélic et al. (1999), which corroborates the existence of a mantle geochemical division near the Easter Microplate. The Easter Microplate sits at the location separating the PAR–EPR into shallow (~2450 m) and deep (~2850 m) axial depths to the south and north, respectively (Vlastélic et al., 1999; Small and Danyushevsky, 2003). The Easter Microplate roughly corresponds to the northern boundary of the large low shear wave velocity province (LLSVP) at the base of the lower mantle beneath the south Pacific (Takeuchi, 2007; Iwamori et al., 2010). More recently, after filling the sampling gap between 53°S and 41°S, Hamelin et al. (2011) found a strong isotopic (Nd–Hf–Pb–He) anomaly between 57°S and 41°S, where the basalts have the highest ²⁰⁶Pb/²⁰⁴Pb and the lowest ¹⁴³Nd/¹⁴⁴Nd, ¹⁷⁶Hf/¹⁷⁷Hf and ³He/⁴He ratios along the EPR–PAR. Despite this finding, data between 28°S and 41°S on the EPR–PAR remain limited (Hamelin et al., 2011), therefore interpretations on the nature

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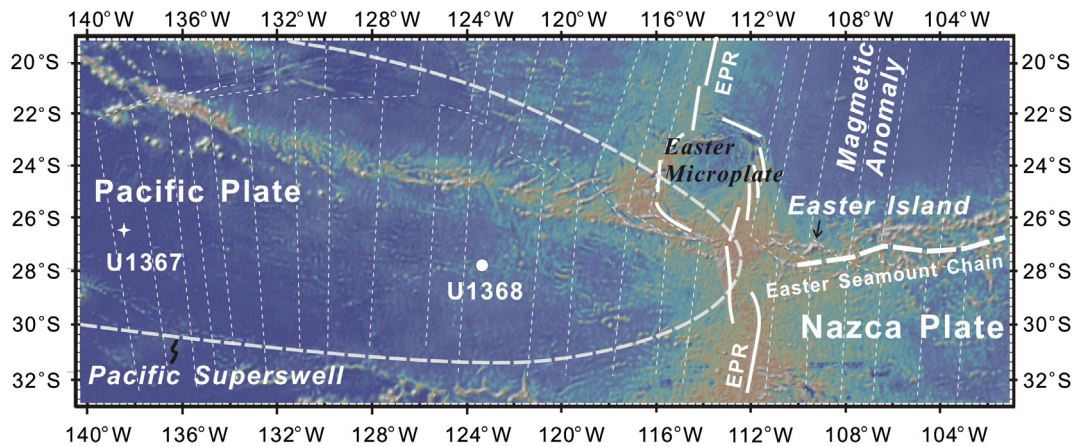


Fig. 1. Map of the central Pacific basin showing locations of IODP Sites U1367 and U1368. The range of the Pacific Superswell is based on Adam and Bonneville (2005).

of the mantle near the Easter Microplate remain highly speculative and debatable.

Several along-ridge mantle compositional discontinuities have been reported, and the Australian–Antarctic Discordance (AAD) is the only one that has been traced off axis in both seafloor morphology and basalt geochemistry (e.g. Kempton et al., 2002). Since the Easter Microplate is considered to be highly influenced by the Easter hotspot (Haase, 2002; Simons et al., 2002; Kingsley et al., 2002, 2007), it is not straightforward to recognize possible along-axis isotopic variation as a result of asthenospheric mantle change in the vicinity of the Easter Microplate. As a result, to trace the possible mantle compositional boundary at the EPR near 28°S–30°S, we choose off axis drilling sites to accomplish this, i.e., crustal samples from IODP Sites U1367 and U1368, drilled off axis at ~33.5 and ~13.5 Ma respectively.

2. Geological setting and sampling

IODP Sites U1367 and U1368 drilled into the oceanic crust that was accreted from the mantle at latitudes near the Easter Microplate on the EPR (Fig. 1) (D'Hondt et al., 2011). All samples, except for sample U1368F-2R-4 (86/90), are aphyric/slightly phyric (plagioclase plus pyroxene). The sample U1368F-2R-4 (86/90) is slightly phyric with only olivine as phenocrysts. The crust at Site U1367 was accreted at ~33.5 Ma (Magnetic Chron 13n). The crust at Site U1368 was accreted at ~13.5 Ma (Magnetic Chron 5n) from the EPR (Okal and Bergeal, 1983; Wilder, 2003). Reconstruction models of the EPR spreading history (Okal and Bergeal, 1983; Wilder, 2003) suggest that the ocean crust at IODP Sites U1367 and U1368 was formed before the Easter mantle plume/EPR interaction. Thus, the Easter plume may not have influenced the formation of the crust at Sites U1367 and U1368.

3. Methods

Nine and twelve basalt samples from Sites U1367 and U1368, respectively, were selected for analyses of major and trace elements and Sr–Nd–Pb–Hf isotopes. Only the freshest/minimally altered samples from Site U1367 and Site U1368 were selected for preparation. These samples were stripped of visibly altered parts and crushed into <3-mm particles. The particles having visibly altered parts were picked out carefully under a binocular leaving only the freshest particles without visible alteration for preparation. The sample grains were cleaned ultrasonically in distilled water for 30 min and were washed with distilled water and left to dry at 60 °C for 12 h before they were pulverized with an agate mortar.

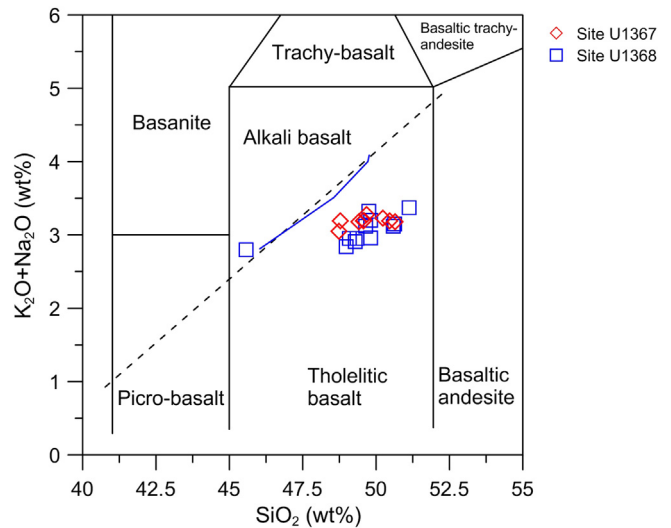


Fig. 2. Chemical classification of Sites U1367 and U1368 basalts on total-alkali and silica (TAS) diagram. The blue solid line indicates the low pressure (1.0 kbar) fractionation path of the alkali basalt. The COMAGMAT (3.57) (Almeev et al., 2007) program was used for the calculation of the fractionation path.

Major elements and some trace elements (Cr, Sr and V) were analyzed on fused glass discs with an Axios sequential X-ray Fluorescence Spectrometer at the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGG-CAS). Trace elements were analyzed using an ICP-MS (Agilent 7500) at Peking University. For analyses of Sr–Nd–Pb–Hf isotopes, sample powders were leached in hot 6 N HCl for ~30 min to remove any potential seawater contamination. The Sr isotope ratios were determined on a Finnigan MAT 262 thermal ionization mass spectrometer equipped with a multi-collector. Nd and Pb isotopes composition analyses were carried out on a Nu instrument MC-ICP-MS. Analyses for Sr–Nd–Pb isotopes were completed in the Institute of Geology Chinese Academy of Geological Sciences. Analyses for Hf isotopes were completed using a MC-ICP-MS (Neptune Plus) at Nanjing University. The particular methods for the above analyses and data for standard reference materials are given in Supplementary 1.

4. Results

4.1. Major and trace element compositions

Major and trace elements are given in Supplementary 2. As indicated by low total alkalis at moderate SiO₂ (Fig. 2) and low incompatible trace elements at moderate MgO (4.94 wt%

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