Petit-spot lava fields off the central Chile trench induced by plate flexure

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In 2009, petit-spot submarine volcanoes were discovered off the oceanward slope of the central Chile trench, offshore from Valparaiso, Chile, at around 33°S. Ar–Ar dating of mugearite and alkali-basalt from the volcanoes yields ages of 10.11 ± 0.22 Ma and 6.69 ± 0.88 Ma, respectively. Back-calculations of plate motion along the present absolute movement direction of the Nazca Plate, conducted using the Ar–Ar age data, indicate that eruption occurred above a zone of plate flexure. The back-calculation results suggest that the mugearite was erupted at a flexural arch prior to arrival at the active site of the Juan Fernández hotspot. In contrast, the alkali-basalt was erupted on a plate flexure at a site of interaction between a flexural moat and an outer-rise area, where the source material was probably influenced by the Juan Fernández hotspot. The geochemistry of the lavas supports this interpretation because the concentration ratios of various rare earth and other trace elements in the mugearite are different from those of the alkali-basalt and Juan Fernández hotspot lavas. Consequently, petit-spot melts could reflect the composition of source materials below the plates at sites of plate flexure.

Keywords: petit-spot, Chile trench, alkali-basalt, Nazca plate, Juan Fernández hotspot

INTRODUCTION

Submarine volcanoes were recently discovered during shipboard acoustic surveys and associated sampling of the subducting Pacific Plate off NE Japan and at the Hawaiian Arch, approximately 300–500 km north of the Hawaiian Islands (Clague et al., 1990; Hirano et al., 2006). Both of these areas are intra-plate locations where the oceanic lithosphere is flexing in response to plate subduction and to loading related to the presence of seamounts, respectively. This flexing is dominantly elastic (McAdoo and Martin, 1984; Watts and Zhong, 2000), but it may also induce brittle fracturing of the bending plate (Hirano et al., 2006). Lavas at both localities are alkaline basalts that contain extremely high concentrations of volatiles and incompatible elements, implying a low degree of partial melting of the mantle. The high volatile content of these magmas prior to eruption is indicated by their remarkably high vesicularity, despite the fact that they were erupted in submarine conditions. Such magmas are believed to be the result of tectonic deformation of a flexed plate, inducing melt-ascent and driving collection of already existing partial melts (Valentine and Hirano, 2010). The location of the tiny submarine volcanoes is, therefore, an important indicator of the stress field of the plate and provides information on the geochemical composition of the mantle below the plate (Hirano, 2011).

The monogenetic petit-spot volcanoes of the NW Pacific Plate represent another kind of volcanism in tectonic settings (Hirano et al., 2006). The petit-spot volcanism, in contrast to hotspot volcanoes, does not derive any heat supply from the deep mantle, even though it occurs in an intra-plate setting. The North Arch volcanic field of the Hawaiian Arch, in contrast, is geochemically influenced by the Hawaiian mantle plume (Frey et al., 2000), although the site is distant from the Hawaiian plume center (currently below the active Kilauea volcano and Loihi seamount, approximately 600 km from the North Arch field). Although the generation of these submarine volcanoes is influenced by cracks in the lithosphere that propagate to the surface, it remains uncertain whether these petit-spot volcanoes have a genetic relationship with the areas where the underlying plate has flexed and fractured. This study presents results from a research cruise undertaken along the oceanward slope of the Chile trench off Valparaiso during March 2009, using the research ship...
R/V Mirai, which aimed to find young petit-spot volcanoes at the region where the Nazca plate is flexing in response to subduction at the Chile trench (Fig. 1).

**GEOLOGICAL AND TECTONIC SETTINGS**

The subduction of the Nazca Plate (which underlies the southeastern Pacific Ocean) is under the South American continent has resulted in the development of the Peru–Chile trenches and subduction of mid-oceanic and hotspot-related ridges. The Juan Fernández seamount chain lies on the Nazca Plate and is orientated semi-perpendicular to the Peru–Chile trenches. The seamount chain is currently being subducted, with gravity anomalies associated with the seamounts forming a flexural arch and mountain along the chain oriented WSW to ENE (Fig. 1). The present study area, off Valparaíso, central Chile, covers the oceanward slope of the Chile trench and the southeastern parts of the O’Higgins Seamount, found at the eastern tip of the Juan Fernández seamount chain where the 35.5–36.5 Ma Nazca Plate is being subducted into the Chile trench (Yáñez et al., 2001).

The Domingo and Friday Seamounts are believed to be active seamounts associated with the modern day Juan Fernández hotspot. It should be noted that these seamounts have not been dated but are formed of alkali basalts highly enriched in incompatible elements (Devey et al., 2000). The two major subaerial volcanoes on the Juan Fernández seamount chain, Isla Alexander Selkirk and Isla Robinson Crusoe, are located approximately 100 km and 280 km from Domingo Seamount, respectively. Basalts from Isla Alejandro Selkirk have been dated using K–Ar methods to 1.0 ± 0.3 Ma (Booiker et al., 1967), and to 1.0 ± 0.1 and 2.4 ± 0.1 Ma (Stuessy et al., 1984). In comparison, basalts from Isla Robinson Crusoe give K–Ar ages of 3.3 ± 0.8 Ma (Booiker et al., 1967), 3.8 ± 0.2 and 4.2 ± 0.2 Ma (Stuessy et al., 1984), and 4.0 ± 0.2 Ma (Baker et al., 1987) (Fig. 1a). The O’Higgins group dominates the eastern end of the Juan Fernández seamount chain and consists of O’Higgins Guyot, O’Higgins Seamount, and O’Higgins Ridge, on the outer-rise of the Chile trench. Ar–Ar total fusion ages of dredge samples from O’Higgins Guyot give an age of 8.5 ± 0.4 Ma (preliminary report in von Huene et al., 1997), whereas magnetic signals suggest that O’Higgins Seamount was formed around 9 Ma (Yáñez et al., 2001). Therefore, the Juan Fernández seamount chain shows a typical hotspot track with an age distribution correlated with the direction of plate motion (Fig. 1a).

The oceanward slope of the Chile trench is characterized by linear horst and graben structures and seafloor spreading fabrics (Ranero et al., 2005), features that are commonly present in subducting ocean floors. A prominent difference between the study area and other equivalent parts of the subducting plates is the presence of faults oblique to the trench axis (Fig. 2). The azimuth of these oblique faults is parallel not only to the Juan Fernández seamount chain but also to the Challenger Fracture Zone, which originates from the Juan Fernández microplate and the Chile Ridge. Ranero et al. (2005) speculated that the lithosphere in the study area was weakened by loading associated with the Juan Fernández seamount chain, leading to the bending of the plate due to plate subduction and initiating volcanism associated with the seamount chain. Alternatively, Kopp et al. (2004) suggested that the fracture zones were reactivated during plate bending prior to the initiation of subduction, because remarkable fractures are only found on the trench side of the Juan Fernández seamount chain. In addition, many hummocks are present to the southeast of the O’Higgins group between 33°S and 73°W, and dominate significant parts of the study area, as apparent on the faulted abyssal plain by SeaBeam sonar bathymetric mapping (Fig. 2).

**SAMPLES AND METHODS**

R/V Mirai MR08-06 Leg 1 cruise was conducted as part of the “South Pacific Ocean Research Activity (SORA)" research project funded by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) (Abe, 2009). The cruise lasted from January 16 to March 14, in 2009, with the R/V Mirai sailing from Hachinohe, Japan to Valparaíso, Chile, and calling at Papeete, Tahiti, on February 5. During the cruise, a multibeam survey system (L-3 Communications, SeaBeam Instruments Inc.) was used to generate data and to produce wide-swat contour maps and acoustic backscatter images of the ocean floor in the range of 73°40′ W to 72°53′ W, and 32°53′ S to 33°35′ S. These data were subsequently filtered, gridded, and plotted using Generic Mapping Tools (Wessel and Smith, 1998) and MBSystem (Caress and Chayes, 1996). Two dredges were also undertaken during the cruise in order to sample rocks from the tiny knolls (dredge D08) and the fault escarpment that truncates the volcanic edifices (dredge D10). At the knoll and escarpment, the acoustic reflectivity is more than 10 times higher than the reflective values of the surrounding abyssal plain, indicating that the lava flows are exposed at the seafloor (Hirano et al., 2008) (Fig. 3). Highly vesicular rocks were obtained from the D08 site, with non-vesicular lavas sampled at D10. Rocks from both sites are fresh clinopyroxene-olivine-bearing basalts with quenched features associated with eruption of lava lobes and breccias within pelagic sediments. Bubbles in the approximately 1.5-cm-thick quenched glass rinds within sample D08-05 decretipated when brought onboard the R/V Mirai.

Major element compositions of fresh glass samples from both sites were determined by electron microprobe...
Fig. 1. Maps of study area. a) and b): Bathymetry and satellite gravity data for the central Chile trench and Juan Fernández seamounts, respectively, using data from Amante and Eakins (2009). The pink dotted line shows the back-calculated positions of eruptive sites on D08 and D10 (around yellow stars) from the sampling site (white star) based on their Ar–Ar age results. In b), the positive gravity anomaly appears along the flexural arch and outer-rise.

Fig. 2. Bathymetry of the study area within the white box in Fig. 1a. The boxes enclosed by dotted lines show the areas of Fig. 3 around sampling sites. The thick arrow indicates the azimuth of trench axis around the study area.
Fig. 3. Bathymetry and acoustic reflectivity around sampling site D08 of a) and b), and D10 of c) and d), respectively. Red lines show the sampling sites.

Fig. 4. Geochemical compositions. a): Total alkali (K₂O+Na₂O) vs. SiO₂ of harker diagram. Red and blue plots show the samples D08 and D10, respectively. Squares show the plot of samples for Ar–Ar dating of bulk composition analyzed by XRF. b): Spidergram of incompatible elements in quenched glass of lavas. Red and blue diagrams show the samples D08 and D10, as well. Normalized values are after Sun and McDonough (1989). In a) and b), the open circles and thin lines show the composition of Friday and Domingo seamounts after Devey et al. (2000).
### Table 1. Major and trace element composition of samples

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<th>D08-03</th>
<th>D08-05</th>
<th>D08-06</th>
<th>D08-07</th>
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Petit-spots off the Chile trench 253
Table 2. Ar–Ar age results. All errors are given as 1σ uncertainties.

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<tr>
<th>Sample</th>
<th>39Ar/36Ar (%)</th>
<th>37Ar/36Ar (%)</th>
<th>38Ar/36Ar (%)</th>
<th>39Ar/39Ar (Ma)</th>
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<td>600</td>
<td>3.408 ± 0.007</td>
<td>0.01 ± 0.02</td>
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<td>0.00248 ± 0.00071</td>
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<td>700</td>
<td>3.162 ± 0.005</td>
<td>0.08 ± 0.04</td>
<td>0.56 ± 0.008</td>
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<td>800</td>
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<td>0.14 ± 0.11</td>
<td>0.66 ± 0.02</td>
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<td>0.88 ± 0.04</td>
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<td>1.12 ± 0.089</td>
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<td>2.10 ± 0.12</td>
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<td>0.71 ± 0.71</td>
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*After corrections for interfering isotopes from Ca and K.

Samples for Ar–Ar dating were prepared by separating groundmass material after crushing it to sizes between 100 and 300 µm. The separated groundmass material was then wrapped in aluminum foil along with K2O biotite, K2SO4, and CaF2 flux monitors. Any amorphous (e.g., quenched glass) parts of rocks were removed prior to Ar–Ar dating because 39Ar may move from one phase to another in a process known as “recoil.” This can create a disturbed age spectrum when 39Ar is created from 39K in amorphous material through interaction with fast neutrons during irradiation of the sample. Samples were irradiated for 24 hours in the Japan Research Reactor No. 3 (JRR-3) with a thermal power of 20 MW. Ar extraction and isotopic analyses were undertaken at the Radioisotope Center, University of Tokyo, Japan. During incremental heating, gases were extracted in 10 to 12 steps between 600°C and 1500°C. The analytical methods used are the same as those used by Ebisawa et al. (2004).
**RESULTS**

The major-element compositions of fresh volcanic glass indicate that the lavas are mugearites (D08) and alkali-basalts (D10), most of which have more differentiated compositions than the lavas from Friday and Domingo Seamounts (Fig. 4a). Spidergrams for both samples have different patterns, and in general, incompatible and light rare earth elements (LREEs) are present in higher concentrations in D08 lavas than in the D10 samples (Fig. 4b). Data were measured by averaging 3–10 points. Analytical uncertainty is 1–2% for major elements. The resulting precision for trace elements, as checked by a standard reference material (analyzed as an unknown), was better than 10% (2σ) for most elements (Table 1).

Ar–Ar age results of D08-03 and D10-05 are shown on Table 2. A well-defined plateau age of 10.11 ± 0.22 Ma was obtained for D08-03 using an atmospheric value for the initial 40Ar/36Ar ratio (Fig. 5). In comparison, sample D10-05 has a plateau age (with large error steps) of 8.32 ± 0.68 Ma, which is 64% of released 39Ar and includes 4 heating steps. However, this age is probably artificially old due to the presence of excess 40Ar, as indicated by the 40Ar/36Ar ratio of 308.8 ± 3.3, which is a value higher than the atmospheric ratio of 295.5 in the inverse isochron. The 6.69 ± 0.88 Ma age derived from the inverse isochron thus appears to be the best age estimate for sample D10-05 (Fig. 5).

**DISCUSSION**

During the initiation of subduction an outer-rise forms, bending the lithosphere to form a downgoing slab and associated oceanic trench (e.g., Caldwell et al., 1976; Watts and Talwani, 1974). The flexural behavior of the subducting lithosphere was studied using bathymetric data of oceanic trenches by Levitt and Sandwell (1995). They showed that, according to plate subsidence models for the Nazca Plate (Parsons and Sclater, 1977), the ~40 Ma Chile trench should be at a depth of 4.7 km below sea level. In reality, a discrepancy of 700–800 m between this modeled depth and the actual depth of the outer-rise cannot be explained by normal subsidence models in the study area (Fig. 2); this discrepancy is most likely due to the convex upward flexure at the pre-subducting slab, as indicated by high positive gravity anomalies adjacent to the Chile trench (Smith and Sandwell, 1997). In the central Chile trench, offshore from Valparaíso, the Juan Fernández seamount chain is subducting along with the underlying Nazca Plate. The Nazca Plate in the area is flexing due to seamount loading, forming a flexural arch and moat, with associated positive and negative gravity anomalies, respectively (Fig. 1b). Therefore, at the intersection of the seamount chain and the trench, the flexural seamount loading is associated with the flexural outer-rise of the Chile trench. Kopp et al. (2004) suggested that plate flexure at the eastern tip of the Juan Fernández seamount chain may be masked by outer-rise flexure. Similarly, we note that the flexural moat associated with loading caused by the Juan Fernández seamount chain seems to disappear at the outer-rise (Fig. 1b).

Given that the D08 and D10 sampling sites are a few tens of kilometers from the O’Higgins group seamounts...
chain, the lavas appear to follow the flexural moat to the
southernmost part of the island sometime after 10.11 ± 0.22
Ma and 6.69 ± 0.88 Ma at the two sites, respectively (Fig.
1). These dates are not within the error margin, indicat-
ing that the volcanic center in the area may be related to
several different tectonic and magmatic events during the
last 10 million years. Consequently, it is not possible to
correlate the lavas with the tectonic activity. The Chal-

engert Fracture Zone on the oceanward slope of the Chile
| 119x378 |
| HREEs are indicative of the metasomatism of CO2-rich
| depletion in Zr, Hf, and Ca, and enrichment in Al and
| the Domingo lavas, Devey et al. (2000). Assuming the Juan Fernández
| hotspot track was fixed over the last 10 million years, the
| D08 lavas, dated at 10.11 ± 0.22 Ma, could have erupted on the
| flexural arch of the western portion of the contempor-
| ary hotspot (Fig. 1) at the present Friday and Domingo
| seamount sites, approximately 1 million years before the
| eruption of O’Higgins Guyot lavas at 10.4 Ma (von Huene et al., 1997).
| In comparison, the 6.69 ± 0.88 Ma age of the
| D10 lava indicates eruption far to the east of the con-
| temporary hotspot, where the flexural moat is negated by
| flexing of the outer-rise plate (Fig. 1). The drastic change from concave bending associated with the flexural moat to convex flexure of the outer-rise was probably enough to allow magma to rise to the surface during brittle fractur-
| ing of the plate.

| The spidergram patterns (Fig. 4b) of D08 lavas, espe-
| cially the heavy rare earth elements (HREEs) Zr and Hf, are dissimilar to those of lavas from the Friday and
| Domingo Seamounts, which are zero-aged seamounts derived from the Juan Fernández hotspot (Devey et al.,
| 2000). In contrast to D08, the D10 samples show similar
| spidergram patterns to the seamounts in terms of incom-
| patible elements such as large ion lithophile elements (LILEs) and light rare earth elements (LREEs) (Fig. 4b),
| although they are not depleted in Zr and Hf. Therefore, the geochemical data suggests that the D08 and D10 mag-
| mas underwent different melting processes. In a study of the Domingo lavas, Devey et al. (2000) suggested that depletion in Zr, Hf, and Ca shows enrichment in Al and HREEs are indicative of the metasomatism of CO2-rich kimberlinitic melt that reacted with harzburgite mantle. The non-depleted nature of Zr and Hf in the present lavas (D08 and D10) indicates a different process than mantle-
| metasomatism during magma ascent, as proposed by
| Devey et al., 2000. D10 lavas were derived from mag-
| mas with a source that was originally similar to the source of lavas from the Domingo and Friday Seamounts, but subsequently underwent a higher degree of partial melt-
| ing (Fig. 4b). The HREE patterns of the D08 lavas, on the other hand, are more depleted than the Friday,
| Domingo, and D10 lavas, indicating a different source than that of the Juan Fernández hotspot lavas. This view
| is supported by the Ar–Ar age data because the site of
| eruption of D08 is estimated to have been on the plate
| prior to its arrival at the Juan Fernández hotspot (Fig. 1).

| Therefore, the geochemical characteristics of petit-spot
| melts could reflect the source materials at the site of plate
| flexure.

| The petit-spot monogenetic volcanoes of the NW Pa-
| cific Plate were first reported by Hirano et al. (2006),
| who proposed that magmas could escape along plate fractures within the flexed outer-rise of the Pacific Plate.
| Based on their model, such tectonically induced volca-
| noes could be ubiquitous in ocean basins if a mantle source
| for the magmas exists under the tectonic plates, ready to
| escape to the surface whenever and wherever the oceanic
| plate flexes. The tiny volcanoes of the Chile trench and
| Juan Fernández hotspot systems could be related to the development of a flexural arch prior to the arrival at a
| hotspot, or related to the interaction between a flexural
| moat and bending associated with an outer-rise, leading
| to the release of geochemically influenced magma by any
| materials below the plate.

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| REFERENCES

| Abe, N. (2009) MR08-06 Leg 1 Cruise Report, Studies on geo-
| physics and paleoceanography in the South Pacific, Japan
| jp/cruisedata/mirai/e/MR08-06_leg1.html

| Amante, C. and Eakins, B. W. (2009) ETOPO1 Arc-Minute
| Global Relief Model: Procedures, Data Sources and Analy-
| sis. NOAA Technical Memorandum NESDIS NGDC-24, 19
| pp. Available at http://www.ngdc.noaa.gov/mgg/global/
| global.html

| Baker, P. E., Gledhill, A., Harvey, P. K. and Hawkinsworth, C.
| J. (1987) Geochemical evolution of the Juan Fernandez Is-

| Palaeomagnetism and age of rocks from Easter Island and

| (1976) On the applicability of a universal elastic trench pro-

| Caress, D. W. and Chayes, D. N. (1996) Improved processing of
| Hydrosweep DS Multibeam Data on the R/V Maurice


