# Initial findings of post-cruise research on IODP Expedition 352 cores II: Radiogenic isotopes

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The isotopic compositions of volcanic rocks recovered during IODP Expedition 352 vary significantly over time reflecting changes in magma sources as the nascent arc system developed. Fore-arc basalts (FAB) drilled at the two deepest sites, U1440 and U1441, were generated during near trench seafloor spreading after subduction initiation. These lavas have Nd and Hf isotopic ratios in the range of depleted mid-ocean ridge and back-arc basin basalts from the Indian and Philippine Sea plates. The FAB sample with the most depleted incompatible trace element composition has the highest Nd and Hf isotope ratios, indicating that the mantle may have been variably depleted in incompatible trace elements long before it was involved in melting to produce FAB. Pb isotopes in most FAB also are similar to those of Indian Ocean mid-ocean ridge basalts. However, some have Pb isotopic compositions trending towards values of the Pacific basaltic crust, which we attribute to alteration by fluids from the subducted Pacific plate. Os isotopes are radiogenic compared to primitive mantle, similar to Indian Ocean MORB. Sites U1439 and U1442 drilled a diverse sequence of boninites upslope from the FAB sites. Nd, Hf, and Pb isotopic ratios for low-Si boninites (LSB), which make up the lower 4/5 of the cores at these sites, plot between FAB and subducting Pacific basaltic crust. High-Si boninites (HSB) atop these sites have a narrow range of Hf isotopic compositions similar to those of the lowest values for LSB, but trend towards lower Nd isotope values. Pb isotopes for these lavas plot between those of Pacific basaltic crust and subducting sediments. Both LSB and HSB record a range of Os isotopes from depleted to mildly radiogenic values. The Nd-Hf-Pb isotopic compositions of LSB can be explained by flux melting of a strongly depleted mantle source involving a subduction component largely derived from basaltic crust. The younger HSB are generated by extreme degrees of melting of harzburgitic mantle, with incompatible trace elements and Nd, Hf, and Pb isotopes modified by fluids and melts derived from subducted basalt and sediment. Eruption of boninites began about the same time as volcanism transitioned from rapid sea-floor spreading to focused edifice building.[1] The enrichment of elements from the subducting slab in all boninites including both relatively low-temperature fluid soluble elements such as Pb, and relatively high-temperature melt-soluble elements such as Hf, is consistent with the boninite genesis in the nascent Izu-Bonin-Mariana subduction system beginning at the time of first slab melting or first formation and subsequent melting of melange diapirs.[2]

[1]Reagan et al. (2017) Intl. Geol. Rev., doi:10.1080/00206814.2016.1276482.
[2]Marschall and Schumacher (2012) Nature Geosci., doi: 10.1038/NGEO1634.

Keywords: Subduction intitiation, Isotope geochemistry, basalt, boninite, Ogasawara

 

# Petrogenesis of Low-Si Boninites Drilled from IBM Fore-arc by IODP Expedition352: implications from LA-ICP-MS study

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We discuss petrogenesis of Low-Si boninites with high Cr content (500-1500 ppm) obtained from IODP Holes U1439C and U1442A in terms of whole-rock major and trace element compositions, trace element compositions of minerals, and Pb isotopic compositions ($^{208}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$) of groundmass. We conducted electron probe micro-analyzer (EPMA) and laser-ablation multiple collector inductively coupled plasma mass spectrometry (LA-MC-ICP-MS) analyses as well as X-ray fluorescence spectrometer (XRF) and ICP-MS analyses on low-Si boninites and FABs in order to reveal the petrogenesis of these rocks.

Many low-Si boninites with high Cr content (500-1500 ppm) contain reversely-zoned olivine and clinopyroxene phenocrysts: Fo# [=Mg/(Mg+$Fe^{2+}$)$_{mol}$] of olivine varies from ~87 at core to >90 at rim, and Mg# [=Mg/(Mg+$Fe^{2+}$)$_{mol}$] of clinopyroxene varies from < 83 at core to >89 at rim. Measured $^{207}Pb/^{206}Pb$ (0.823–0.842) and $^{208}Pb/^{206}Pb$ (2.02–2.06) of boninites' groundmass from Expedition 352 are similar to the reported $^{207}Pb/^{206}Pb$ (0.814–0.839) and $^{208}Pb/^{206}Pb$ (2.021–2.063) of boninites from Izu-Bonin and Mariana (IBM) fore-arcs. Low-Si boninites with intermediate Cr content (500-800 ppm) show higher $^{207}Pb/^{206}Pb$ (0.828–0.842) and $^{208}Pb/^{206}Pb$ (2.035–2.063) than those with the highest Cr content (~1400 ppm) ($^{207}Pb/^{206}Pb$ ~ 0.827–0.831 and $^{208}Pb/^{206}Pb$ ~ 2.042) but lower than the reported $^{207}Pb/^{206}Pb$ (0.830–0.856) and $^{208}Pb/^{206}Pb$ (2.055–2.097) of FABs from IBM.

Low-Si boninites with high Cr content show positive correlation between Zr/Ti and Cr content, which is hard to reproduce simply by differences in the degree of melting, fractional crystallization or crystal accumulation. One plausible mechanism to reproduce the geochemical variations observed for low-Si boninites with high Cr content is mixing between low-Si boninite with the highest Cr content and FAB. The intermediate $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ of low-Si boninites with intermediate Cr content as well as the presence of reversely-zoned clinopyroxene phenocrysts support mixing model, which can also reproduce variations in published whole-rock trace elements and isotope compositions of boninites and FABs.

Keywords: boninite, forearc basalt, Izu-Bonin-Mariana

 

# Evolution of the proto-Izu-Bonin-Mariana arc volcanism: Constraints from statistical analysis on geochemical data of melt inclusions

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IODP Expedition 351 "Izu-Bonin-Mariana (IBM) Arc Origins" drilled volcaniclastic sediments deposited immidiately after subduction initiation and the inception of island arc volcanism at ~52 Ma around Site U1438 in the northwest margin of the Philippine Sea Plate. In order to unveil the magmatic history of the proto-IBM arc, we have analyzed major and volatile elements (S and Cl) of 339 melt inclusions from Unit III (30-40 Ma), Site U1438, which record magmatic evolution of island arc from 40 Ma to 30 Ma. Clinopyroxene- and plagioclase-hosted melt inclusions are diverse in composition, ranging from low- to high-K series basalt through rhyolite. These melt inclusions were recovered from volcaniclastic sedimentary cores and thus can be a mixture of material derived from several volcanic centeres. In order to better link the melt inclusions with the magmatic evolution of the proto-IBM arc, we performed statistical analysis (K-means cluster analysis) on geochemical data of melt inclusions.

After performing cluster analysis, melt inclusion data were separated into 6 clusters termed Clusters 1 to 6. Four clusters (Clusters 1, 3, 4 and 5) are composed of basaltic to andesitic melt inclusions. Geochemical trends of these four clusters can be explained by fractional crystallization from respective primitive melts at $f_{O2}$=NNO+1. Variations in the degree of partial melting and dissolved $H_2O$ concentration in melt are necessary to fully reproduce geochemical variations of melt inclusions. Cluster 1 melt inclusions (medium-K tholeiitic series) and Cluster 5 melt inclusions (calc-alkaline high-Mg andesites) are independent. Cluster 5 melt inclusions could be derived from partial melts of depleted mantle, which disappeared at ~37 Ma. Cluster 1 melt inclusions could be derived from partial melts of replenished fertile mantle, which occur throughout Unit III but became dominant after disappearance of Cluster 5 melt inclusions at ~37 Ma. Clusters 3 and 4 melt inclusions steadily occur throughout Unit III. Cluster 3 melt inclusions are characterized by higher S concentrations, which would be derived from partial melts of metasomatized mantle by S-rich slab fluids. Cluster 4 melt inclusions are characterized by higher concentrations of Cl and $K_2O$, which would be derived from partial melts of metasomatized mantle by Cl- and K-rich slab fluids. Besides four clusters reflecting heterogeneity of the mantle wedge arc magma source, other two clusters are identified. Cluster 2 is characterized by extremely high Cl concentration (up to 1 wt.%) and can be explained as Cluster 1 melts being assimilated by brine. Cluster 6 is composed of silicic melt inclusions ranging from dacite to rhyolite.

Identification of subgroups of melt inclusions as summarized above cannot be made by conventional graphical approach using two-dimensional diagrams, demonstrating usefulness of introducing statistical approach into geochemistry.

Keywords: Izu-Bonin-Mariana volcanic arc, Amami Sankaku Basin, Kyushu-Palau ridge, Melt inclusion, Statistical analysis

 

# Volcanic Ashes Recovered by IODP Expedition 350 Site U1436 in the Izu Arc: A Prologue of Submarine Caldera Formation?

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International Ocean Discovery Program (IODP) Site U1436 (32°23.88' N, 140°21.93' E) lies 1,776 m below sea level and about 60 km east of the arc front volcano Aogashima, and was drilled as a geotechnical survey for proposed D/V *Chikyu* drilling at Site IBM-4. Coring at Site U1436 recovered a 132 m record of Quaternary explosive volcanism in the Izu arc. Because the prevailing wind blows from west to east across the Izu arc, the forearc is a repository of medial and distal aerially dispersed ashes and tuffs from Izu and Japan, as well as eastward flowing density currents from the frontal arc. Effusive eruptive products (e.g., lavas) are better preserved on the frontal arc islands, while deep marine depocenters form a complement, by chiefly preserving products from explosive eruptions. However, which volcano or volcanoes did these ashes erupt from? Could the ash record at Site U1436 be nothing but a haphazard collection of Izu arc volcanoes?

There are several interesting features of Site U1436 cores.

1) The biostratigraphic datums indicate a possible hiatus between 66 mbsf and 74 mbsf. The 66 m of the cores above the hiatus provides a nearly complete record of the Late Pleistocene (< 0.91 Ma). They show higher linear sedimentation rates (LSRs) and mass accumulation rates (MARs) than the lower parts below the hiatus (> 1.5 Ma).

2) Ash fallout and volcaniclastic flow deposits (~150 intervals) are present at Site U1436. The majority of tephra fall layers at Site U1436 are from volcanoes of the Izu volcanic front as well as from mainland Japan (Schindlbeck et al., pers. comm.).

3) Site U1436 is bathymetrically isolated from all Quaternary volcanic front volcanoes through submarine troughs and edifices except for Higashi Aogashima caldera. Therefore, Higashi Aogashima caldera is the only likely source for eruption-fed density currents at Site U1436

4) One distinctive interval of black ash (~55 mbsf, 0.75 Ma) is comprised of glassy shards of basaltic andesite (~55 wt% $SiO_2$) that comprise an extension of the dominantly basaltic compositional array of Aogashima volcano (major and trace elements). The evolution of magma chemistry of this black glassy ash and its possible Higashi Aogashima caldera origin are consistent with the hypothesis of submarine rhyolite caldera formation in the Izu arc by Tamura et al. (2009) as follows. Rhyolite calderas have no mantle roots beneath the crust. Instead, Tamura et al. (2009) proposed that dikes from the adjacent basalt volcanoes provide the heat source to partially melt the surrounding crust to produce rhyolite magmas. Thus, dikes from Aogashima volcano and their fractional crystallization may have resulted in andesitic magmas and transferred latent heat to the crust. They could be the heat source that produced the rhyolites and resulting Higashi Aogashima caldera.

Tamura, Gill, Tollstrup et al. (2009). Silicic Magmas in the Izu-Bonin Oceanic Arc and Implications for Crustal Evolution. *Journal of Petrology* **50**, 685-723.

 

Keywords: Higashi Aogashima Caldera, Izu arc, rhyolite, submarine caldera, IODP

 

# Toward achieving the “100% recovery rate” of information in deep, hard rock drill sites using physical properties logging

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Borehole informatics has been a powerful approach to investigate drilled hard rock formation especially where core recovery operations are strategically not planned and/or core recovery rates can be suffered from various environmental and operational reasons. Establishing a realiable downhole lithostratigraphy model at a drilled site is one of the most basic missions to be accomplished for our understanding of the subsurface architecture. Throughout the history of scientific ocean drilling, it has been one of the biggest challenges, however, to draw such a reliable downhole stratigraphy model of any drilled igneous section because core recovery rates are typically very low. Any conventional shipboard volcanostratigraphy includes a great degree of uncertainty due to (a) biased recovery of rock, fractures, and alteration types (e.g., loss of highly altered breccia materials and fracture fillings), (b) uncertainty of the in situ location of recovered core pieces, and (c) inconsistent core description criteria onboard when developed from several cruises. Consequently, critical elements for the understanding of evolution of the oceanic crust, such as alteration processes, changes in physical properties, and crustal accretion system may lead to mistaken conclusions. As an important alternative to the piecemeal shipboard lithostratigraphy, we introduce a complete, less-subjective volcanostratigraphy model by integrating wire-line logging and recovered core data using an example from Ocean Drilling Program (ODP) Hole 1256D, the first drilled hole that penetrated through the entire upper oceanic crust into the top of gabbro sequence, located at the super-fast spreading 15 Ma crust at Cocos Plate. From the Hole 1256D logging data, quasi-2D resistivity contrast images of borehole wall, so-called electrofacies acquired by multiple Formation MicroScanner (FMS) runs, were found particularly useful in deciphering the detailed crustal architecture with unprecedented resolution (i.e. centimeter scale). A volcanostratigraphy model was built by translating these FMS electrofacies into end-member lava flow types observed in the modern day EPR, shedding new light on crustal construction processes. Any future hard rock drilling effort, including proposed arc crust drilling (IBM), continental rifted margin drilling (Lord Howe Rise), and core-mantle boundary drilling (“MoHole”) will evidently foresee challenges in recovering continuous core materials; nevertheless, the “100% recovery rate” of information from these hard rock drilled sites can be achievable by effective physical properties logging.

Keywords: Crust-Mantle Drilling, Borehole Informatics, Well logging

 

# P-wave velocity reduction toward to the Moho in the oceanic lower crust? : Implications from lithological variation of gabbroic core samples

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Variety of gabbroic samples were taken from the Atlantic Ocean (ODP Legs 153 & 209, IODP Exps. 304&305), the Indian Ocean (the Atlantis Bank: ODP Legs 118 & 176) and the Pacific Ocean (Hess Deep: IODP Exp. 345). Those gabbroic core samples were originated from the upper part and lower part of the oceanic crust.
IODP Exp. 360 Phase I of the "Nature of the Lower Crust and Moho at Slower-Spreading Ridges" (SloMo) project, a Multi-Leg Drilling Project, drilled into the lower crustal gabbroic rocks at Atlantis Bank, and penetrated from the ocean floor to 789.7 mbsf. The cored interval is 742.7m and total recovered core length 469.65 m (63.2% recovery). Olivine gabbro is the dominant lithology of the core samples, followed by gabbro, oxide gabbro, and oxide-bearing gabbro. Lithological variation is small in the core samples. In order to understand the petrophysics of the site, we measured physical properties on whole rounds, section halves, and discrete samples. We also achieved three runs of wire-line logging (Triple-combo, sonic/FMS, and UBI). The data suggests that those gabbroic samples show high Vp values (6.0 ~ 7.5km/s) degardless the lithology.
On the other hand, Hole U1309D at the Atlantis Massif at 30 degree N, Mid-Atlantic Ridge was penetrated 1415 mbsf during IODP Exp. 304 and 305 (Blackman et al., 2006). Variable types of gabbroic cores were sampled with high recovery (74.8%). They are mainly gabbro (Cpx + Pl), olivine gabbro, gabbronorite, oxide gabbro, troctolite, olivine-rich troctolite, felsic veins and diabase. The most samples include olivine even gabbro in a narrow sense. The modal composition of olivine varies from less than 5 vol% in gabbro, gabbronorite and oxide gabbro to 85 vol% in the olivine-rich troctolite. On-board measurement of the compression wave velocity of those samples from Hole U1309D shows a slightly slower range (5.0 ~6.7 km/s) than that (6.0 ~ 7.0km/s) of the typical gabbroic rocks.
The total alteration intensity of the samples has a negative correlation with the P wave velocity, and a positive correlation with the porosity in general. Except for the olivine-rich troctolite, the olivine mode of the samples, however, more affects to the porosity and P wave velocity as same as the serpentinization of peridotite samples. This is because that olivine is easier to be altered (serpentinized) compared to other phases in gabbroic rocks. The connectivity of the olivine grains in the samples also influence to reduce the velocity. The result of our study implys the possibility of the reversal velocity structure in the oceanic lower crust if it is olivine-rich and is sufficiently serpentinized, although the pressure effects should be considered.

Keywords: P-wave velocity, Gabbro, Lower crust, IODP, Moho, olivine

 

# The Lateral Variability of the Lower Ocean Crust at an Ultraslow Spreading Ridge: Evidence for Dynamic Accretion

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During Phase I of the SloMo Project, ODP Hole U1473A was drilled 809.4 m into a 700-m deep wave-cut platform at Atlantis Bank on the SW Indian Ridge. This constitutes the eroded top of an oceanic core complex where massive gabbro was emplaced into the footwall of a single detachment fault for 3.74 Myr, with total slip 38.9 km. It was then uplifted to its present position flanking the 6,100 m deep 199-km Atlantis II Transform. The gabbros are back-tilted ~20°S, while a sub-horizontal ~30-km long mantle peridotite-gabbro contact lies along the transform wall at~4200 m depth ~11.5 km west of Hole U1473A. Hole U1473A is 1.4 km north of 158-m deep Hole1105A and 2.2 km NNE of 1508-m deep Hole 735B. Together these holes document the lateral continuity of the lower ocean crust at ultraslow rates (14 mm/yr.), and compare it to 1400-m Hole U1309D in the Atlantis Massif MAR core complex (24 mm/yr.) flanking the 63-km Atlantis Transform. The three Atlantis Bank holes are very similar, consisting of a complex series of intercalated oxide-rich gabbros and olivine gabbros. Several dikes crosscutting the gabbro sections show that they passed through the dike-gabbro transition after crystallizing and cooling deeper in the crust. They all show extensive high-temperature crystal-plastic deformation predating dike intrusion. A small amount of troctolite was recovered only in Hole 735B. By contrast, gabbro, rather than olivine gabbro was the dominant lithology in Hole U1309D, with intercalations of troctolite and mantle peridotite, and subordinate oxide gabbro. Oxide gabbro is often associated with crystal-plastic deformation. While these are concentrated in the upper 1/3 of Hole 735B, they are more uniformly distributed in Hole U1309D. While one section cannot be traced directly to the other at Atlantis Bank, it appears that they can be correlated based on chemical and structural similarities, with the 1105A and 1473A sections lying some hundreds of meters deeper structurally than Hole 735B, consistent with erosion on the platform. All these sections represent sequential emplacement of small gabbro bodies in an active dynamic environment where the lower crust could support a shear stress, and simultaneous upward compaction of late melt through the section. Locally, shear zones related to the uplift of the section into the partially molten gabbro localized late permeable melt flow, hybridizing the olivine gabbro to high evolved oxide gabbro. These simultaneous processes created a stratigraphy of enormous complexity unlike any intrusion seen on land.

Keywords: Gabbro, dynamic accretion, Ocean Drilling

# Geochemical and petrological interactions between felsic rocks and the host gabbros in the Oceanic Plate: An example from IODP Hole U1473A

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IODP-Hole U1473A was drilled on the summit of Atlantis Bank, Southwest Indian Ridge during Expedition 360 brought back for us a chance to get more information about the lower crust at the ultra-slow spreading ridges. Felsic veins rich in plagioclase, are common, though locally concentrated in the core. The veins occur as planar or branched networks with a variety of sizes in the gabbroic rocks. They are generally interpreted as formed from evolved melts in the late stage of crystallization of the gabbros. It has been recently accepted that reaction between the gabbroic mineral assemblage in the earlier stage of crystallization and migrating melts is an important process in melt evolution beneath mid-ocean ridge (Lissenberg et al., 2008, 2013). In order to expand our knowledge of nature of the lower crustal section of slow-spread ocean crust, we will present modes of interactions between felsic veins and the host gabbros. Based on X-ray mapping combined with EPMA analyses, we classified the felsic veins into three types following the nomenclature of Le Maitre et al. (2002): Granodiorite, quartz diorite and quartz monzodiorite. The veins contain mainly plagioclase with lesser amounts of amphibole, quartz; Fe-Ti oxides. Accessory minerals consist of apatite and zircon, ±biotite. Secondary minerals such as actinolite-tremolite, chlorite, are commonly present.

Plagioclase is the most abundant mineral in the veins, and has a large size range. Most crystals are subhedral or euhedral with normal zoning. Most grains have cores of oligoclase-andesine and rims of albite-oligoclase with the composition ranging from $An_4$ - $An_{38}$. Myrmekitic texture of albite and quartz occurs in some felsic veins. Amphibole is the second most abundant mineral in the felsic veins with 2 main categories: pale-green amphiboles and brownish-dark brown amphiboles. On the IMA classification scheme (Hawthorne et al, 2012; Locock, 2013), the amphiboles range from tremolite, to magnesio-hornblende and pargasite. Some quartz occurs interstitially between plagioclase crystals indicating that some might have crystallized from fluids rather than silicate melt. Zircon and apatite are present in all our 5 vein samples with different levels of concentration.

We find that the Hole U1473A felsic veins share a lot of similarities to those described by Robinson et al (2002) in ODP Hole 735B. We propose that the occurrences of these intrusions play a key role in the alteration processes of the host minerals and they could have some different origins as follows. The veins morphology and the myrmekitic textures as well as the abundance of zircon, apatite in all the felsic vein samples clearly demonstrates that they formed from the late magmatic melts. On the other hand, the continuous texture gradation between a felsic vein and the host olivine gabbro in one sample suggested a pseudomorphic replacement process in the lower crust.

Keywords: Atlantis Bank, gabbros, felsic veins, melts, fluids, replacements

# Genesis of EPR lower crust: Petrographical and chemical evidence for mixing between MORB type and OIB type melts

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IODP Expedition 345 aimed to drill lower crust gabbros at Hess deep rift (East Pacific Rise, 2°14' N-101° 30' W), which is located at the junction between EPR and the Cocos, Nazca and Ridge. Lower oceanic gabbros were sampled on a about ~200 m wide bench located on the intrarift's southern slope between 4675 and 4850 m below sea level, and total of 11 holes (A to P) were drilled among which two reached a depth over 100 m below seafloor (Holes 1415J and 1415P) (IODP Expedition 345 Scientific Report, 2013). Primitive troctolites and olivine-rich gabbros were the main lithologies recovered from these two holes. Shipboard data showed a high Mg# whole rock chemistry in concordance with their primitive nature.

We studied about 70 samples from Holes J and P for their petrography and mineral chemistry. The olivine gabbros show an overall cumulate texture with ophitic to subophitic domain consisting of large clinopyroxenes enclosing plagioclase chadacrysts. Non-ophitic clinopyroxenes are in association with orthopyroxene in an interfingered relationship. Olivine is subhedral to subrounded and plagiolse appear as subhedral laths. Overall texture points to a crystallisation order starting with olivine and plagioclase, and finishing with clinopyroxene in association with more or less orthopyroxene as expected for a crystallising MORB. Mineral chemistry show primtive characteristics with olivine forsterite content above 85% and clinopyroxene Mg# higher than 86% for all samples. Mg# in Cpx and the forsterite content in olivine show relatively narrow downhole variation ranges (from 86 to 89% for Cpx and 85 to 90% for olivine) together with a large scatter in minor elements (Ti, Al, Cr, Ni, Mn), suggesting that, at a global scale, only a moderate degree of differentiation occurred during the gabbro formation process. Chemical zoning observed in the ophitic cliopyroxenes show that the crystallisation process may be locally dominated by small scale differentiation.

Minor and trace elements contents in olivine, Cpx and plagioclase show a great variability scattered over the MORB chemical range. Calculated compositions for liquids in equilibrium with all minerals using both minor and trace elements are consitently between the EPR MORB and the Galapagos basalts chemical domains. This demonstrates that magmatic contamination from the Galapagos hotspot is significant in the Hess Deep lower crust. Interestingly, a weak degree of contamination from the Hawaii hot spot was detected in EPR basaltic glasses (Niu et al.,1999) but Hess Deep basalts seems to be of purely MORB nature (Batiza et al, 1992) without any chemical evidence of Galapagos influence . This shows that either lower gabbros, and especially Cpx in these rocks as this mineral represent the main incompatible element reservoir, may act as a chemical filter by preventing contamining primitive melts from the Galapagos hot spot to be expelled out of lower levels magmatic mushed.

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Keywords: Hess Deep, IODP Expedition 345, Gabbros, Magma Mixing, MORB, OIB

# ISLA ISABEL, MEXICO: A THIN CRUST UNDER A SHALLOW CONTINENTAL PLATFORM

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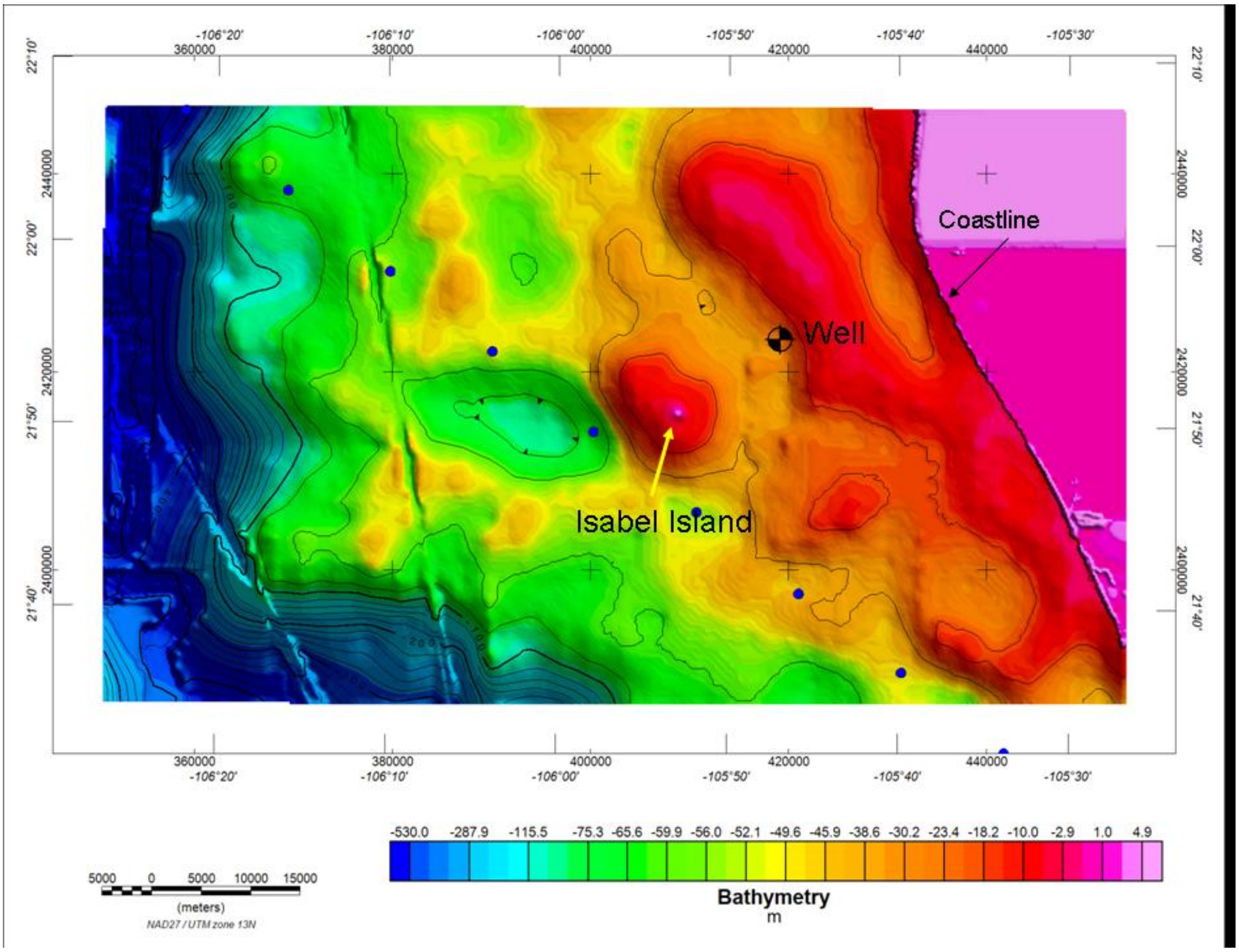
The crust at Isabel Island in the Mexican Pacific continental platform is only 17 km thick; this thickness has been determined by seismic studies, and more recently corroborated by a magnetotelluric one. The thin crust is the result of rifting and extensional tectonism induced by the separation of Baja California Peninsula from mainland Mexico. The island shows Plio-Pleistocene volcanic activity, including the formation of maars and the presence of mantle xenoliths. Alkali basalts transported peridotite xenoliths to the island's surface. Furthermore, pressure estimates for the Isabel xenoliths indicate that they equilibrated at relatively low pressures (5.9–15.5 kb), supporting the occurrence of shallow crustal processes. Gravity and magnetic models show that the island represents the emerged portion (0.03 $km^3$) of a larger laccolith (12 x 8 km) where apparently successive magma intrusions have deformed the shallow (100 m) continental platform where it is located. A nearby exploration well distant 8 km from the island reached 3157 mbsl; from 1400 to 3157 m-depth the recovered nuclei consisted of oceanic crust, where the deepest 250 m were of dolerite composition. At the bottom of the well a temperature of 231ºC was reported, yielding a geothermal gradient of 73 ºC/km, one of the largest in the world, indicating an anomalously high heat flux in the area. Since dolerite dikes often occur in swarms it is likely that they are present throughout the area. Nearby gravity and magnetic anomalies of similar characteristics to those of Isabel Island support the probable presence of additional intrusive bodies in this region. A thin crust with high heat-flow, combined with a shallow continental platform represents an opportunity area to carry out hard-rock drilling projects.

Keywords: Isabel Island, Mexico, Thin crust, Laccolith


Coastline
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m
-530.0 -287.9 -115.5 -75.3 -65.6 -59.9 -56.0 -52.1 -49.6 -45.9 -38.6 -30.2 -23.4 -18.2 -10.0 -2.9 1.0 4.9
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NAD27 / UTM zone 13N

 

# Pre-existing crust and a mantle anomaly in the tectonic evolution of the South China Sea

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One of the main objectives of International Ocean Discovery Program (IODP) Expedition 349 is to determine the spreading history and tectonic development of the South China Sea (SCS) and the mechanisms responsible for the initiation of spreading. Two of the suggested mechanisms involved 1) back-arc basin opening as a result of slab pull from subduction of pre-existing proto-SCS crust and 2) the role of an upwelling mantle anomaly. Cores of oceanic crust were successfully recovered, close to the fossil spreading centers at the East Subbasin (U1431) and at the Southwest Subbasin (U1433B and U1434A). Isotopes and geochemical data of representative samples from Site U1431E, U1433B, and U1434 are used to determine the different source inputs during the last stages of spreading in the SCS. The Os-Nd isotope data indicate three isotopically distinct magma types, representing at least three sources. The most radiogenic Os isotopic compositions occur in Site U1434 basalts and may be attributed to the influence of continental lower crust input toward the end of spreading in the Southwest Subbasin. In contrast, the earlier stage of spreading in the Southwest Subbasin, at Site U1433B, produced basalts that show the least radiogenic Os, combined with radiogenic Nd isotopic compositions, which could represent a normal ridge mantle source with altered oceanic crust input. Spreading at Site U1431E may have also occurred in two stages, with an earlier stage dominated by mixed sources involving enriched mid-ocean basalt (MORB)-type mantle with altered normal oceanic crust input, which later evolved into enriched MORB-type magmatism with ocean island basalt-type source input. The oceanic basement composition at both Site U1433 and Site U1431 indicates a similar enriched MORB-type mantle source but requires an altered MORB crust assimilant, suggesting incorporation of old oceanic crustal component. Alternatively, the Os-Nd isotope data could indicate that the upwelling magma at both sites interacted with old pre-existing crust, possibly from a previous back-arc spreading phase. Our results highlight evidence for pre-existing proto-SCS and the increasing role of a melting anomaly during the latest stages of rifting, leading to seamount volcanism for another 3-10 m.y., before magmatic activity finally ceased.

Keywords: South China Sea, melting anomaly, proto-South China Sea crust

 

# Parameterized lattice strain model for HFSE partitioning between amphibole and silicate melt with application to arc magma evolution

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The role of amphibole fractional crystallization in generating differentiation trends in arc magmas [1, 2] can be better understood by constraining the parameters responsible for the large range in experimentally determined trace element partition coefficients between amphibole and melt. In this study, we used published experimental high field strength element (HFSE) partitioning data between amphibole and silicate melt, the lattice strain model [3], and non-linear least squares regression method to parameterize key parameters in the lattice strain model ($D_0$, $r_0$, and $E$) for amphibole as a function of pressure, temperature, and both mineral and melt compositions. In our tetravalent HFSE (Zr, Hf, Ti) partitioning model, $D_0$ negatively correlates with Ti content in the melt, $r_0$ negatively correlates with Ti content in the amphibole, and $E$ positively correlates with $r_0$. The pentavalent HFSE (Nb, Ta) partition coefficients were empirically modeled as a function of amphibole composition and $D_{Hf}$. Application of our HFSE partitioning models and our previous REE partitioning model [4] to experimental data simulating fractional crystallization of arc magmas [5] suggests that (1) HFSE and REE partition coefficients between amphibole and melt can vary by a factor of three and ten respectively during arc magma fractional crystallization due to variation in the amphibole and melt compositions, (2) amphibole fractional crystallization causes significant fractionation within and between HFSEs and REEs (e.g. it increases Zr/Hf and Zr/Nd ratios, and decreases Dy/Yb and Dy/Dy* ratios) in arc magmas, and finally (3) it plays a key role in buffering the HFSE and REE concentrations in arc magmas.

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Keywords: amphibole, HFSE and REE partitioning, arc magma evolution

# The earliest stage of Izu rear arc volcanism revealed by drilled cores at Site U1437, IODP Expedition 350

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The present Izu arc system consists of three types of volcanic structures, which are (1) the Quaternary volcanic front, (2) the rear-arc seamount chains and (3) bimodal rift-type volcanoes in a back-arc knoll zone and an active rift area, situated between the volcanic front and the rear-arc seamount chains. Ishizuka et al. (2003) show that the Izu rear arc volcanism migrated from eastward after the cessation of the Shikoku Basin opening (25-15 Ma; Okino et al., 1999). The rear-arc seamount chains volcanism began at 17 Ma and continued until 3 Ma, and was followed by rift type volcanism from 2.8 Ma to present (Ishizuka et al., 2003).

IODP Expedition 350 Site U1437 is located in the boundary area of the back-arc knoll zone and rear-arc seamount chains and drilled between the Enpo and Manji rear-arc chains. The first complete sequence of rear-arc rocks dated <15 Ma (Schmitt et al., in preparation) were recovered at this Site (Tamura et al., 2015), and develop over Unit I (top) to Unit VII (bottom).

The major and trace element compositions collected from the deepest parts of the Hole (Unit V and VII) show different types of magmatism. The lowermost Unit VII (~15 Ma) shows rift-type magmatism which have a relatively flat REE patterns, and Unit V (8 Ma) shows rear-arc seamount chains type with LREE-enriched patterns. This suggests that the area around Site U1437 used to be an extensional zone following the Shikoku Basin opening. At 17-8 Ma, volcanism in the Izu back-arc side occurred only in the western part of the seamount chains (Ishizuka et al., 2003) and in the eastern part of the Shikoku Basin (e.g. Kinan Escarpment; Ishizuka et al., 2009). Simultaneously rift-type volcanism occurred in the eastern part of the present seamount chains region.

The difference between the Unit VII and V indicates the temporal change of the subduction components with time. It is suggested that the subducting slab below Site U1437 had deepened with time.

# Reconstruction of proto-arc basalt lava emplacement at the Amami Sankaku Basin

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How forearc oceanic crust was developed is a key to investigate evolution of the subduction system. However, few proto-arc oceanic crust is exposed below the modern oceanic arc and it is a problem for study how the arc was grown up. IODP Exp. 351 successfully recovered a proto-arc oceanic crust at the Amami Sankaku Basin which have similar geochemical feature to forearc basalts (FABs) of the Izu-Bonin-Mariana Arc which lacks geochemical evidence of subduction-recycled components (Arculus et al., 2015, Nature Geoscience).
Exp. 351 cored a 1611-m-long cores composed of 1461 m thick sediments (Unit I-IV) and 150 m thick basement rocks (Unit 1) at Site U1438, just west of Kyushu-Palau Ridge. Based on the biostratigraphy and paleomagnetism of sediments, the age of the basement is estimated to Eocene (e.g. Brandl et al., 2017, EPSL). The Unit 1 is built up with mostly sheet flows with sparsely vesicular tholeiitic basalts. The lower half of Unit 1 is composed of thin sheet flow of sparsely olivine (Ol)-plagioclase (Pl)-clinopyroxene (Cpx) phyric basalt, while the upper Unit 1 consists of thick sheet flows containing Ol and Pl phenocrysts up to 3 mm in maximum. The top 12 m of Unit 1 consist of moderately vesicular, Ol-Cpx phyric basalt sheet flows. Top surface crust of Unit 1 is conformably covered with umber-like dark mudstone of Unit IV. Limestone and tuff layers in the lower part indicate that the intermittent volcanism or the site U1438 was located at a basin in the early phase. Homogenized geochemistry of the lower half suggests that they were emplaced in an axial summit trough and on the spreading ridge. Upper half of the Unit 1 may be emplaced off ridge by flood of voluminous lava flows. Top basalt flows may be derived from a relatively high-Mg magma at ˜3 km off ridge.

Keywords: Subduction initiation, forearc magmatism, U1438, Izu-Bonin-Mariana Arc

 

# Forward modeling of the magma genesis for the deepest lithostratigraphic unit at Site U1437, IODP Expedition 350

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Site U1437 is located in the Izu rear-arc region, approximately 330 km west of the Izu-Bonin Trench axis and about 90 km west of the submarine Myojinsho volcano, 2117 meters below the sea level (mbsl). The stratigraphic Units VI and VII of this site, 1320–1806.5 meters below the seafloor (mbsf), contain volcaniclastics and hyaloclastites with coarse lava clasts. One of the research objectives of the IODP Expedition 350 is the analysis of the geochemical characteristics of Izu rear-arc magmas, which are not accessible by dredging (Tamura et al., 2015).

The geochemical characteristics of the Unit VII volcaniclastics (1459.8–1806.5 mbsf) are expected to reflect the mantle source of the magmatism soon after the opening of the Shikoku Basin, which occurred between 24–15 Ma (Okino et al., 1994). Major-element and trace-element compositions of the Unit VII lava clasts differ from those of the Neogene rear-arc seamounts or Quaternary arc-front volcanoes. Most lava clasts from Unit VII have trace-element characteristics indicating weak influences from the slab (fluid or melt) (Sato et al., in preparation). Sr-Nd-Pb-Hf isotope ratios of the same samples are consistent with the trace-element characteristics.

In this study, ABS4 (Arc Basalt Simulator version 4) by Kimura et al. (2014) and PRIMACALC2 (Primary Magma Calculator version 2) by Kimura and Ariskin (2014) were used to model the source conditions of the magma genesis based on the major and trace elements, and Sr-Nd-Pb-Hf isotope compositions. Compositions of the primary magmas were estimated using PRIMACALC2 for one lapilli-tuff sample from the upper part of Unit VII and two volcaniclastic samples from the lower part of Unit VII. The forward modelling using ABS4 was performed on the primary magma compositions.

The model results suggest that the slab flux (fluid/melt) were derived from mixtures of the liquids from altered oceanic crust layer (50–52 %), sediment layer (18–32 %), and mantle-wedge base peridotite layer (17–32 %). These slab liquids were generated at depth of 3.7–4.5 GPa with slab surface temperature 775–804 °C. The conditions of fluxed melting of the mantle wedge showed large differences between the lower part (F = 1.4–4.2 %) and the upper part (F = 25 %) of Unit VII, but the melting depth is limited within the depth range 1.5–1.8 GPa. The flux fraction of the slab-derived liquid also differs between the lower part (0.4–0.6 %) and the upper part (2.5 %) of Unit VII.

Using the previously published Quaternary basalt compositions from the volcanic front, active rift, back-arc knoll, and rear-arc settings, source conditions were compared with that of the Unit VII. The Unit VII magmas were generated from the conditions similar with those in the active rift, back-arc knoll, and rear-arc environments, except for their higher degrees of melting with higher flux rate of the slab liquids. These characterize the source conditions of the upper part of Unit VII.

 

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Keywords: Arc Basalt Simulator, Izu rear-arc , magma genesis

 

# Asthenospheric contribution to magmatism at the active rift zone in the northern Izu-Bonin arc

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The active rift zone lies just behind the Quaternary volcanic front in the northern Izu-Bonin arc. Volcanism at the active rift zone has been active since ca. 2 Ma, and late Quaternary basaltic lavas (< 0.1 Ma) and hydrothermal activity occur along the central axis of the rifts (Taylor, 1992; Ishizuka et al., 2003). The southern part of the active rift zone has greater subsidence of the basement than the northern part (Ishizukda et al. 2002). In this paper we present new Sr, Nd, and Hf isotope and trace element data for the basalts erupted in the active rift zone, composed of northern Aogashima rift, Myojin rift, and southern Sumisu rift. Three geochemical groups can be identified within the active rift basalts: Low-Zr basalts (LZB), Mid-Zr basalts (MZB) and High-Zr basalts (HZB). The MZB and LZB occur at all rifts, whereas the HZB only at the Sumisu rift. The MZB has higher Zr/Yb and Nb/Yb, lower Ba/Nb than the LZB. The HZB has the highest Zr/Yb, and exhibits a similar Nb/Yb and Ba/Nb to the LZB. The MZB from the Aogashima rift has higher Ba/Th and lower Th/Nb than the HZB and MZB from the Sumisu rift. The HZB and MZB from the Sumisu rift show a similar Ba/Th and Th/Nb to the western back-arc seamount chains. Depletion of Zr-Hf in the N-MORB-normalized spiderdiagram characterizes the MZB and LZB. The $^{176}Hf/^{177}Hf$ values are slightly lower in the HZB than in the MZB and LZB, decoupling of $^{176}Hf/^{177}Hf$ and $^{143}Nd/^{144}Nd$ values. ODP Leg126 site 788, 790, and 791 reached the basaltic basement of the Sumisu rift (Gill et al., 1992). The geochemical data and stratigraphic relations of the basement indicate that the HZB is younger than the MZB. Estimated primary magma compositions suggest that segregation depth of primary magma for the basalts at the Sumisu rift exhibits 30 km (˜ 1.0 GPa), whereas that at the Aogashima and Myojin rifts more than 45 km (˜ 1.5 GPa). The correlation between Zr/Yb, Nb/Yb and Ba/Nb indicate that the MZB and LZB were produced by different degree of partial melting of a common source mantle. The MZB and LZB volcanism at the early stage of the back-arc rifting is best explained by a partial melting of subducted slab saturated with trace quantities of zircon under low-temperature condition in the mantle wedge. On the other hand, the HZB requires a partial melt of subducted slab accompanied by full dissolution of zircon under high-temperature condition in the mantle wedge. Spatial geochemical variation of the active rift zone basalts indicates that contribution of a slab melt component (high Th/Nb relative to Ba/Th) dominates in the Sumisu rift, whereas that of an aqueous fluid component dominates in the Aogashima rift. We propose that the back-arc rifting could have been caused by asthenospheric injection with high-temperature in the south during the syn stage.

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Keywords: back-arc basin, the northern Izu-Bonin arc, the active rift zone, slab-derived component

 

# Discovery of low-Ca, high-Si boninites from the northern Zambales Ophiolite: Doubly-vergent subduction initiation along Philippine Sea Plate margins

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We report the discovery of low-Ca, high-Si boninite from the middle Eocene Zambales Ophiolite in Luzon Island, Philippines. Boninite occurs as lapilli fall deposit and pillow lava flows in the upper volcanic unit of the juvenile arc section (Acoje Block) in northern Zambales Ophiolite. Following the classification of Kanayama et al. (2013) and Reagan et al. (2015), high-Si and low-Si subtypes are recognized in the upper unit together with boninitic basalts of Hawkins and Evans (1983). This upper volcanic unit in turn overlies a lower volcanic unit consisting of basaltic andesite to andesitic lavas and explosive eruptives (subaqueous pahoehoe and lobate sheet flows, tuff breccia, agglutinate, scoria and spatter deposits) forming a low-Si boninite series. Zambales high-Si boninites, mostly of the aphyric type, consist of subhedral olivine microphenocrysts (Mg#=0.88-0.91), abundant elongate enstatite microphenocrysts (Mg#=0.86-0.87) with augite±pigeonite overgrowth and chromian spinel (Cr# =0.7-0.8) set in glassy groundmass with quench clinopyroxene. This assemblage corresponds to Type II and III of Umino (1985) in samples described from the boninite type locality. Enstatite microphenocrysts with spongy cores and reverse zoning, together with embayed quartz xenocrysts are also recognized. Whole-rock composition of Zambales high-Si boninite, with 55.9-58.5 wt% $SiO_2$, 0.25-0.35wt% $TiO_2$, 8.5-13.8 wt% MgO and FeO*/MgO ratios less than 1, is akin to that of a typical Ogasawara boninite. Ni and and Cr contents are remarkably high as well. MORB-normalized trace element pattern of Zambales high-Si boninites show enrichment in LILEs (Rb, Ba, Th, K, Pb, Sr) and depletion in HFSEs (Nb, Ta) with positive Hf anomaly relative to Sm and negative Ti anomaly relative to Y. In contrast with samples from Ogasawara, Zambales high-Si boninites exhibit spoon-shaped REE pattern with strong LREE depletion relative to less depleted HREEs. Trace element ratios also distinguish Zambales boninites, having lower Zr/Ti and higher Ba/Yb ratios than Ogasawara boninites and are comparable with samples from Troodos and Oman Ophiolite. The presence of boninite and boninite-series volcanics in Acoje Block (44 Ma) and protoarc basalt (PAB)-like transitional MORB in Coto Block (45 Ma) indicate that the distinct subduction initiation chemostratigraphy is present in Zambales Ophiolite, albeit supplied by separate magma plumbing systems with stratigraphic relationships obfuscated by post-emplacement tectonic deformation. The occurrence of a massive sulfide deposit in the lower volcanic unit and possibly up to lowermost section of the upper unit is consistent with massive sulfide-bearing horizons in Troodos and Oman as well as on the Bonin Ridge.
Unfolding of subducted slabs beneath southern Eurasia reveals that the Philippine Sea Plate at 44Ma is bordered by Cretaceous oceanic crust (the East Asian Plate of Wu et al., 2016) in its western margin. Coupled with available paleomagnetic data from Zambales and Luzon, we make the case for a subduction initiation origin of the Zambales Ophiolite in the western margin (leading edge) of the northwestward moving, clockwise rotating Philippine Sea Plate. In addition, the complementary nature of Cretaceous ophiolites in eastern Philippines and the Amami-Daito region implies a common history prior to the onset of spreading in the overriding plate.

Keywords: Zambales Ophiolite, boninite, Philippine Sea Plate, subduction initiation

 

# Amphibolites and a garnetite: Geodynamic implications of crustal lithologies from the southeast Mariana fore-arc

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A transect of Shinkai 6500 dives in the Challenger segment of the Mariana fore-arc recovered samples mantle and crustal lithologies. One plutonic rock collected at 4900 meters depth has an age of 46.1 Ma and mingled boninitic to arc tholeiitic domains suggesting that it is a piece of the nascent IBM arc crust. Epidote amphibolites and a hornblende garnetite were retrieved from depths between 5938 and 6277 meters depth in an area dominated by peridotite. The amphibolites have trace element compositions similar to enriched MORB, whereas the garnetite appears to be the crystal cumulate of basalt fractionation or the residue after melting of deep crust at pressures of 1.2 GPa or higher and at temperatures exceeding 780°C. There is little evidence for the involvement of subducted fluids in the genesis of the amphibolites. The garnetite is enriched in fluid soluble elements, but this enrichment might have occurred during retrograde metamorphism. The amphibolites and garnetite have initial Hf, Nd, and Pb isotopic values suggesting that they represent metamorphosed fragments of Eocene to Cretaceous terranes akin to those at the north end of the Philippine plate. The high pressures achieved by the garnetite suggest that it represents a fragment of the delaminated root of one of these terranes. Coeval Sm-Nd, Lu-Hf, and 40Ar-39Ar ages of the garnetite indicate rapid ascent and cooling at 25 Ma. The amphibolites and garnetite were tectonically juxtaposed with peridotites by complex mantle dynamics in the S. Mariana Forearc associated with the opening of the Parece-Vela Basin and the collision of the Caroline Ridge.

Keywords: Amphibolite, Ganetite, Mariana Trench

# Direct evidence of hydration into mantle during shearing below a transform fault: Prince Edward transform fault, Southwest Indian Ridge

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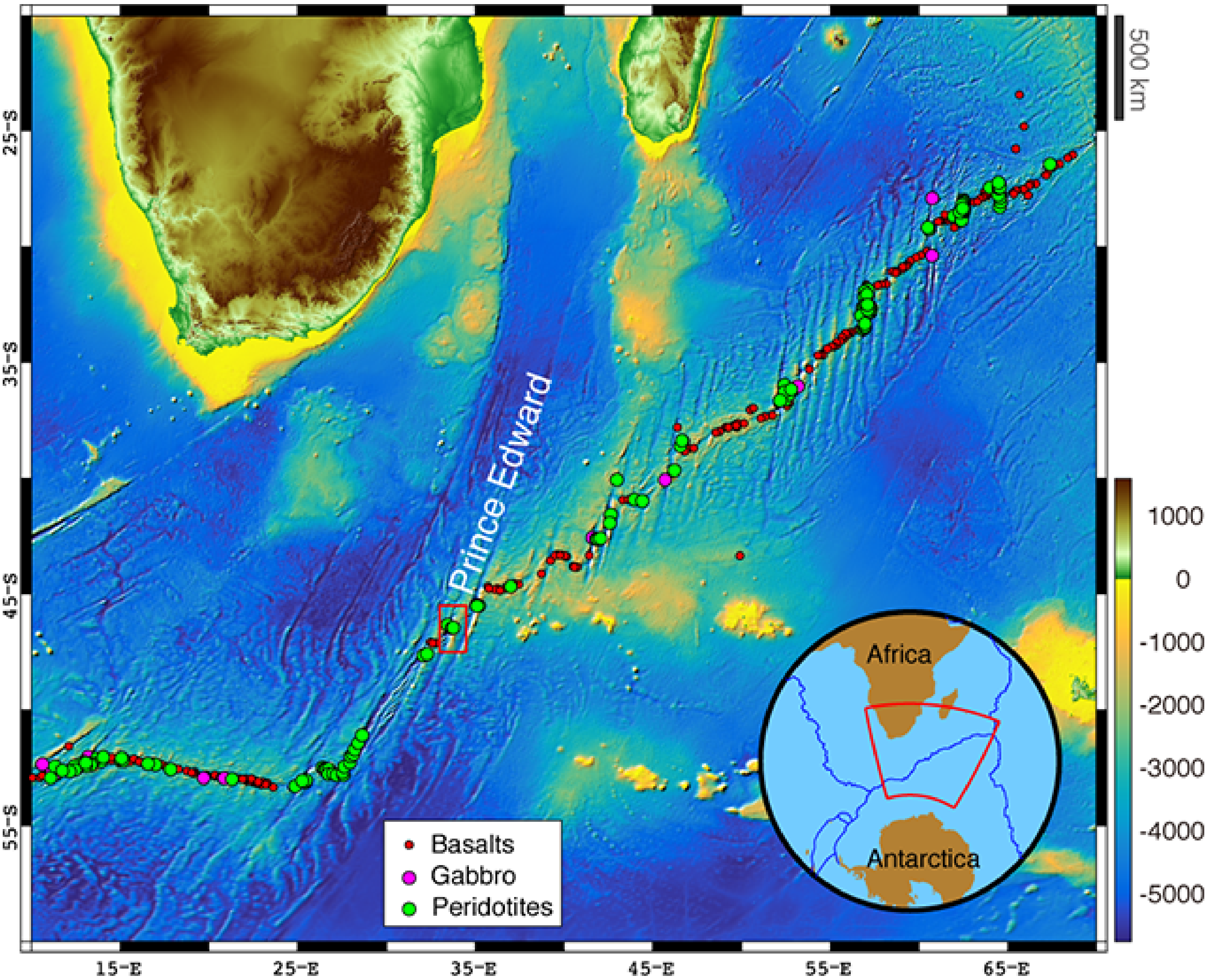
Southwest Indian Ridge (SWIR) is located to the southwest of Rodriguez Triple Junction, where three Indian ocean ridges meet (Zhou & Dick, 2013, Nature). SWIR is one of the slowest spreading ocean ridges in the world. In this study, we studied microstructural development of 21 peridotite samples obtained from Prince Edward transform fault of SWIR by PROTEA5 cruise in 1983. The peridotites consist dominantly of olivine, orthopyroxene and clinopyroxene with minor amounts of amphibole and plagioclase as well as secondary minerals such as serpentine and magnetite. The peridotites were classified into four groups based on their microstructures: 3 ultramylonites mostly consisting of extremely fine crystals (3-5 $\mu$m), 13 heterogeneous tectonites consisting of coarse-grained crystals and fine-grained matrix, 1 cataclasite and 4 intensely serpentinized peridotites. Olivine Mg# is 0.90-0.91 and spinel Cr# is 0.1-0.35. Amphibole crystals have chemical compositions of tremolite and magnesio-hornblende and they were intensely deformed within the ultramylonites and the heterogeneous tectonites, indicating that they have occurred before or during intense shearing in mantle. Moreover, extremely fine grain sizes of olivine and microboudin textures in both pyroxene and spinel crystals suggest that these peridotites have been sheared under high stress conditions. Furthermore, olivine crystal-fabrics within the amphibole bearing peridotites have B and E types that could be developed under hydrous conditions, whereas olivine fabrics within the other peridotites have A and D types that could be developed under anhydrous conditions (Karato et al., 2008, Annu. Rev. Earth Planet. Sci.). Consequently, the petrophysical characteristics of peridotites in this study indicate that the uppermost mantle below the Prince Edward transform fault has been locally but intensely hydrated during shearing due to transform movement.

Keywords: Transform fault, mantle, olivine fabrics



25°S
35°S
45°S
55°S
15°E
25°E
35°E
45°E
55°E
65°E
500 km
Prince Edward
Basalts
Gabbro
Peridotites
Africa
Antarctica
1000
0
-1000
-2000
-3000
-4000
-5000

# Mantle heterogeneity under Hawaii site of M2M

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The project of MoHole to Mantle (M2M) has three candidates for the prospective drilling sites. North Arch of Hawaii is one of candidates, and the seismic site survey will be performed in the near future. Therefore, it is important to increase knowledge of the mantle materials under the Hawaii region. In this study, we discuss the chemical and petrological heterogeneity under the Hawaii region using the experimental data for physical properties of silica under high pressures and high temperatures.

We performed the high-pressure experiments using a multi-anvil high-pressure system combined with a synchrotron radiation source made it possible to acquire precise data from samples under high-pressure and high-temperature conditions. Experimental details have been described elsewhere [1,2]. The starting material was powdered silica to observe the phase transition from coesite to stishovite at around 10 GPa corresponding to ~300 km depth in the upper mantle.

The phase boundary between coesite and stishovite in $SiO_2$ was determined over the range of 1200–1700 K. The stability of each phase was determined by observing the powdered X-ray diffraction data. The transition boundary between the coesite and stishovite phases was found to occur at P (GPa) = 4.7 + 0.0031 x T (K). The phase transition determined in our study occurs at around 10 GPa at the normal mantle geotherm, coinciding with the seismic discontinuity around 300 km depth known as the X-discontinuity [3].

The silica minerals do not appear in normal mantle rocks, such as peridotite, under the upper mantle conditions. In contrast, it is known that the existence of silica minerals has been confirmed in the subducted oceanic crusts or sediments [4]. Previous studies of seismic observations inferred that the X-discontinuity was discovered under the Hawaii region [5]. According to these discussions, the compositional heterogeneity is necessary to explain the observations of the seismic X-discontinuity under the Hawaii region.

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Keywords: Mantle drilling, Mantle heterogeneity, Phase transition, Silica, Oceanic plate

 

# Petrological diversity of abyssal peridotites from the ultraslow-spreading Gakkel Ridge, Arctic Ocean

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The Gakkel Ridge is the world's slowest-spreading mid-ocean ridge varying from about 14 mm/year to 8 mm/year in full spreading rate (Cochran et al., 2003 JGR). It is widely accepted that the ultraslow-spreading ridge limits melting, leading to an idea that peridotites beneath the ultra-slow spreading ridges are relatively fertile in melt components. The ultraslow-spreading ridges, therefore, provide us unique opportunity to insight into original mantle heterogeneity before partial melting beneath the ocean ridge. Peridotite samples were recovered from the Gakkel Ridge during the international Arctic Mid-Ocean Ridge Expedition (AMORE) (Micael et al., 2003 Nature). Recently, D’Errico et al. (2016 GCA) reported a variety of peridotites corrected by the expedition. We also examined petrology and mineralogy of 12 abyssal peridotites from the Sparsely Magmatic Zones of the Gakkel Ridge. Our samples show a wide range of textures from protgranular to mylonitic textures. Based on trace element pattern of clinopyroxene, peridotites can be classified into three types: (Type-1: simple residue) systematic depletions in light rare earth elements (LREEs) from Heavy REEs (HREEs), (Type-2: residue after influx melting) concave-down REE pattern with highly enriched LREE, and (Type-3: unusual mantle) systematic depletions in LREEs from HREEs with no Zr negative anomaly. Type-1 peridotite can be explained as residue after partial melting and melt extraction, and are similar to other abyssal peridotites recovered from other mid-ocean ridges. Trace element pattern of clinopyroxene in Type-2 peridotite is similar trend to that in harzburgie sample of D’Errico et al. (2016). Type-2 peridotite can be explained as residue after influx melting in the melting column beneath the ridge. Type-3 peridotite has not been reported yet. We need further investing on origin of this sample: either reaction/influx melting with a Zr-rich fluid/melt or originally Zr-rich mantle source.

Keywords: Mantle beneath the ultraslow-spreading ridge, Mantle heterogeneity, Peridotite

 

# Petrological and geochemical diversity of mantle section revealed by comparison between northern and southern Oman ophiolite

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The Oman ophiolite is a former oceanic lithosphere formed at Neo-Tethyan oceanic ridge about 95 million years ago and is now distributed along the eastern border of Arabian peninsula over 500 km length. It is suitable for studying formation of oceanic lithosphere at spreading ridge and arc-related magmatism initiated by thrusting of oceanic lithosphere (Lippard et al., 1986; Nicolas, 1989). The volcanic rocks in the crustal section in the northern part of the Oman ophiolite record an evolution in tectonic setting from spreading ridge (N-MORB) to convergent margin (arc tholeiite and boninite) (Alabaster et al., 1982; Ishikawa et al., 2002; Kusano et al., 2013, 2014, 2016). The harzburgites and dunites in the mantle section of northern Oman ophiolite (Salahi and Fizh massifs) are highly refractory indicated by high Cr# (=Cr/[Cr+Al] atomic ratio) of spinel (Cr# >0.6) (Arai et al., 2006; Kanke et al., 2014). The spinel Cr# of harzburgites and dunites show positive correlation with the Ce/Yb ratio of clinopyroxenes. The increase of spinel Cr# accompanies the increase of Ce/Yb ratio of clinopyroxenes. In general, during partial melting of harzburgite in a closed system spinel Cr# increases with increasing the degree of melting (Dick and Bullen, 1984; Arai, 1994). At the same time the Ce/Yb ratio of residual clinopyroxene decreases (Johnson et al., 1990). On the other hand, when melt/rock ratio increase by reaction between exotic fluid/melt and harzburgite in an open system, the Cr# of spinel may forms a positive correlation with the Ce/Yb ratio of clinopyroxene. The plots of harzburgites and dunites produce the same positive trend although the Cr# of spinel and Ce/Yb ratio of clinopyroxene in dunites are greater than harzburgites. The dunites may have reacted with some fluid/melt with high Cr# spinel and clinopyroxene with high Ce/Yb ratio such as boninite. The reaction of harzburgite with boninitic melt may have produced dunites with high Cr# (>0.7) spinel and precipitated clinopyroxene with high Ce/Yb ratio. Although peridotite with high Cr# spinel is common in the northern massifs they are rare in the southern massifs such as Wadi Tayin massif in the southern Oman ophiolite. Similar to the northern massifs, the Cr# of spinel in the Wadi Tayin massif forms a positive correlation with the Ce/Yb ratio of clinopyroxene. Also the range of spinel Cr# for dunites tend to be greater than those of harzburgites. Thus in the Wadi Tayin massif the reaction of harzburgite with a light REE enriched fluid/melt increased melt mass resulted in the formation of dunite with high Cr# of spinel and high Ce/Yb ration of clinopyroxne. However, in the spinel Cr# vs Ce/Yb diagram the trend for the Wadi Tayin massif is sifted to lower Cr# side relative to that for the northern massifs. The high Cr# end of the trend for the Wadi Tayin massif does not coincide with boninite. Alternatively a possible end member is MORB or arc tholeiite that were active before boninite in the northern Oman ophiolite. Chondrite-normalized pattern for clinopyroxenes in the dunite with the highest Cr# of spinel and the highest Ce/Yb ratio of clinopyroxene is characterized by negative anomaly in the high field strength elements such as Nb, Ta, Zr and Hf. This may indicate that arc tholeiite is responsible for the formation of positive trend in the spinel Cr# vs Ce/Yb diagram for the peridotites from the Wadi Tayin massif in the southern Oman ophiolite. Further investigation is required to prove this hypothesis.

Keywords: Oman ophiolite, mantle, peridotite, oceanic lithosphere, subduction zone, mantle wedge

 

# Geochemistry of Wadi Tayin mantle section in the southern Oman mantle section with special reference to suprasubduction zone magmatism

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The Oman ophiolite is the fragment of oceanic lithosphere that was produced by Neo-Tethyan oceanic spreading ridge systems. This oceanic mantle lithosphere has been modified by arc-related magmatism during oceanic thrusting prior to obduction onto the Arabian continent.

The northern Oman ophiolite contains a large amount of volcanic sequence and dykes that show signature of subduction zone setting. On the other hand, in the southern massifs most of volcanic sequence has been eroded out during emplacement. In fact volcanic rocks with arc signature has not been found from the southern massifs. So it is important to study geochemical features of peridotites from the mantle section to clarify whether arc signature is present in the southern massifs.

In this study, we report the mineral compositions of peridotites from the Wadi Tayin massif in the southern Oman ophiolite to investigate the influence of arc magmatism and modification of oceanic lithospheric during oceanic thrusting. We systematically corrected harzburgites and dunites along wadis to cover the mantle section from the boundary between lower crust and uppermost mantle (namely "Moho") to the basal thrust.

Spinel Cr# [=Cr/(Cr+Al) atomic ratio] of harzburgite varies from 0.22 to 0.58. It tends to elevate from the basal thrust to the Moho. Spinel Cr# of dunite has a peak of frequency at 0.55 - 0.60, and the number of spinels with Cr# greater than 0.6 decline significantly. In addition, the spinels with Cr# greater than 0.6 occur either in the basal part of the mantle section or along NW-SE striking shear zone. The relationship between concordant and discordant dunites (Arai et al., 2006) is often observed. Spinel Cr# of concordant dunites is in a range of 0.38-0.40 whereas that of discordant dunites is in a range of 0.52-0.54. Similar to the previous study the spinels in the discordant dunites are tend to have greater Cr# than those in the concordant dunites (Arai et al., 2006).

Abundances of trace elements in clinopyroxenes were analyzed by LA-ICP-MS and were normalized to those of C1 condrites (Sun and McDonough, 1989). The chondrite-normalized patterns show that clinopyroxenes are depleted in LREE relative to HREE although abundance of LREE is more variable than that of HREE. Harzburgite with lowest spinel Cr# of 0.28 is strongly depleted in LREE whereas harzburgite with moderate spinel Cr# of 0.45-0.55 is more enriched in LREE relative to the former. Clinopyroxenes in dunites (spinel Cr# 0.40-0.68) also tend to be more enriched in MREE to LREE with increase of spinel Cr#. Particularly dunite with the highest spinel Cr# of 0.68 from the shear zone is the most enriched in MREE to LREE relative to other dunites. The chondrite-normalized trace element patterns for clinopyroxenes from this dunite show negative anomaly in high field strength (HFS) elements such as Nb, Ta, Zr and Hf indicating affinity to arc magma.

A positive correlation is observed in the diagram of spinel Cr# vs Ce/Yb ratio for clinopyroxene from dunites thereby indicating a reaction trend formed by flux-melting of harzburgite. Because the dunite with the highest spinel Cr# shows negative anomaly in the HFS elements, fluid that caused flux-melting in the mantle section might be carried from metamorphic sole due to dehydration of oceanic crust during suprasubduction stage. According to the distribution of dunites that contain spinels with high Cr# (>0.6), the fluid might have been locally migrated both in the basal part and along shear zone. However, dunite

 

that contains spinel with high Cr# (>0.6) is rare and not abundant unlike Fizh and Salahi mantle section in the northern Oman ophiolite.

Keywords: ophiolite, mantle, mid-ocean ridge, suprasubduction zone, mantle-melt reaction

# Arc magma-induced mantle refertalization: a case study of plagioclase peridotite in the Mineoka-Setogawa Belt, central Japan

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The Mineoka-Setogawa Belt, a Paleogene accretionary complex, is distrusted in the northern surroundings of the Izu Peninsula, central Japan. This belt contains ophiolitic mélange composed of serpentinized peridotite, mafic to felsic plutons and mafic volcanics. The serpentinized peridotite consists mainly of harzburgite, with a trace amount of lherzolite and dunite (Arai, 1991). In particular, the Mineoka-Setogawa harzburgite is characterized by containing calcic plagioclase (Takasawa, 1976; Arai and Takahashi. 1988). The Mineoka-Setogawa peridotite is sometimes intruded by the various sizes of hornblende gabbro dikes and veins. In the boundary between peridotite host and gabbro dike/vein, orthopyroxene (or sometimes anthophyllite) walls formed. In the case of thin gabbroic veins (<1 cm), HFSE-rich phases, such as zircon, ilmenite, rutile, and apatite, crystallized in the veins and wall minerals. These HFSE-rich phases could have formed through the interaction between magma and mantle. The above characteristics of the Mineoka-Setogawa peridotite are well similar to those of refertilization observed in abyssal peridotite from spreading axes (e.g., Dick et al., 2010; Morishita et al., 2004). The formation of the orthopyroxene walls as reaction products in the Mineoka-Setogawa peridotite indicates that the reactant magma could have been hydrous and Si-rich arc-related magma.

Keywords: Refertalization, Peridotite, Mineoka-Setogawa Belt

# Role of plutonics in the generation of felsic magmas at ocean island volcanoes —Oki Dozen and Ascension Island

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Ocean island volcanoes have the potential to erupt both effusively and explosively, with magmatic compositions ranging from basalt to rhyolite, similar to ocean islands such as the Canaries[I] and the Azores [II]. The generation of highly-evolved magmas in thin oceanic crust remains enigmatic with various islands preserving evidence for open-system magmatic processes, and generation by partial melting of oceanic crust[III]. The eruption of felsic magmas can also greatly increase the hazards they pose, and thus the more that can be understood about the processes leading to the generation of these evolved-magma compositions, the more we can hope to understand any potential future activity. Plutonic xenoliths represent the crystallized remains of magma storage regions, and can yield significant insights into the nature of magmatic processes, which may not be otherwise determined from looking at volcanic products alone. This contribution addresses the mechanisms for the production and eruption of evolved magma compositions at two contrasting ocean island volcanoes of Ascension Island in the Atlantic and at Oki Dozen in the Sea of Japan. While Oki Dozen is now extinct - K-Ar dating reveals the majority of activity occurred between 7.4 Ma and 5.4Ma[IV]-, recent Ar-Ar dating of Ascension Island has shown subaerial eruptions began around 1094 ka[V] with the most recent eruption to have occurred in the last 1000 years[VI] thus making future eruptions likely, and the importance of understanding the nature of the magmatic plumbing system even more vital.
We present whole rock XRF analyses, FTIR analyses of melt inclusions -and major and trace element concentrations within their host crystals- and textural information from BSE and CL images of crystal from the plutonic rocks from both Ascension Island and Oki Dozen. Our new data reveals that while the plutonic rocks from Ascension Island are generally more-evolved that the exposed volcanics, they still show no evidence for magma mixing or repeated use of a single storage region. While plutonics from Oki Dozen are of similar composition to the volcanic products, again there is no evidence for magma mixing in crystal textures, which is very different from the felsic magmas of the Canaries or Iceland[I,III]. Our data is used to highlight the importance of fractional crystallisation in the production of evolved magmas in ocean island volcanoes not directly related to any plate tectonic boundary, and reveals the importance of a pre-established crustal structure in the evolution of magmas in relatively thin oceanic crust.

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Keywords: Volcanic-plutonic connection, Ocean island volcanism, Magma plumbing systems

 