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

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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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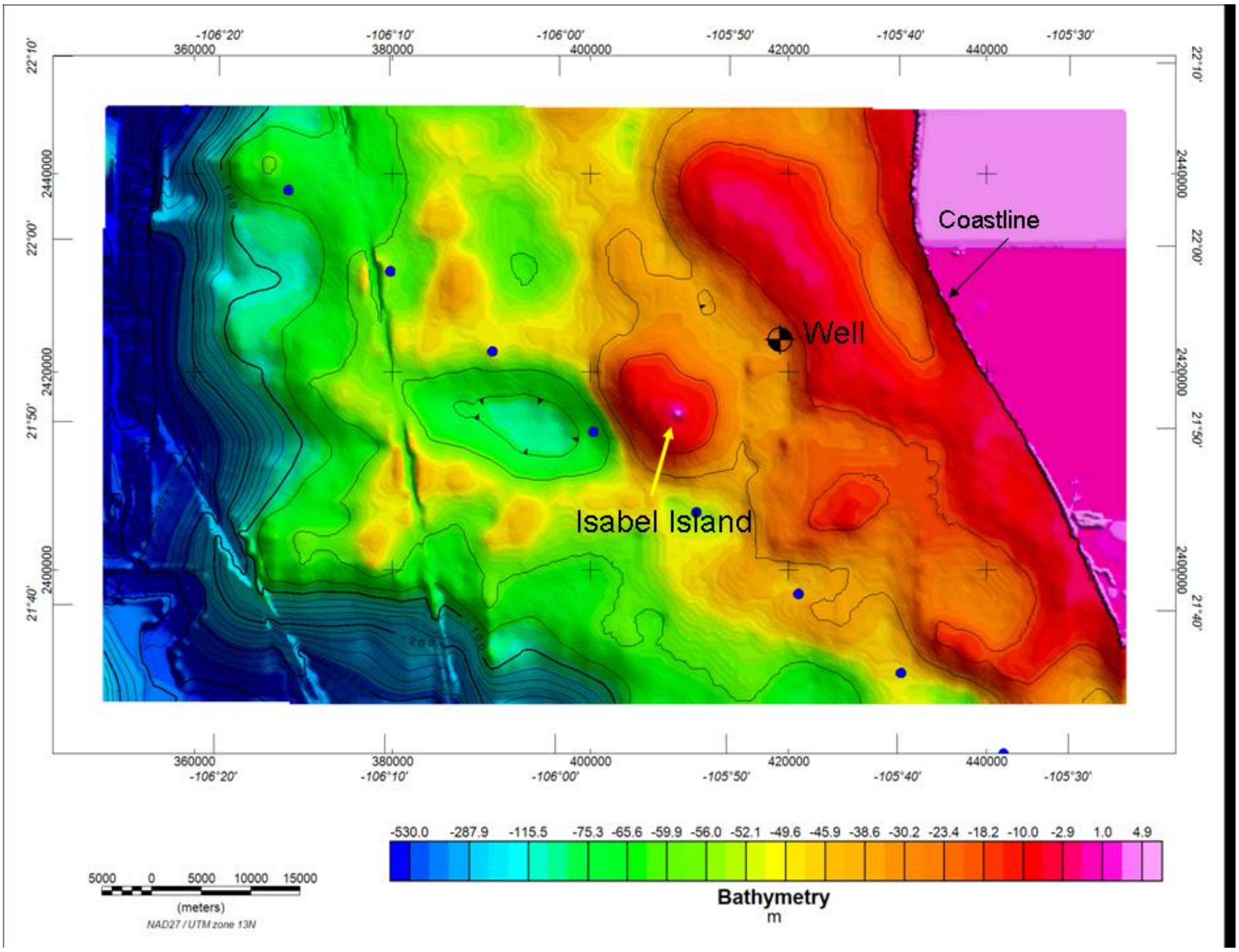
The crust at Isabel Island in the Mexican Pacific continental platform is only 17 km thick; this thickness has been determined by seismic studies, and more recently corroborated by a magnetotelluric one. The thin crust is the result of rifting and extensional tectonism induced by the separation of Baja 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
Well
Isabel Island
Bathymetry
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
5000 0 5000 10000 15000
(meters)
NAD27 / UTM zone 13N
-106°20' -106°10' -106°00' -105°50' -105°40' -105°30'
360000 380000 400000 420000 440000
22°10' 22°00' 21°50' 21°40'
2440000 2420000 2400000

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