Generation processes of magmas of large pyroclastic eruption cycles at Aso volcano, SW Japan

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Activities of Aso volcano, which has the largest caldera in SW Japan, are characterized by four large pyroclastic eruption cycles (LPEC) with 10^2 km^3 DRE and many minor eruptions between them after 300 ka. In order to understand magma plumbing system of Aso volcano, we investigated petrological and geochemical features of magmas of three LPECs with 20-30 ky interval between 141 ka and 90 ka.

In each of the three LPECs, the magmas were ejected from a gravitationally stratified magma chamber with a silicic magma overlying a mafic magma. Important geochemical features of them are summarized as follows. (1) Variation diagrams of incompatible element concentrations show same trends throughout the three LPEC. (2) The silicic and mafic magmas of each of the LPECs have the same Sr isotope ratio. (3) The Sr isotope ratio of each of the LPEC is slightly but clearly different from the other LPECs. (4) Whole-rock Ni concentration of a silicic magma is equal to or larger than that of a mafic magma in each of the LPECs. (5) K_2O contents of melts of the mafic magmas in the three LPECs are same and those of the silicic magmas are also same. These geochimecal features of the LPEC magmas indicate that the magmas of each of the LPECs were produced by distinct generation events from the other LPECs (features 3) and that the silicic and mafic magmas of each of the LPECs were generated from the same source (feature 1) whereas they have no parent-daughter relationship on fractionation (feature 4).

Magma genesis of each of the three LPECs can be explained qualitatively as follows. The magmas were generated by partial melting of gabbro in lower crust due to injections of hot magmas from the mantle. The mafic magma was produced by partial melting with high degree near the hot magmas, followed by fractional crystallization which decreased Ni concentration of the mafic magma. The silicic magma was generated by partial melting of the same gabbro with low degree relatively far from the hot magmas. The two magma batches segregated upward from the source areas and formed a shallow layered magma chamber.

For the above magma genesis, segregation processes of the magmas from the source areas are important. Although the Sr isotope ratios are slightly different between the three LPECs, the compositional trends on incompatible elements do not change (feature 1). If the source gabbros of the three LPECs have almost the same concentrations of highly incompatible elements, their concentrations of melt are approximate indices of degree of partial melting regardless of detail petrological processes. In that case, the feature 5 suggests that the silicic and mafic magmas segregated from the source areas at a certain degree of partial melting, respectively. Estimation of chemical composition of the source materials is needed to obtain degree of partial melting in magma genesis and physical constraints of the segregation processes.

Evolution of a large, hot, restless rhyolitic magma system at Laguna del Maule, Chile

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The Laguna del Maule Volcanic Field (LdM) is the foremost example of post glacial rhyolitic volcanism in the Southern Andes. New 40Ar/39Ar age determinations indicate that silicic eruptions began with deglaciation at about 19 to 20 ka and persisted until less than about 2 ka. These rhyolitic and rhyodacitic domes and coulees total 6.5 km3 and encircle the 23 by 16 km lake basin. This is not only the greatest concentration of post-glacial rhyolite in the Andes, but to our knowledge there has been no comparable rhyolite flare up this recently anywhere else on Earth. Colinear major and trace element variation suggests these lavas share a common evolutionary history (Hildreth et al., 2010). Moreover, geodetic observations (InSAR and GPS) indicate that LdM is inflating at a rate of 30 cm per year since 2007. Modeling predicts that an expanding magma body located at 5 km depth is driving this inflation (Fournier et al., 2010; LeMevel et al., 2013). The distribution of high-silica rhyolite lavas erupted 12 km apart on opposite sides of the lake within a few kyr of each other, magnetotelluric data showing an extensive zone of low resistivity at 5 km depth, and numerous local volcano-tectonic and long period earthquakes shallower than 5 km, suggest that the magma intrusion may represent only a portion of a much larger rhyolitic body, potentially of caldera-forming dimensions. Significant andesitic and dacitic volcanism is absent from the central basin of LdM since the early post-glacial silicic flare up began suggesting that a large body of low density rhyolite has blocked mafic magmas from reaching the surface. Temporal trends in the major element compositions of the phenocryst-poor and glassy rhyolite domes show the most evolved was erupted early in the post-glacial period followed by slightly lower-silica rhyolites. Two oxide thermometry reveals that the rhyolites tapped highly oxidized and hot melt stored at 760 to 850 oC and fO2 at Ni-NiO plus 1.25 log unit. Fractional crystallization modeling using the rhyolite calibration of the MELTS algorithm (Gualda et al., 2012) reproduces the high-silica compositions from a basaltic parental magma. The preferred model predicts 86 percent crystallization while cooling from 1290 to 800 deg. C at a depth of 5 to 8 km resulting in a water content of 4-6 wt. percent in the residual high-silica magma. The suite of recent LdM lavas lies on a single evolutionary pathway supporting a cogenetic origin. Our observations and modeling are are consistent with a large active, hot, crystal-poor, rhyolitic body of melt underlying much of the LdM lake basin. This body has the potential to fuel either a modest explosive eruption, or perhaps a caldera-forming eruption.

Changing the metaphor: from magma chamber to magma reservoir

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Two basic tenets of volcanology are: (1) volcanic eruptions are driven by exsolution of volatiles and (2) eruptions of near-liquidus (crystal-poor) melts require prior segregation/assembling of that melt into a single coherent body, or chamber. The first tenet derives from the prevalence of highly vesicular pyroclasts expelled by explosive eruptions coupled with clear evidence for syn-eruptive volatile loss during magma ascent and eruption coupled with the large volume change accompanying gas exsolution and decompression. The second is supported by the homogeneity of erupted magma compositions and physical properties erupted during single events, particularly during early phases of large eruptions. There is growing evidence, however, that both assumptions should be re-evaluated. First, not all explosively erupted pyroclasts are highly vesicular. Second, accumulation of very large volumes of crystal-poor melt is difficult to reconcile with (a) thermal models that suggest that large coherent volumes of eruptible magma should represent transients within the crust, (b) evidence that most magma is stored as crystal-rich mush, and (c) new data showing that erupted magma batches may be assembled shortly prior to eruption.

The inadequacy of conventional models is highlighted by mafic explosive caldera-forming eruptions, where storage of large melt volumes is thermally implausible and explosive ejection of large volumes of poorly vesicular magma is puzzling. To explain these eruptions, we suggest that melt is stored within, and erupted directly from, magma reservoirs, where we use the term reservoir in the sense used for water-, oil- and gas-bearing systems. This model extends the concept of eruptible melt assembled from a rigid sponge to the idea that the sponge itself may feed eruptions. Tapping an over-pressured network of melt pockets within a rigid crystal framework provides an attractive model for several reasons: (1) it does not require a large (thermally and physically unstable) body of molten magma to be assembled prior to an eruption, but instead allows erupted magma to be stored within a thermodynamically stable crystal mush; (2) it allows syn-eruption tapping of large melt volumes from within the reservoir through permeable networks established both prior to and during eruption; (3) decompression of an over-pressured reservoir provides a physical mechanism for magma ascent and eruption that does not rely on ascent-related gas exsolution as the only driving force; and (4) a reservoir model can link the timing of caldera collapse directly to the strength of the reservoir framework. We then examine the conditions under which this model may apply more generally to eruptions of crystal-poor melt.

Amphibole barometry in rhyolitic systems: an experimental recalibration and application to the Cappadocian ignimbrites (Turkey).

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Classical Al-in hornblende barometry relies on the hypothesis that the Al content in amphibole only depends on pressure, through the Tschermack substitution MgSi=^{VI}Al^{IV}Al. When temperature variations are taken into account, however, Al content in amphibole also varies through the edenite substitution _Si=Na^{IV}Al. Accurate Al-in hornblende barometers thus needs either to take into account the effect of temperature, or exclude the edenite substitution. We have performed a detailed experimental study of amphibole compositions as a function of pressure and temperature in a rhyolitic pumice from the Kizilkaya ignimbrite (Central Turkey). Samples were analyzed using optimized microprobe conditions in order to reduce uncertainties on Al content. Our data, combined with existing litterature data, show a very good pressure-dependence of the Tschermack substitution (correlation coefficient of 0.95) for amphiboles in equilibrium with biotite, plagioclase and quartz, reproducing experimental pressures with an average error of 36 MPa in the 100-400 MPa range. More experiments are underway to improve the accuracy of the barometer.

The Cappadocia area of Central Turkey superbly exposes a succession of Neogene dacitic to rhyolitic ignimbrites and fallout deposits, recording 10 Ma of magmatic activity. This provides an excellent example of long-lived, low frequency magmatic system, with a low average magma production rate (about 0.001 km3/a), but short-lived large eruptions (up to 300 km3 for the Cemilkoy ignimbrite). Extensive fieldwork campaigns, followed by AMS measurements, geochronology and geochemistry allow us to refine the characterization of the various units and provide a framework for petrological studies. Most of the ignimbritic and fallout units share a very similar phenocryst mineralogy (plagioclase + biotite + amphibole + magnetite + quartz). The low-variance phenocryst assemblage of those units makes them perfect target for our new Al-in amphibole barometer.

Amphibole-plagioclase thermometry of the six ignimbrite units and one plinian fallout unit investigated so far indicate relatively stable pre-eruptive temperatures between 700 and 760 °C for most units. Pressure estimates indicate that amphiboles crystallized in the upper crust, between 9 and 14 km depth, hinting at a constant depth of magma storage beneath the Cappadocian ignimbrite field over the last 10 Ma. Detailed investigation of various samples of one of the more recent unit, the Kizilkaya ignimbrite, produces a tight unimodal pressure distribution at 260 MPa (9.8 km), with a maximum data dispersion of 20 MPa (0.8 km), lower than the 2 sigma uncertainty of the barometer. If the erupted reservoir was homogeneous, as suggested by the absence of magma mixing, and amphibole was present in the entire reservoir, the aspect ratio of the erupted volume would be relatively low, with a minimum diameter of 7.5 km for a 1.5 km maximum height.

Experimental study of origin of silicic magmas in the primitive, intra-oceanic Tongan arc

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The origin of felsic magmas in intra-oceanic arc settings has been an active topic of debate. Currently, there are two main, but very different, processes suggested: fractional crystallization of basaltic magma and partial melting of lower crustal mafic amphibolites. The physical conditions, such as pressure, melt reactions, rates of melting and fluid dynamics of melt extraction differ markedly between these two mechanisms. A number of sophisticated numerical models of lower crustal amphibolite melting have been developed over the past decade. Such models are becoming widely invoked so there is a need for their applicability to be tested. Fonualei is unusual amongst subaerial volcanoes in the primitive Tongan arc because it has erupted dacitic vesicular lavas, tuffs and phreomagmatic deposits for the last 165 years and makes for an excellent natural laboratory. All of the products are crystal-poor and formed from relatively low viscosity magmas inferred to have crystallized at high temperatures.
Major, trace element and isotopic data, along with experimental data from partial melting of amphibolites and phase equilibria experiments on the basaltic andesites from Late have been combined to assess competing models for the origin of the dacites. Positive correlations between Sc and Zr and Sr rule out evolution by closed-system crystal fractionation and an origin by simple direct partial melting of amphibolite cannot reproduce the data either. Instead, we develop a model in which the dacites reflect mixing between two dacitic magmas, both products of fractional crystallization of basaltic-andesite magma. Mixing was efficient because the two magmas had similar temperatures around. Low-pressure equilibration of the magmas has been suggested by the Late phase equilibria experiments.

Mantle origin of basalts parental to tholeiitic differentiation products in the Andean Southern Volcanic Zone (SVZ): Confirmed by U-series disequilibria and $^{10}Be/^{9}Be$

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Some dominantly mafic volcanoes in a restricted part of the SVZ (37-41°S) have erupted basaltic andesites (52-56 % SiO2) with high Ti, Fe, and V that are the products of tholeiitic (TH) differentiation related to closed-system fractional crystallization and a high proportion of plagioclase in the fractionating assemblage. These volcanoes have not produced voluminous andesite with strong calc-alkaline (CA) affinities. Abundant CA andesite and dacite at volcanoes from 36.8-33°S are products of variable combinations of high-P (wet) fractionation and crustal assimilation. The most pronounced TH differentiates are young, crystal-poor lavas from Lonquimay (38.45°S: 2-3 ka to 1989; 53-64 % Si02). The most evolved have FeO∗/MgO 10, comparable to oceanic TH andesites. Major and trace element systematics eliminate open-system processes during differentiation, but the keys to linking these evolved magmas directly to mantle-derived parental basalts are U and Pa excesses, which we argue must be mantle signals. Lonquimay lavas have among the highest $^{10}Be/^{9}Be$ we have measured at six volcanoes in this arc segment. High ^{10}Be must also be mantle-derived. Nine Lonquimay magmas analyzed for U-Th-Pa-Ra activities have ($^{231}Pa/^{235}U$) 1.75-1.85, which is typical of basaltic magmas at Antuco, Llaima, Villarrica, Puyehue, and Osorno (1.5-2.1). These values extend to the most evolved Lonquimay magmas, verifying an absence of crustal contributions. Minor contamination (5-20%) of some historic eruptive products at Llaima is recorded by major and trace elements and diminished U, Ra, and Pa excesses. Elemental U/Th and ($^{238}U/^{230}Th$) are lower at Lonquimay (0.31, 1.15; 53-64 % SiO2) than in uncontaminated basalts at nearby Llaima (38.7°S; 0.37, 1.25), in accord with other distinctions. Evolved Lonquimay magmas have Sr-Nd-Pb isotopic compositions typical of mantle-derived, uncontaminated basalts in this part of the SVZ (e.g., 0.7039-0.7040), which are closely similar in terms of Sr and Nd isotopes to local Miocene granitoids. Inferred origins of TH magma series by partial melting of crustal lithologies under special circumstances, as has been proposed for Zao and Azuma volcanoes in the NE Japan Arc (Tatsumi et al., 2008; Takahashi et al., 2013), cannot be extrapolated to all TH differentiation trends in continental arcs.

Tomography of crustal magma bodies

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Because of the simplicity of the blob model for magma accumulation in the crust, geophysicists have long been intrigued by the potential signature a large magma body in the subsurface seismic imaging of volcano magma chambers is now relatively common and has been explored at numerous sites. Distinct and clear seismic evidence of large accumulations of molten material has proven elusive, perhaps as a result of poor resolution and lack of critical data, or because the magma plexus does not conform to pre-conceived notions. Furthermore, technical difficulties in the inversion schemes associated with noise suppression may be masking larger anomalies expected for high percent melt anomalies. Inherent blurring of seismic images, though, prevents detailed structural features from being isolated and associated with specific eruptive events. Examples illustrating inversion results at large volcanoes like Kliuchevskoi and the recently erupted Sheveluch appear to be feeding from deep within the mantle, well below crustal reservoirs where magma chambers are commonly imaged at eruption centers like Mt. St. Helens, Mt. Fuji, and Unzen. Typical crustal magma anomalies reside in the 7-15 km depth range and extend over from one to tens of km in radius. Attenuation analysis holds some promise for advances in estimation of partial melt percentages, although Q (quality factor) is elusive and difficult to constrain.

Deep magma feeding system of Fuji volcano, Japan

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Fuji volcano is the largest among Japanese Quaternary volcanoes. For the last 100kya, Fuji has erupted dominantly basalt magma, but its eruption style changed (from debris flow and tephra dominant Ko-Fuji or Older Fuji, to lava flow dominant Shin-Fuji or Younger Fuji) at 15 kyaBP. The incompatible trace element composition of the magma changed abruptly between Ko-Fuji and Shin-Fuji. The origin of the voluminous yet monotonous basalt production and the simultaneous changes in volcanic style and magma chemistry in Fuji volcano have been discussed but remain unanswered.

Here we report the seismic tomographic images of Fuji volcano for the first time, which reveal the existence of strong upwelling flow in the mantle and its connection to the voluminous lower crustal magma chamber. The velocity perturbations in the upper mantle and lower crust beneath Fuji volcano are much greater than other volcanoes in Izu arc (e.g., Hakone, Izu Oshima) and those in North Japan arc (e.g., Azuma, Iwate) suggesting higher degree of melting or larger volume of magma storage. Magma chamber is imaged in the lower crust 20-40 km depth and is wider in NW section but is narrower in EW section.

We also carried out high-pressure melting experiments on Fuji Basalt (Hoei-IV, AD1707) and demonstrate that its main magma chamber is located at ca.25km depth (Asano et al., this conference). The chemistry of Fuji magma is buffered by a lower crustal AFC magma chamber located at 25-35km depth. Very frequent low frequency earthquakes just above the magma chamber may be due to the injection of basalt magma and/or fluids (Ukawa, 2007). The total lack of silica-rich rocks (basaltic andesite and andesite) in Fuji volcano must be due to the special location of the volcano. The plate boundary between the Eurasia plate and the subducting Philippine Sea plate is located just beneath Fuji volcano (5 km depth). Large tectonic stress and deformation associated with the plate boundary inhibit the survival of a shallow level magma chamber, which would allow the evolution of basalt to silica-rich magma (as observed in nearby volcanoes, e.g., Hakone, Izu Oshima).

The change in volcanic eruption style may be understood by assuming the existence of a glacier (or thick ice-cap) during Ko-fuji. A landslide occurred at 17 kyBP and a large part of its volcanic edifice, including the summit of Ko-fuji, has been lost. This landslide would have been triggered by melting of the glacier and should have caused a significant deloading effect on the magma feeding system. Very large magma production with a peak at 10 kyBP might be explained by this deloading effect.

Upper crustal structure of Newberry Volcano from P-wave tomography and finite difference waveform modeling

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We show that seismic tomography combined with waveform modeling can constrain the dimensions and melt content of a magma body in the upper crust at Newberry Volcano, Oregon, USA. We obtain a P-wave tomographic image by combining travel-time data collected in 2008 on a line of densely spaced seismometers with active-source data collected in the 1980s. The tomographic analysis resolves a high-velocity intrusive ring complex surrounding a low-velocity caldera-fill zone at depths above 3 km and a broader high-velocity intrusive complex surrounding a central low-velocity anomaly at greater depths (3-6 km). This second, upper-crustal low-velocity anomaly is poorly resolved and resolution tests indicate that an unrealistically large, low-velocity body representing ~60 km^3 of melt could be consistent with the available travel times. This uncertainty in magma volume is largely due to wavefront healing of the first arriving seismic phase.

Here we show that we can more accurately constrain the magmatic system when, in addition to using arrival times of the primary phase, we also include amplitude information as well as the timing and amplitude of secondary phases that have interacted with the magmatic system. The densely spaced 2008 Newberry seismic data exhibit low amplitude first arrivals and an anomalous secondary P wave phase originating beneath the caldera. Two-dimensional finite difference waveform modeling through the tomographically obtained velocity model does not reproduce these observations. To reproduce these phases, we predict waveforms for models that include synthetic low-velocity bodies and test possible magma chamber geometries and properties. Three classes of models produce a transmitted P-phase consistent with the travel time and amplitude of the observed secondary phase and also match the observed lower amplitude first arrivals. These models represent a graded mush region, a crystal-suspension region, and a melt sill above a thin mush region. The three possible magma chamber models comprise a much narrower range of melt volumes (1.6-8.0 km^3) than could be constrained by travel-time tomography alone.

The New Tolbachik Fissure Eruption in Kamchatka, 27.XI 2012-2013. Earthquakes Preceding the Event and First Estimates of its Duration

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Magmatic feeding system and mechanisms of activity of the Kliychevskaya Group of Volcanoes (KGV) are considered. The KGV is one of the most significant volcanic center in subduction zones. It is located in the northern part of the Kuril-Kamchatka volcanic belt and consists of: the Kliychevskoi basaltic stratovolcano (the largest erupting volcano in Eurasia), the Bezymianny andesite volcano, the basaltic Hawaiian-type Plosky Tolbachik volcano (PT) with summit caldera, the Tolbachinskaya zone of cinder cones and fissure eruptions (TZ) and the Ushkovsky volcano.

In 1975-1976 the Great Tolbachik Fissure Eruption (GTFE) in TZ produced 2.2 km3 of basalts.

Development of the New Tolbachik Fissure Eruption (NTFE) started 27.XI 2012 is analysed, including: the location of the feeding fissure and the two eruptive centers on it in TZ; effusive nature of eruption with lava flows of liquid alumina basalts produced during the first two months covering an area of more than 27 km2.

Remarkable features of the process of local seismic activation preceding the NTFE are considered. Increase in the number of earthquakes under PT (at a depth of about 4 km near the peripheral magmatic chamber of PT) has started in mid-2012 and continued up to the beginning of NTFE. It has culminated during the last two days before NTFE in the form of a large swarm of small earthquakes that propagated towards to the surface. The swarm was the forerunner of the impending eruption and highlighted the position and depth of magma origin of the NTFE .

It is demonstrated, that during the first months, until January 20, 2013, NTFE was the large fissure lava eruption, slowly decreasing over time. Quantities of produced material and duration of such eruptions are subject for theoretical estimations. The first rough estimates have been given for the NTFE on December 15, 2012 and on January 22, 2013 respectively.

The initial forecast has assumed continuation of the NTFE while the amount of volcanic products will not exceed the amount of alumina basalts (500 million tons) potentially accumulated in the peripheral magmatic chambers of the PT volcano. Thus in this case, an exponential decay of the eruptive activity could last up to 110 days.

According to preliminary estimates of volumes of erupted lava in the NTFE, available by mid-January 2013, the number of produced basalts significantly exceeded the volume of excess magma, potentially located in the peripheral magma chamber of the PT volcano. For the next forecast the redundant magma volume accumulated up to the NTFE in magmatic systems throughout the KGV (2,100 million tons) has been considered as a possible upper limit of the volume of eruptive products. In this case, the volume of lava produced by the NTFE may exceed 1 km3 and reach the amount of lava erupted in the Southern breakthrough of the GFTE in 1976. Thus, the NTFE may continue for up to 300 days.

Low velocity structure beneath Kyushu island, Japan, inferred from Receiver functions.

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The Kyushu island, Japan, there are many active volcanos, for example, Aso, Kirishima, and Sakurajima volcanos along with the volcanic front, and Unzen volcano located far from the volcanic front. Information on structures beneath active volcanos is very important, and many researchers have revealed the structures under the active volcanos. Receiver function analysis is a useful tool to image the seismic velocity structures. We apply it to image the Kyushu volcanic area. In this study, we use teleseismic records from Hi-net and F-net seismic stations in Kyushu, which are supplies by the National Research Institute for Earth Science and Disaster Prevention. When those seismic stations are located at the top or in the sedimentary layer, the records include strong effect of reverberation within the sedimentary layer, which makes the image of the structure unclear. To overcome this problem, we exploit the modified S-wavevector receiver functions (SWV-RFs) [Takenaka and Murakoshi, 2010, SSJ]. The SWV-RFs is derived by deconvoluting the upgoing S-wave component with the upgoing P-wave component of the records [Reading et al., 2003, GRL]. For suppressing the sedimentary layer effect, we virtually move the seismic sensor to the top of the basement layer, and calculate the SWV-RFs at that location [Takenaka and Murakoshi, 2010]. This method needs the structure model from the surface to the sensor location. We employ the Integrated Velocity Structure Model by the Headquarters for Earthquake Research Promotion. We take several cross sections in Kyushu island to map the calculated SWV-RFs. We then interpret the continental Moho, the Philippine Sea Plate and low velocity regions in the mapped SWV-RFs. It can be seen that characteristic low velocity regions beneath the crust around volcanic area, some of which may be related to magma. We will also model some SWV-RF sections by the 2.5-D finite-difference method [Takenaka and Okamoto, 2012, InTech] to confirm our imaging results.

Why we need ultra-deep drilling into IBM arc crust?

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At first glance, intra-oceanic arcs do not appear to be the right place to study the production of andesitic magmas, because (1) modern magmatism at the intra-oceanic Izu-Bonin-Mariana (IBM) arc is bimodal, with basalt and rhyolite predominating (Tamura and Tatsumi, 2002); and (2) turbidites sampled during Ocean Drilling Program (ODP) Leg 126 in the Izu-Bonin arc, which range in age from 0.1 to 31 Ma, are similarly bimodal (Gill et al., 1994), suggesting that the bimodal volcanism has persisted throughout much of the arc's history. Moreover, such bimodal magmatism is not unique to the Izu-Bonin arc, with the 30-36.5 degrees S sector of the Kermadec arc, another example of an intra-oceanic arc, also exhibiting it (Smith et al., 2003; 2006; Wright et al., 2006). So why and how do we study the intra-oceanic arcs to solve the 'andesite problem'?

Closer inspection of the IBM arc remarkably reveals the presence of a significant volume of middle crust with seismic velocities of 6.0-6.8 km/s throughout the entire arc (Calvert et al., 2008; Kodaira et al., 2007a,b; Kodaira et al., 2008; Kodaira et al., 2010; Takahashi et al., 2007; Takahashi et al., 2008; Takahashi et al., 2009). This is remarkable because these velocities are characteristic of a wide range of intermediate-felsic plutonic/metamorphic rocks (Christensen and Mooney, 1995; Behn and Kelemen, 2003, Behn and Kelemen, 2006) and are similar to the mean velocity of andesitic continental crust, such material would not be expected to be present on the basis of the bimodal volcanism. Moreover, this crust is presently thickest beneath basaltic volcanoes and thinnest beneath rhyolitic volcanoes (Kodaira et al., 2007), which is another enigma.

One possible way to understand this phenomenon is to investigate arc crustal sections exposed on land in order to examine the relationship between volcanic and plutonic rocks and the generation of andesitic magmas, as exposed arc crustal sections typically include middle crust composed of diorite to tonalite to granodiorite (e.g. Kawate and Arima, 1998; Busby et al., 2006; DeBari and Greene, 2011). However, any continental crust we observe on the surface of the Earth will have experienced deformation, metamorphism, and been otherwise processed, perhaps several times from its creation in subduction zones to the present day, thus overprinting, resulting in the loss of, key information that can provide clues to its genesis.

'Ultra-Deep Drilling into Arc Crust' is the best way to sample unprocessed juvenile continental-type crust in order to observe the active processes that produce the nuclei of new continental crust, and to examine the nature of juvenile continental crust being generated at intra-oceanic arcs.

Along-arc geochemical and isotopic variations in Javanese volcanic rocks: constraints on the crustal architecture of the Sunda arc, Indonesia

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Understanding the genesis of volcanic rocks in subduction zone settings is complicated by the multitude of differentiation processes and source components that exert control on lava geochemistry. However, through detailed studies of individual magmatic systems it is possible to identify and establish the relative importance and contributions of various potential source components and differentiation processes that modify composition, such as crustal contamination. Geochemical and isotopic constraints on the 'crustal' end members involved in assimilation at individual volcanoes, can then be combined to gain insight into the nature of the arc crust on an island- or arc-scale. Along-arc changes in lava geochemistry have long been recognised on Java in the Sunda arc, Indonesia, but debate still prevails over the cause of such variations and the relative importance of shallow (crustal) versus deep (subduction) contamination. We present new Pb isotope data for Javanese volcanoes, which, when combined with our recently published geochemical and isotopic data of Javanese volcanic rocks and results from other detailed geochemical studies, elucidate the potential changing nature of the arc crust and its control on lava chemistry. In $^{207}Pb/^{204}Pb$-$^{206}Pb/^{204}Pb$ isotope space the Javanese volcanic data reveal two distinct trends. One trend, which consists of one West Javanese and the Central Javanese volcanoes, exhibits a wide range in $^{207}Pb/^{204}Pb$ at relatively constant $^{206}Pb/^{204}Pb$ (a steep positive correlation) and is attributed to strong control by crustal assimilation processes. The second trend shows a shallower positive correlation between $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ and is consistent with source contamination by local sedimentary material on the down-going plate. Sr isotope ratios of volcanic rocks generally increase from West to Central Java, showing a wide range within individual volcanic centres and broadly correlating with inferred crustal thickness implying a strong, shallow level control on isotopic composition. However, East Javanese volcanic rocks show significantly lower Sr and Pb isotopic ratios and extremely restricted isotopic variation at individual volcanoes. Key trace element ratios combined with radiogenic isotopic data of Javanese volcanoes reveal three distinct trends, which roughly equate with the geographical boundaries West, Central and East Java. These results provide evidence for major transitions in the crustal architecture of Java.

Andesites and the continental crust

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The relationship between andesites and the continental crust occupies a special place in petrology. Compositionally andesites resemble continental crust both in intermediate silica contents, and in their LREE enrichment. The relationship between andesites and subduction is also compelling given that continental crust seems to have formed predominantly at subduction zones. The association suggests that if we can establish how andesites form we can, as a consequence, determine the origin of the continental crust.

One possibility is that andesites are the natural result of density filtering by the crust. Such a suggestion gains support from consideration of tectonic environments such as the Andes. Here subduction related magmas rise through continental crust at composite volcanoes, while to the east on the Altiplano, extension permits shoshonitic and more mafic magmas to pass through the crust. The composite volcanoes of the Andes therefore seem to be filtered or stewed in the crust. But there is perhaps a circular argument here if we are suggesting that the manufacture of andesites actually requires a crustal filter. It may well be that andesites are self filtering.

The hydrous character of andesites at subduction zones means that they will be subject to prolific crystallisation. For mafic primary or primitive magmas, olivine crystallisation will be promoted. This will lead to rapid decreases in MgO and NiO and increases in silica, generating major element compositions similar to the crust. Nevertheless, olivine crystallisation alone cannot rotate REE patterns to match those of the crust. For this, and to satisfy Dy Yb relationships, the involvement of amphibole appears to be required (either as a fractionate or a residue). Amphibole crystallisation will similarly leverage silica contents to intermediate values. Note that some models advocating an adakitic origin for the crust (high pressure wet melting of basalt) are more consistent with garnet fractionation, which, in turn, does not fully satisfy the Dy Yb systematics of continental crust. So wet andesites may fractionate olivine at first, but the most significant differentiation will likely involve plagioclase and amphibole fractionation, producing continental crust like compositions via multiple mixing and cannibalisation of magma batches. Magmas will contain significant crystal cargoes, and will be capable of filtering via both density and rheology.

A witness to this processs is provided by the crystal cargo itself, especially plagioclase, for which examination of crystal core rim stratigraphy, in particular Sr isotopes and dissolution surfaces, invariably provides evidence of multiple open system cycling and mixing.

Sr-Nd-Pb-Hf isotopic study of Cretaceous to Paleogene granitic rocks from northeast Japan

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The Japanese Islands represent a segment of a 500 Ma old subduction related orogen developed along the western Pacific convergent margin, and most tectonic units are composed of late Paleozoic to Cenozoic accretionary complexes and their high P/T metamorphic equivalents (e.g., Maruyama, 1997; Isozaki et al., 2010). Maruyama (1997) described the formation of the Japanese Islands has been taken as the standard model for an accretionary orogeny. He also stated that the most important cause of the orogeny is the subduction of an oceanic ridge, by which the continental mass increases through the transfer of granitic melt from the subducting oceanic crust to the orogenic belt. On the other hand, Jahn (2010) described that the subduction-accretion complexes consisting of granitic and sedimentary rocks in southwest Japan are composed mainly of recycled old continental crust.

We present Sr-Nd-Pb-Hf isotopic ratios for granitic rocks in northeast Japan. Kagami et al. (1999) described that the Honshu Arc can be divided into three groups based on their Sr-Nd isotope characteristics: the Kitakami, North (Abukuma belt), and South (Ashio/Mino belts) Zones, in order of increasing Sr isotopic enrichment, with Nd isotopic depletion from NE to SW. Among these zones, the Kitakami zone is characterized by the occurrence of adakitic rocks probably related to Lower Cretaceous ridge subduction. Sr-Nd-Pb-Hf isotopic study are made for granitic rocks from the Kitakami belts (Kitakami Mountains), the Abukuma belts (Shirakami Mountains, Obonai area, Taihei Mountain, Sekiryo Mountains, and Abukuma Mountains), and the Ashio/Mino belts (Okutone area, Tadami area, Okutadami area, Taisyaku Mountains, and Ashio Mountains). Newly isotopic data from these granitic rocks show increasing enrichment of crustal component in order of the Kitakami, Abukuma, and Ashio/Mino belts. Multi-isotope plots of these rocks indicate that the trend in variation could result from the mixing of depleted and enriched components. The depleted components are likely to originate from the magmatic flux related to the Lower Cretaceous ridge subduction. On the other hand, the enriched components probably originate from the old continental fragments of proto-Japan initially developed along the southeastern margin of the South China Block.

Geophysical Investigations of Cerro Negro Volcano, Nicaragua: Insights on magmatic plumbing systems

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Cerro Negro near Léon, Nicaragua is a very young (163 years), relatively small basaltic cinder cone volcano that has been unusually active during its short lifespan (recurrence interval 6-7 years). Multiple explosive eruptions have deposited significant amounts of ash on Léon and the surrounding rural communities. While there have been a number of studies investigating the geochemistry, stress regime, and hazard implications of the volcano, subsurface structures have only been studied by shallow soil gas surveys. These studies have raised several questions as to the proper classification of Cerro Negro and its place in the regional stress regime. Should Cerro Negro, very young but very active, be considered a short lived, low intensity polygenetic cinder cone on the Cerro La Mula-Cerro Negro alignment, or as the early stages in the development of a longer lived, higher intensity stratovolcano? Is Cerro Negro a separate entity from neighboring Las Pilas-El Hoyo with a separate magma source, or merely the newest vent on the Las Pilas-El Hoyo volcanic complex? While surface features at Cerro Negro follow definite alignments that correspond to the regional stress regime, is this pattern continued and controlled by similar mechanisms at depth? In order to address these questions, we collected both gravity and magnetic data on Cerro Negro volcano in February and March of 2012 and 2013 in an attempt to delineate deep structures at the volcano. The gravity survey included a tight grid on Cerro Negro itself, an irregular grid of several stations on Las Pilas-el Hoyo, and several distal stations forming a ring approximately 24 x 31 km around Cerro Negro . Magnetic data was collected along several profiles within 3 km of Cerro Negro.

Analysis of gravity and magnetic data have revealed a marked NE-SW regional gravity trend, a 5 km^3 positive anomaly beneath the neighboring Las Pilas-El Hoyo volcanic complex, a NNW trending linear anomaly beneath the Cerro Negro-Cerro La Mula alignment, and a 3 km^3 positive anomaly to the southeast of Rota volcano. These findings suggest that eruptions at Cerro Negro may be tapping a large magma reservoir beneath Las Pilas-El Hoyo, implying that Cerro Negro should be considered the newest vent on the Las Pilas-El Hoyo volcanic complex. As such, it is possible that the intensity of volcanic hazards at Cerro Negro may eventually increase in the future to resemble those pertaining to a stratovolcano.

Nature of Sub-volcanic Magma Chambers in Emeishan Province, China: Evidence from Quantitative Textural Analysis of Plagioclase Megacrysts in the Giant Plagioclase Basalts

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Sub-volcanic magma chambers in the Crust might be a widespread component of large flood provinces, however these magma processes in Emeishan large igneous province (LIP) remain unclear. The Giant Plagioclase Basalts (GPB) which can reveal the sub-volcanic magma chambers' presence widely occur in Emeishan LIP. The plagioclase megacrysts are 2 -5 mm , have compositions ranging from An_{53} to An_{60} and are generally weakly zoned, The GPBs are texturally classified into isolated coarest crystals(IC) and glomeroporphyritic crystals(GC) type. A completed Permian basaltic section in the middle Emeishan LIP is studied in order to further constrain GPBs' petrogenesis and sub-chambers magma process. The IC basalts and the GC basalts in this section are interlayered, the GPB flows can be divided into five flows which are GC1 flow, IC1 flow, GC2 flow, IC2 flow and GC3 flow. The crystal size distributions(CSD) of these megacrysts mostly plot as almost straight lines on a classic CSD diagram, and the characteristic lengths of the five flows are 1.54 mm, 2.99 mm, 1.70 mm,3.22 mm and 1.86 mm, respectively. Taking a simple assumption of plagioclase steady-state magma chamber models and simple continuous growth at the rate of 10^{-10}mm/s, the results suggest the possible every flow magma residence times of 489.2 years, 946.7 years, 538.7 years, 985.9 years and 588.3 years, respectively. Using the thickness and duration of IC1 flow, GC2 flow and IC2 flow, we may get the megacryst-bearing magma eruption rate of 0.422 m/year,0.324 m/year and 0.350 m/year. However, the lack of crystals smaller than 2 mm suggests that coarsening may have been involved because of temperature cycling. A possible history is as follows:(1) magmas derived from mantle start to accumulate at crust, forming the sub-volcanic chambers;(2) the glomeroporphyritic crystals grow in higher-level static sub-volcanic chamber, the isolated coarest crystals grow in lower-level sub-volcanic chamber which is filled gradually with hot, new magma and coarsen in response to thermal cycling;(3) the five flows of GC type and IC type are the products of volcanic magma cycle.If we take the duration of IC1 crystallization as aphyric basalts eruption duration, we can give a 23.9-m-thick aphyric basalts flow rate of 0.049 m/year. Quantitative integration of textural and field information for igneous rocks can contribute to our understanding of physical processes and petrogenesis in the sub-volcanic chambers of Emeishan LIP.

Across arc variation of strontium isotopic and K_2O composition in the quaternary volcanic rocks from west java: evidence for crustal assimilation and the involvement of subducted components

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Many studies in the West Java suggested that Sr isotopic ratios and K_2O contents increase from the volcanic front to the back arc side volcanoes. In detail, however, when the normalized of K_2O wt% to SiO_2=55 wt% from the West Java Arc (WJA) are closely examined and compared with the Northeast Japan Arc (N 38°-41°, NEJA), the WJA shows rough across-arc variation and more diverse in K_2O especially in the volcanic front. For this reason, Sr isotope, major and trace elements data from 54 volcanic rocks of Quaternary volcanoes from WJA were collected and compared to 46 volcanic rocks of Quaternary volcanoes from NEJA. The increasing K_2O and decreasing of $^{87}Sr/^{86}Sr$ ratios with distance from trench have been found in NEJA but there are rough and no across arc variation of K_2O and Sr isotopic ratios in WJA. Our study shows that the across arc variation of magma chemistry on the WJA can be explained by crustal assimilation and the involvement of subducted components (e.g. altered oceanic crust and subducted sediment).

Structure of the Tongariro Volcanic Complex Magmatic System, New Zealand: Insights from Magnetotelluric Imaging

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A key step in understanding a volcanic system is the determination of the location and size of the magma reservoir beneath the volcano. The electrical conductivity or resistivity of a magma reservoir containing an interconnected melt fraction will be much more conductive than the surrounding host rock. Here we use the results from 136 magnetotelluric (MT) measurements to determine the location and structure of the magmatic system beneath the Tongariro Volcanic Complex. 3-D inverse resistivity modelling of the MT data shows a narrow vertical conductive zone located beneath Mount Ngauruhoe linked to but offset from a larger more conductive region about 4 km beneath the surface centred under the north-eastern flanks of Mount Tongariro. The location of the recent eruption and seismicity prior to the eruption occurred at the margin of this larger conductive region.

Magnetotelluric images of magma distribution beneath Volcan Uturuncu, Bolivia

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The Altiplano-Puna magma body (APMB) is recognized as one of the largest magma bodies on Earth. Geophysical studies reveal a thin ultra-low velocity zone at a depth of about 20 km that is inferred to be 14-27 percent partial melt and less than 1 km thick (1,2). The APMB was also noted to have a very low resistivity by early MT studies. Furthermore, the APMB is spatially associated with the major ignimbrite eruptions of the Altiplano-Puna Volcanic Complex (APVC). Volcan Uturuncu in Southern Bolivia is located near the centre of the APMB and has been inflating over the past two decades at rates of 1-2 cm/year. It has been suggested that this represents a location where pluton formation may be occurring in real time (3,4).

The PLUTONS project is making a comprehensive set of geological and geophysical measurements to define the distribution of magma beneath Volcan Uturuncu, and also to understand the eruptive history. This has included geological studies, seismic monitoring, and detailed geodetic measurements. Magnetotelluric (MT) data use passive electromagnetic signals to image subsurface resistivity from the surface to the upper mantle. Electrical resistivity is an important property because it is sensitive to the presence of partial melt and hydrothermal fluids in the crust.

An extensive MT data set was collected at Volcan Uturuncu in 2011 and 2012. Broadband MT data in the frequency band 0.001-300 Hz were collected at 149 stations. These data are being analysed to generate both 2-D and 3-D resistivity models of the subsurface. Initial analysis of the data has revealed a number of interesting features. An anomalous region of low resistivity at a depth of about 20 km is detected and can clearly be identified as the APMB. This region disappears as we move farther west. The upper boundary bulges upward below Volcan Uturuncu. A number of low resistivity fingers can also be seen, which connect the APMB conductor to the surface above, possibly representing past conduits with hydrothermal alteration, or shallow accumulations of magma beneath Volcan Uturuncu.

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Towards a sharper image of the Lazufre complex in the Central Andes by combining independent data from magnetotellurics and InSAR

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The Lazufre volcanic complex in the Central Andes constitutes one of the largest inflating volcanic systems in the world. An InSAR time series produced by combining the ERS1, ERS2 and Envisat radar data archives allowed to detect an uplift increasing to currently 3-4 cm/a, affecting an area of over 2000 sq km. Geodetic inversion modeling hints at influx of magmatic material into the upper crust at approx. 10 km depth. Since partial melts are good electrical conductors, such a system forms an ideal target for deep electromagnetic investigation, particularly magnetotellurics (MT).

Preliminary long-period magnetotelluric soundings were carried out along a W-E running profile across the structure from the Chilean Precordillera into the Argentinian Puna. Additional sites were placed around the center, although coverage was limited due to difficult accessibility and other logistical issues. Dimensionality and strike analysis did not yield an unequivocal electrical preference direction; induction vectors clear hint at a three-dimensional subsurface conductivity distribution. Thus two-dimensional modeling needs to be regarded with care. Nevertheless, the resulting model already shows a vast conductor beneath Lazufre, extending through the entire crust. This is corroborated by three-dimensional inversion: a high-conductivity zone rises obliquely from the upper mantle to a depth of approximately 10 km. Therefore, the depth of the roof of the high conductivity region correlates well with the depth of the magmatic sill inferred from InSAR data. Although the mantle source is only poorly resolved, we believe that melts originating from the upper mantle constitute the source of the volcanic uplift. Other features of the model comprise a conductor associated with the Precordillera Fault System and the well-conducting Puna; both structures are in accordance with earlier studies farther to the north.

Geophysical and laboratory constraints on the size and composition of crustal magma bodies

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A number of magnetotelluric (MT) and seismic studies have detected coincident zones of low resistivity, low seismic velocity, and high attenuation in the mid-crust of active orogens. These have been detected in both continent-continent collisions such as the Tibetan Plateau (1), and in the thickened crust formed above a subduction zone in the Altiplano (2). These anomalies have been interpreted as zones of fluids, most likely a combination of aqueous fluids and partial melts.

In addition to causing volcanic eruptions, these zones of partial melt are key geodynamic features since they weaken the crust and can control how the orogen deforms. However, the rheology is very sensitive to the amount of melt, its composition, and distribution. Geophysical data alone cannot define these parameters reliably. Laboratory measurements of the electrical and rheological properties of melts provide invaluable constraints when determining these properties. In this paper we analyse MT data from Southern Tibet and the Altiplano with available seismic and laboratory data to constrain the properties of mid-crustal magma systems.

In Southern Tibet, magnetotelluric studies have reported a high conductance in excess of 10000 S. This is the product of the layer thickness and conductivity, and is the quantity most reliably determined from MT data analysis. These observations were combined with laboratory data from partial melting experiments on metapelites (3) and passive seismic studies. The results suggest that the pure melt phase has a higher resistivity than previously thought, requiring a relatively thick layer of leucogranite partial melt.

Magnetotelluric and passive seismic data from the Southern Altiplano has detected a major magma body termed the Altiplano-Puna Magma body. Seismic data gives a thickness and velocity constraint that can be combined with the high conductance to yield revised estimates of the melt fraction and layer thickness.

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Accelerating unrest within a large rhyolitic magma system during 2007-2013 at Laguna del Maule volcanic field, Chile

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The Laguna del Maule (LdM) volcanic field is remarkable for its unusual concentration of post-glacial rhyolitic lava coulées and domes that were erupted between 20 to less than 2 thousand years ago. Covering more than 100 square kilometers, they erupted from 24 vents encircling a ∼20 km diameter lake basin on the range crest of the Andes. This recent concentration of crystal-poor rhyolite is unparalleled both in the Andes and globally. Geodetic measurements at the LdM volcanic field show rapid uplift since 2007 over a ∼20km diameter area centered on the western portion of the young rhyolite domes. By quantifying this active deformation and its evolution with time, we aim to investigate the storage conditions and dynamic processes in the underlying rhyolitic reservoir that drive the ongoing inflation. Analyzing interferometric synthetic aperture radar (InSAR) data, we infer the following evolution of the deformation: the rate of vertical displacement is negligible from 2003 to 2004, and then accelerates from at least 200 mm/yr in 2007 to more than 300 mm/yr in 2012 (Feigl et al., 2013, in review). The deformation signal is modeled as inflation of a 7.5 km by 5.5 km sill at a depth of 5 km, assuming a rectangular dislocation in a half space with uniform elastic properties. The sill's maximum rate of inflation is $51 \pm 8 \times 10^6$ m^3/yr in 2012. In total, the volume increase of the source is about 160 million cubic meters since inflation began, no later than March 2007. Three continuous GPS stations installed in April 2012 around the lake confirm this extraordinarily high vertical uplift rate of more than 280 mm/yr and a significant radial expansion. As of January 2013, the rapid deformation persists in the InSAR and GPS data. During this interval, the rate of deformation at Laguna del Maule is higher than at any other volcano that is not actively erupting. For example, the remarkable recent inflation episodes at the Yellowstone (Chang et al., 2010) and Santorini calderas (Newman et al., 2012;Parks et al., 2012) exhibit rates two to five times slower than at LdM. Using the dynamic models, we can calculate changes in the local stress field. In particular, a large increase in stress in the magma chamber roof might lead to initiation and/or reactivation of ring faults. A finite element model is being developed to describe the configuration of the magmatic system and overpressure responsible for the observed uplift. Several hypotheses are considered for driving the deformation, including: (1) an intrusion of basalt into the base of a melt-rich layer of rhyolite leading to heating, bubble growth and subsequent increase pressure in the reservoir, and/or (2) the possibility of inflation of a hydrothermal system above the rhyolite melt layer.

Structural control on magmatism along divergent and convergent plate boundaries

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Plate boundaries, characterized by seismic and volcanic activity, are the most active, unstable and hazardous areas on Earth. Our knowledge on the structure and magmatic processes along plate boundaries has dramatically improved in the last decade, allowing proposing a timely overview on the structural control on magmatism.

I first provide an overview of the main structural features along divergent and convergent plate boundaries, as well as their relationships to volcanism. Such an overview is meant to summarize the current state of the art, offering a comprehensive perspective, highlighting tectono-magmatic relationships, similarities and differences in the various settings.

I then propose an original and innovative frame to understand and study tectono-magmatic processes along plate boundaries, based on the two following major points. a) Tectonics and magmatism are both effective in controlling the development of any plate boundary. Along divergent plate boundaries, regional tectonic extension may play a major role in the early phases of rifting, at least in the upper crust; however, magmatism is the most effective way to spread plate boundaries apart along mature continental rifts and oceanic rifts. Along convergent plate boundaries, at least three different processes may allow magma to play a crucial role in controlling the structure of volcanic arcs. This suggests that a significant part of the evolution of both divergent and convergent plate boundaries is magma-induced. b) Magmatism along both divergent and convergent plate boundaries focuses along wedges, or magmatic systems, usually controlled by a dominant volcano. Magmatic systems display specific geometric features, suggesting that the linear mode of magmatic accretion of divergent plate boundaries and extensional arcs is replaced by a punctiform mode of accretion in compressive arcs. Also, magmatic systems in each tectonic setting are characterized by specific compositional features, as a function of the opening rate: these compositions range from mafic (fast oceanic ridges), passing to bimodal, with a progressively higher amount of felsic component (from slow spreading ridges to immature continental rifts), to reach andesitic terms (compressive arcs).

Magma genesis of the acidic volcanism and association with basaltic volcanism in the intra-arc rift zone of the Izu volcanic arc, Japan

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The Izu volcanic arc extends over 550 km from the Izu Peninsula, Japan, to the Nishinoshima Trough or Sofugan tectonic line. It is the northernmost segment of the Izu-Bonin-Mariana arc system, which is located at the eastern side of the Philippine Sea Plate. The recent magmatism of the Izu arc is bimodal and characterized by basalt and rhyolite (e.g. Tamura and Tatsumi 2002). In the southern Izu arc, volcanic front (VF) from the Aogashima to the Torishima islands is characterized by submarine calderas and acidic volcanisms. The intra-arc rifting (IAR), characterized by back-arc depressions, small volcanic knolls and ridges, is active in this region. The echelon seamount chain (ESC), backarc side of the intra-arc rift zone, was active before 2.8Ma. Volcanic rocks were obtained in 1995 during a research cruise of the R/V MOANA WAVE (Hawaii University, cruise MW9507) from VF to ESC in the southern Izu arc, and that of the R/V TANSEI-MARU (University of Tokyo, cruise KT09-12) around the Myojin Depression in the intra-arc rift zone. Geochemical variation of volcanic rocks and magma genesis were studied by Hochstaedter et al. (2000, 2001), Machida et al (2008), etc. These studies focused magma and mantle dynamics of basaltic volcanism in the wedge mantle. Acidic volcanic rocks were also dredged during the cruises MW9507 and KT09-12 mainly from the IAR. However, studies of these acidic volcanics were rare. Herein, we present petrographical and chemical analyses of these acidic rocks, and compare these results with those of other acidic rocks in the Izu arc and lab experiments, and propose a model of magma genesis in a context of acidic volcanism and association with basaltic arc volcanism.

The petrographical features of rhyolites exhibit massive or flow textures, and aphyric or rare phyric. Phenocrysts are mainly plagioclase and quartz. Colored minerals are rare and observed mainly orthopyroxene. Amphibole and biotite are not observed. The phenocryst and groundmass mineral compositions of rhyolites exhibit felsic characteristics and narrow ranges. These mineral compositions are not overlapped on those of andesites and basalts. Bulk composition of rhyolite shows depleted in the VF side and enriched in the backarc side. Especially, HFSE systematics indicates the parent material of rhyolites was enriched in the backarc side.

Acidic volcanism in the Izu arc is considered to partial melting of arc middle to lower crust (e.g. Tamura and Tatsumi, 2002) because rhyolite exhibits similar composition to melting experimental results of basaltic or andesitic parental material under anhydrous, low pressure and low temperature (e.g. Shukuno et al., 2006). Compare to these experiments, we consider that volcanics in the rift zone was produced from decompressional melting of andesitic middle crust under anhydrous melting, and this crust exhibits depleted in the front side and enriched in the reararc side caused by across-arc variation of basaltic volcanism.

Petrology and geochemistry of java volcanoes, indonesia: a key for understanding the lithospheric interior beneath western sunda arc

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Phenocryst assemblage, Sr isotopic, K_2O and Nb concentration data from 28 Quaternary Java Volcanoes were collected. The distinct lateral variations in the abundances of Sr isotopic ratios, K_2O and Nb are observed along the Java but only rough lateral variation across the Java. Based on phenocryst appearance, Java Volcanoes can be divided into 3 groups, which are: Muria group (biotite), Tangkuban Prahu group (amphibole and pyroxene) and Papandayan group (pyroxene) which show inter fingering relation. From Krakatoa to Lamongan (West to East); K_2O and Nb contents increase gradually. Whereas, Sr isotopic ratios decrease along the Java Arc, except: Papandayan and Merapi Volcanoes. On the other hand there is only rough and no across arc variation for Sr isotopic ratios, K_2O and Nb contents. Lateral and across arc variation of phenocryst assemblage, Sr isotopic, K_2O and Nb concentration from Java possibly related to crustal thickness and composition, condition of magma's pathway (conduit) and also segmentation of subducted slab, creating condition that promote different degree of magma differentiation.

The crustal structure in the cinder cones zone of Plosky Tolbachik volcano, Kamchatka

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Regional zone of cinder cones of Plosky Tolbachik volcano (Tolbachik Dol) is situated in the southwest area of the Klyuchevskaya group of volcanoes in Kamchatka. The most important historic eruption of this area is the Large Tolbachik Fissure Eruption (LTFE) 1975-1976. Among the described big fissure eruptions of the world, the LTFE is distinguished by a unique variety of phenomena and is considered as one of the largest basaltic eruption in the Kuril-Kamchatka volcanic belt and one of the most studied volcanic eruptions. However, some aspects require extended studies. In particular, these are the issues related to the structure and properties of shallow magmatic chambers and feeding channels, as well as the main peculiarity of the eruption - the change in the composition of erupted basalts. In order to restore the deep structure of Tolbachik Dol a passive seismic technique - low-frequency microseismic sounding method (Gorbatikov et al ., 2008) - was applied. In this technique surface Rayleigh waves of different frequencies are used as sounding signals. The method is based on the fact that the crustal heterogeneities distort the spectrum of the low frequency microseismic field in the vicinity of the underground object. The spectral amplitudes on the Earth's surface decrease above high velocity heterogeneities and increase above low velocity ones.

Registration of the wide frequency band microseismic field was carried out in Tolbachik Dol along 3 linear parallel profiles (14-15 km in length, step of measurement 500 m) embedded transversely to the line of cinder cones throw 3 very much alike volcanic fissure vents of different ages: Northern Vent of LTFE, 1975; Vent-1004 occurred about 2000 years ago; Vent-Alaid occurred about 1500-1000 years ago.

The crust vertical cross-sections, reflecting the distribution of relative velocities of transverse seismic waves up to 20 km were constructed.

The detected structural heterogeneities were interpreted with consideration of previously received data of complex studies of Tolbachik Dol and LTFE. We confirmed the existence of shallow magma chambers on the depth 2-3 km, 7-8 km and 15-20 km under Northern Vent of LTFE found during previous geophysical investigations. The same objects were detected under Vent-1004 and Vent-Alaid too. So we assume the regularity in the configuration of magmatic system in the cinder cones area (in central part of Tolbachik Dol). A new result is localization of magma conduits of the eruptions. Configuration of the conduits allows the possibility of magma supply to the surface from various deep sources, and this is the possible reason for changes in the erupted basalt composition. The structure of the areal volcanism zone was shown in detail with obviously expressed change in the character of magma intrusions from a consolidate basement to sedimentary crust: subvertical magmtic channels are replaced with a system of inclined ones and sills.

Petrology of felsic rocks dredged from the Myojin Seamount and the Myojin Rift in the north Izu-Bonin arc - Contribution of intra-oceanic subduction system to making continental middle crust -

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The Myojin Seamount, located in the volcanic front of the north Izu-Bonin arc, is a submarine composite volcano with a large caldera. The Myojin Rift, western back arc side of the Myojin Seamount, exhibits graben structure rifting at present. The volcanic rocks from the Myojin Seamount are comprised of basalt, andesite, dacite and rhyolite, whereas the Myojin Rift is characterized by basalt and rhyolite assemblage. The felsic rocks from the Myojin Seamount and Rift consist mostly of pumices with variable vesicularity and lesser amount of massive lava and plutonic rocks, which are divided into three suites on the basis of incompatible element and isotopic characteristics: type 1 rocks with low Na, Zr, LREE, and high Ba, $^{87}Sr/^{86}Sr$, type 2 rocks with low K, Rb, Ba, and high $^{87}Sr/^{86}Sr$, type 3 rocks with high Na, K, Rb, Zr, Nb, LREE, and low Ba, $^{87}Sr/^{86}Sr$.

The type 1 felsic rocks occur in the Myojin Seamount of the volcanic front, the type 3 felsic rocks in the Myojin Rift side, and the type 2 felsic rocks overall from volcanic front to back arc. Isotopic compositions of basalts from the volcanic front are similar to the type 1 and 2 felsic rocks, whereas those of basalts from the Myojin Rift are similar to the type 3 felsic rocks. Geochemical signatures and occurrences of the felsic and basaltic rocks suggest that the type 1 felsic magma may be derived from the basaltic sources beneath the volcanic front, and the type 3 felsic magma from the basaltic sources beneath the back arc. Isotopic compositions of the type 2 felsic rocks are similar to the type 1 felsic rocks, however, the differences of major and trace elements between the type 1 and the type 2 felsic rocks can not be explained by different conditions from the common basaltic sources, such as variable fO_2 (e. g. Sission et al., 2005; Tatsumi and Suzuki, 2009). An alternative model of the type 2 felsic rocks is partial melting of another source material, such as pre-rifting stage basaltic crust (e.g. the Oligocene middle crust of Tamura et al., 2009). The dispersed distribution of the type 2 felsic rocks from the volcanic front to the back arc is consistent with the old pre-rifting stage lower crust model.

The Calc-alkaline andesite and dacite from the Myojin Seamount at the volcanic front have magma mixing evidences, such as mixing trend of bulk chemistry, mingling texture under thin sections, and sieve texture of plagioclase phenocrysts. This suggests that the intermediate composition volcanic rocks may be originated by mixing of the basaltic magma and the type 1 felsic magma beneath the volcanic front at the Myojin Seamount, which process contributes to make intermediate composition continental crust in the Izu-Bonin oceanic arc.

Tomographic image of the crust beneath the Aira caldera in southern Kyushu

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Associated with the Philippine Sea plate subduction, a nearly straight chain of active Quaternary volcanism runs almost parallel to Nankai Trough in the central part of southern Kyushu. In this region, there are four large calderas: the Kakuto, the Aira, the Ata and the Kikai calderas.

We applied the tomography method with a fine grid configuration to the P- and S-wave arrival times of 829 local earthquakes well observed at 101 stations in central and southern Kyushu, and revealed the detailed three-dimensional seismic velocity structure of the crust, especially the region beneath the Aira caldera.

In a shallow range from 0 to 10 km depth, low velocity zones (LVZs) are found in the eastern part of Kyushu, where basement rocks are made up of uplifted sedimentary marine terraces (Nakada et al., 2002). The LVZs are also distributed along the volcanic front between Kirishima volcano to Kaimon volcano. Meanwhile, the hypocenters occurred in the inland area are obviously concentrated in regions with a relatively higher velocity and a low Poisson's ratio at a depth of 10 km.

At 20 km depth, the most interesting feature is that a distinctly high Poisson's ratio zone is located exactly beneath the Aira caldera. This compacted zone also extends southward and connects the Aira caldera with the Ata caldera. At 30 km depth, a small zone with high Poisson's ratio appears to remain beneath the Aira caldera. This small zone is assumed to be a portion of the distinctly high zone at 20 km depth. We also found that the velocity distribution in the western region (Satsuma Peninsula) is quite different from that in the eastern region (Ohsumi Peninsula): the western region is characterized by high P- and S-wave velocities, while the eastern region is characterized by the low velocities.

The anomaly with a very high Poisson's ratio at 20 km depth beneath the Aira caldera possibly suggests the presence of partial melts and the source of volcanism in the area. It is also found that LF earthquakes occur in the lower crust in and around the Aira caldera. A deeper part of the focal zone of these LF earthquakes appears to overlap the high Poisson's ratio zone observed at 30 km depth. These facts lead us to postulate that magma penetrating into the crust from the upper-most mantle may construct the high Poisson's ratio zone at about 30 km depth, and move upwards through the LF focal zone, and finally be stored at about 20 km depth.

Ishihara (1990) described the magma supply system of Sakurajima volcano wherein one magma reservoir is located at about 4 km depth just beneath Sakurajima volcano and another at 8 to 10 km depth beneath the Aira caldera. Although space resolution in our tomography is insufficient to distinguish these magma reservoirs in the upper-most crust, our result puts forward a possibility of the deeper magma reservoir supplying two shallow magma reservoirs previously found.

The significance of two-pyroxene pseudo-decompression paths (PDPs) in mafic to intermediate arc magmas

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Two-pyroxene thermobarometry of a range of mafic to intermediate arc magmas from the Chile, Japan, New Zealand, and Taiwan yield P-T paths that are approximately isothermal and range from mantle to upper crustal pressures. Using MELTS modeling, we show that such features can be successfully reproduced by combining pyroxene crystals that formed at a range of crustal pressures but happen to be in Fe-Mg exchange equilibrium. We refer to these P-T paths as "pseudo-decompression paths" (PDPs), because they give the illusion of rapid melt ascent at constant temperature, whereas in reality they may have resulted from magma mixing or crystal uptake. We show that many "microlites" in explosively erupted arc magmas are actually small crystal fragments, arguing for crystal uptake rather than conventional magma mixing models. Further, while we cannot preclude magma mixing as a process that may result in PDPs in theory, we show that high-Mg andesite (HMA) would likely be required as one mixing component. While HMA magmas are being recognized in some volcanic arcs, they do not typically erupt at the volcanoes we studied, again arguing for crystal uptake. We conclude that many mafic to intermediate arc magmas (with the exception of remobilized porphyritic dome lavas) leave their source as aphyric melts and acquire their crystal cargo en route to the surface from previously intruded plutons. Crystallization of the host melt itself is likely prevented due to rapid ascent and superheating. Ironically, the observed PDP's may therefore actually mirror the quasi-isothermal ascent paths of these magmas. Our results have profound implications for volcano monitoring and for the compositional range of melts leaving the mantle wedge.

Preliminary petrologic and geochemical observations of volcanic rocks associated with an area of active surface uplift in the Lazufre region, Andean Central Volcanic Zone

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The Lazufre region is an area of active surface uplift (~25°14'S) situated between two potentially active Quaternary volcanic centers, Lastarria and Cordon del Azufre, in the Andean Central Volcanic Zone. InSAR observations show signs of unrest with an elliptical deformation area 45 by 37 km with a maximum inflation rate of ~2.5 cm/yr. The inferred depth of the magma chamber is 10 km below sea level. Given this depth, deformation and surface uplift are unlikely to be solely hydrothermal in origin and imply active pluton growth. Whole rock K-Ar dates of lavas from Cordon del Azufre place the most recent eruptions at 0.6-0.3 Ma $\pm$0.3 Ma. The most recent eruptive activity at Lastarria has been dated at ~0.5-0.1 Ma. Bombs and blocks of banded pumice are common on the surfaces of Lastarria lava flows indicating intermittent explosive and effusive eruptive activity. Eruptive products of Lazufre are primarily andesites and dacites (59-67 wt.% SiO_2) with plagioclase-pyroxene-amphibole-biotite-opaque-quartz phenocryst assemblages. Many plagioclase phenocrysts in all composition rocks possess resorption textures with finely-sieved, dusty zones near the margins of the crystals suggesting that magma mixing and mingling occurred at a late stage after the phenocrysts formed but prior to or during eruption. Trends in major and trace element concentrations suggest that crystallization-differentiation processes were also important processes in the evolution of the magmas. These trends include consistent decreases in MgO (4.0-1.5 wt.%), CaO (6.4-3.5 wt.%), TiO_2 (1.03-0.61 wt.%), and FeO (6.8-3.9 wt.%); variable increases in K_2O (2.3-4.1 wt.%), and little variation in Na_2O (2.9-3.6 wt.%) with increasing SiO_2 contents. Large ion lithophile trace elements show enrichments beyond those that can be produced by crystallization-differentiation alone (Rb=103-291 ppm and Th=18-66 ppm); while compatible trace elements are strongly depleted relative to inferred primitive mantle melts: Sr (578-294 ppm), Cr (61-10 ppm), Ni (33-14 ppm). Closed system crystallization-differentiation processes alone cannot be the only factors influencing magma compositions, however, as $^{87}Sr/^{86}Sr$ values are highly elevated (0.70651-0.70715). Collectively these data attest to a multitude of differentiation processes and magma sources including crystallization-differentiation from more mafic magmas, melting and assimilation of older crustal rocks, and magma mixing and mingling.

8 Ma time series of explosive volcanism at the Central American Volcanic Arc (marine tephras from ODP and DSDP sites)

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The Central American Volcanic Arc (CAVA) is, and has been, one of the most active volcanic regions on earth and generated numerous Plinian eruptions along his 1200 km extension.

Numerous ash layers up to 8 Ma, which occur in ODP and DSDP cores of Legs 66, 67, 170, 202 and 205, originated in Central America and southern Mexico. The best preserved tephra archive lies in the cores across the ash distribution areas expected from dominant wind directions as identified by mapped fallout deposits. We analyzed > 150 ash layers of all Legs for first detailed analysis of these sites to 1) built up a arc-wide recent to Tertiary tephrostratigraphy and 2) evaluate how magmatism, and especially the influence of subduction parameters, sediment input and crustal assimilation/interaction change with time at the CAVA.

The black to gray to white ash layers have commonly sharp contacts at the bottom and diffuse transitions to terrigenous and pelagic sediments at the top. Ash layer thicknesses range from 0.5 to 60 cm with typical grain sizes from medium silt to coarse sand. The mineral assemblages are typical for arc volcanism (plagioclase, pyroxene, hornblende, and olivine). The most evolved tephras also contain biotite.

Electron microprobe analyses of 1748 glass shards yield compositions ranging from basalt to rhyolite and trachyte. Felsic ashes can be divided into seven compositional groups by means of silica and potassium contents. Definition of source areas on land, but also their variations are based on major element geochemistry of glasses and minerals, and trace element data from LA-ICP-MS analyses combined with Ar/Ar age dating. First results show that source areas of the ash layers are distributed along the entire CAVA, as well as at the Southern Mexican Arc. Making use of typical systematic CAVA along-arc variations of trace-element characteristics (Zr/Nb, Ba/La, Ce/Yb, La/Yb and Ba/Zr) of the arc rocks with time is the main key to unravel the long-term changes in magmatic variability and its causes along the arc in future.

Therefore, the marine tephra record provides important data for ongoing studies of CAVA volcanism: (a) dating of undated land tephra by correlation with marine ashes and the ages derived by sedimentation rates and Ar/Ar dating; (b) regional stratigraphic correlations along the entire arc; (c) reconstruction of long-term changes in magmatic evolution of volcanic complexes.

Santorini volcano magma plumbing system: constraints from a combined experimental and natural products study

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Santorini Volcano constitutes a serious hazard in the Aegean region of Greece. The recent 2011-2012 episode of caldera unrest has focussed attention on the magma plumbing system of the volcano, and notably on the depths of storage of different magma batches. We investigated the differentiation conditions of mafic-intermediate magmas, as well as the pre-eruptive storage conditions of dacitic-rhyodacitic magmas prior to the four largest Plinian eruptions of the volcano over the last 200 ka (Minoan, Cape Riva, Lower Pumice 2, Lower Pumice 1). The intensive variables (P, T, fO_2, volatiles content) were determined by combining laboratory crystallization experiments with study of the natural products (including volatiles in melt inclusions). Our results show that the magma plumbing system is dominated by a large, long-lived ($\geq$ 200 ka) storage region at about 8 km depth (2 kb), from which the silicic magmas are derived. This region is fed by injections from a deeper, mafic reservoir located at the boundary between the upper and lower crust ($\sim$15 km; 4 kb). Mantle-derived basalts stall in the 15 km storage region, where they fractionate to basaltic andesite (55 to 58 wt.% SiO_2) with 2-3 wt.% H_2O through crystallization of about 60 wt.% of oliv, cpx, plag, mt/ilm and opx, at 1040-1000℃, 4 kbar, fO_2 = FMQ-0.5. The basaltic-andesitic magmas then ascent to about 8 km where they either (1) experience a last episode of equilibration prior to eruption, or (2) fractionate to produce dacitic to rhyodacitic liquids.

Prior to the major Plinian eruptions, the silicic magmas were stored at T = 850-900℃, under relatively reduced conditions ($\sim$FMQ or, ΔNNO = -0.9 to -0.1), with melts depleted in fluorine ($\sim$500-700 ppm) and particularly in sulphur (<100 ppm) but rich in water and chlorine (5-6 wt.%, ca. 2500-3500 ppm, respectively) probably co-existing with a hydrosaline liquid, at pressure $\geq$ 2 kbar. The fact that Santorini dacites-rhyodacites have high enough dissolved Cl for the melts to be saturated with hydrosaline liquid (and maybe vapor) before Plinian eruptions has significant consequences on the Cl degassing budget, which was previously estimated as insignificant. A re-evaluation is under progress and the results will be presented in our communication.

The redox states of basaltic and boninitic magmas throughout the early stage of the Bonin arc formation; Fe-K edge XANES study

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One of the significant features of arc magmas is their relatively oxidized nature compared to those from other tectonic settings. Previous studies discussed that the nature is attributed to relatively high oxygen fugacity (fO_2) conditions in their source mantle region, and accession of subducting slab-derived fluid may have raised fO_2 of the MORB source-like mantle. However, it is unknown how the fO_2 condition of melting region in mantle wedge develops throughout the early stage of arc formation. In this study, we investigated the fO_2 conditions of basaltic and boninitic magmas erupted during the initial ca. 12 million years of the Bonin arc formation based on the Fe valence states of quenched silicate glasses, which is a sensitive indicator of magmatic fO_2, to examine how fO_2 of their source mantle region developed with time.

Fe-K edge micro-XANES (X-ray Absorption Near Edge Structure) measurements enable us to determine valence state of Fe in silicate glass with spatial resolution of several microns. In this study, Fe-K edge XANES spectra were measured for quenched silicate glasses included in pillow lavas and hyaloclastites of basalt and boninite from Bonin arc, using a X-ray micro-beam system at Beam Line 4A in Photon Factory, KEK, Japan. Mole ratios of ferric to total iron, Fe^{3+}/Fe_{total}, were determined from the spectra, and then the ratios were used to estimate fO_2 of silicate melts. Precision of our analyses was evaluated to be within standard deviation of 0.4 log unit in fO_2 using basaltic and andesitic standard glasses synthesized at controlled fO_2 conditions.

The measured samples include forearc basalt (FAB) collected at Bonin Ridge, which is the earliest volcanic product from Bonin arc and has MORB-like geochemical feature, erupted right after the initiation of subduction (ca. 51Ma), boninites from Chichijima, Otojima, and Mukojima, erupted at ca. 44-48 Ma, and arc basalts from Anejima and Hahajima, erupted at ca. 37-44Ma. The measured Fe^{3+}/ Fe_{total} ratios of quenched glasses are ca. 0.20 for FAB, 0.17-0.24 for boninites from Chichijima, Otojima, and Mukojima, and 0.20-0.22 for arc basalts from Anejima and Hahajima, respectively. All measured samples show Fe^{3+}/ Fe_{total} ratios higher than that of MORB. fO_2 of the measured glasses are estimated to be near Ni-NiO buffer which is consistent with the range of arc magmas. The results suggest that fO_2 of magmas erupted at Bonin arc has been higher than that of MORB since the initiation of arc volcanism. In addition, the similarity of fO_2 among MORB-like FAB, boninites, and arc basalts implies that the oxidation process may be independent of accretion of subducting-slab derived aqueous fluid.

Petrological and petrochemical investigations of Iwanoyama-Iyuzan volcanic chain in Higashi-Izu monogenetic volcano group, Izu-Bonin volcanic arc, central Japan

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Higashi–Izu monogenetic volcano group consists of more than 75 volcanoes in northeastern part of Izu Peninsula northern Izu–Bonin volcanic arc. These monogenetic volcanoes were interpreted to have formed mainly under the tensional stress regime due to the several block movement (Koyama and Umino, 1991). Some of these monogenetic volcanoes forming volcanic chains (NW–SE in direction) with different space, time are somewhere distributed (e.g., Hayakawa and Koyama, 1992; Koyama et al., 1995). These eruptions are thought to have occurred in 142.5 ka–2.7 ka (e.g., Hayakawa and Koyama, 1995). Erupted products of these monogenetic volcanoes have wide compositional variations, from basalt to rhyolite, and SiO2 wt.% of 48–73. Some generation processes have been provided for those variations. Andesitic magmas were formed by differentiation from basaltic magma, or crustal contamination, while dacite–rhyolite magmas were by partial melting of granitic crustal materials (e.g., Hamuro, 1985; Miyajima, 1990; Suzuki, 2000). Recent melt inclusion study proposed a model that the chemical variability was attributed to the crystallization within magma chamber (Nichols et al., 2012).

Iwanoyama–Iyuzan volcanic chain is the youngest one in this region (2.7 ka), and also has wide compositional variations from basaltic andesite to dacite, even within one monogenetic volcano (e.g., Kurasawa, 1984; Suzuki, 2000). These variations in this volcanic chain are not yet fully discussed with enough data. Therefore, the purpose of this study is to clarify their magma genesis, origin and evolution of magma in this volcanic chain based on detailed petrographic, petrological and geochemical investigations.

The Iwanoyama, Ananoyama, Yahazuyama and Ananokubo in this chain are mostly composed of dacite and have some different petrography and mineral chemistries. The dacites of former three volcanoes are characterized a bimodal plagioclase anorthite content (An). High An group of plagioclases (An=92–96) indicates normal chemical zoning, but low An group (An=56–70) are dominated, in most cases, by dusty–zoned, or reversely zoned texture. Clinopyroxene has Mg# of around 80 both in core and rim, while orthopyroxenes are grouped into two: 70–72 and 76–80. Major and trace element characteristics give similar bimodal data distributions, which suggest some mixing including crustal materials as important process. Measured Sr isotope ratios (87Sr/86Sr) of Ananoyama and Yahazuyama dacites range in 0.70325–0.70349, indicating inhomogeneous magma and exclude simple crystal fractionation model. They probably reflect the mixing of basaltic magma and crustal material, or mixing of basaltic magma and crustal–derived felsic magma. We will focus our discussion on the generation mechanism and compositional variability within single volcano, or within 2.7 ka volcanic chain, and possibly the relationship with regional tectonics.

Evolution of volcanism and magmatism during initial arc stage of the Oman ophiolite

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We present detailed volcanostratigraphy, petrology and geochemistry of juvenile arc tholeiite and subsequent boninite magmatism from the Oman ophiolite. Volcanic sequences of the Oman Ophiolite are divided into a spreading stage V1 (Geotimes, Lasail), a subduction stage V2 (Alley, Cpx−phyric) and a pre−obduction alkaline stage V3 (Salahi) in ascending order (Alabaster et al., 1982, Ernewein et al., 1988, Umino et al., 1990).
The V2 sequence considered to begin <2 Ma after the V1 (e.g. Hacker et al., 1996) is a suitable site to investigate magmatic and volcanic developing processes of an infant arc.
An 1110 m thick V2 sequence is divided into the lower 970 m (LV2) and upper 140 m (UV2) thick subsequences by a 1.0 m thick sedimentary layer. Pahoehoe flows dominate in the lower part of the LV2, while the upper part consists mainly of sheet flows with intervened few pelagic sediments, a fissure vent and a cylindrical plug. In addition to the presence of feeder conduits, the flow−dominant lithofacies with a few thin sedimentary interbeds in the LV2 indicates that the study area was the center of a monogenetic volcano grown in a short period.
The UV2 is composed of sheet flows overlain by a 2.0 m thick subaqueous pyroclastic fall deposit. The LV2 consist of arc tholeiite with orthopyroxene phenocrysts increasing in amount upward. The UV2 lavas are composed of boninite containing olivine and clinopyroxene phenocrysts with plagioclase in the groundmass.
Successive orthopyroxene−bearing arc tholeiitic volcanism in LV2 followed by a relatively small amount of boninite lavas in UV2 overlain by thick pelagic sediments suggests that the infant arc volcanism was short lived and terminated long before the ophiolite obduction.

New geochemical classification of global boninites

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Boninite is an important volcanic rock type associated with the initiation of a subduction zone. It is generally defined as a variety of high-magnesian andesites with SiO_2 >52 wt%, MgO >8 wt% and TiO_2 <0.5 wt%. Compilation of the global data on bulk geochemistry of boninites defined as such shows a broad compositional range consisting of a number of regional trends which are characteristic to the individual volcanic suites, suggesting that the genetic conditions of boninite magmas are highly variable dependent on the tectonomagmatic situations. Therefore, re-evaluation of the classification scheme of global boninites is crucial to understand the genetic conditions of boninite magmas and their relationships with the tectonomagmatic settings.

Boninite is usually a part of volcanic rock suites which forms a continuous fractionation trend from magnesian (MgO >20 wt%) boninite through less magnesian andesite to dacite and rhyolite. These regional fractionation trends form subparallel curves on a SiO_2-MgO plot, namely boninite series, that differ from volcanic suites to suites. We advocate to classify these boninite-series rocks into high- and low-Si boninites by a discrimination line running through points of SiO_2 = 55 wt% at MgO = 20 wt% and SiO_2 = 59 wt% at MgO = 8 wt% on a SiO_2 vs. MgO plot. Boninites from Ogasawara (Bonin) Islands on the Izu-Ogasawara (Bonin)-Mariana forearc and western Pacific ophiolites in Papua New Guinea and New Caledonia show compositional trends of high-Si boninite series which are controlled by crystal fractionation of olivine and orthopyroxene. Whereas, boninites from Tonga arc, DSDP Site 458 and Guam, and Neo-Tethys ophiolites such as Oman and Troodos show low-Si boninite series trends controlled by olivine, orthopyroxene and clinopyroxene fractionation. Low-Si boninite-series rocks do not evolve across the discriminate line by crystallization differentiation. Primary magmas of Low-Si boninites are characterized by enhanced LILEs and LREEs by slab-derived H_2O-rich fluids. Melting experiments of peridotites have demonstrated that low-Si boninite-like melts with SiO_2 <54 wt%, MgO <23 wt% could be produced under 1-2.5 GPa and dry and water-undersaturated conditions. On the contrary, SiO_2-rich (SiO_2 >54 wt%) melts like high-Si boninites have never been produced by peridotite melting experiments. Instead, highly depleted REEs and high Zr/Ti ratios of high-Si boninite magmas require slab-derived felsic melts that reacted with the depleted harzburgite in the mantle wedge.

Magma mixing mechanism of Fujiyama lava dome in Takahara volcano, northeast Japan

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We carried out petrological and petrochemical studies on Fujiyama lava dome in northern part of Takahara volcano which is a Quaternary stratovolcano located on volcanic front in the southern part of northeast Japan arc. Fujiyama is mainly composed of dacites. Takahara volcano was presumed to have finished its volcanic activity ca. 100 ka (Inoue et al., 1994), but Fujiyama was assumed to have been formed at 6.5 ka (Okuno et al., 1997; Takashima, 1999).

Magma mixing is accepted as one of the important processes leading to the formation of mafic inclusions (e.g., Eichelberger, 1975; Koyaguchi, 1986). The presence of mafic inclusions was already reported in Fujiyama (Ikeshima and Aoki, 1962). However, there are no investigations for the mafic inclusions in Fujiyama, and their petrogenesis is not yet understood. Therefore, we tried to study to intend to understand genetic processes of these mafic inclusions and magma mixing mechanism in Fujiyama lava dome.

The mafic inclusions in Fujiyama dacites (SiO2=67.4-70.4 wt.%) have andesitic composition (SiO2=60.7 wt.%). They are dark in color and most inclusions have spherical to oblate in shape. In the boundary between host rock and inclusion, a few phenocrysts straddle the boundary. All inclusions have abundant vesicles. These features are similar to mafic inclusions reported from other volcanoes, and indicate that the inclusions were liquid when they were entrained by the silicic magma (e.g., Heiken and Eichelberger, 1980; Bacon, 1986). The host rocks (dacite) contain phenocrysts of plagioclase, quartz, orthopyroxene, hornblende, Fe-Ti oxides and rarely augite. The inclusions contain phenocrysts of plagioclase, orthopyroxene, augite, Fe-Ti oxides and rarely include hornblende and quartz.

Whole-rock major and trace element composition of the inclusions are plotted between host dacites and basalts erupted during the earliest activity in Takahara volcano. In general, chemical compositions have liner data trend which may be evidence of magma mixing between dacitic and basaltic magma. Plagioclase and orthopyroxene phenocryst cores in the host rocks and inclusions have a large variation in composition. Both rocks contain Ab-rich plagioclase, An-rich plagioclase, Fe-rich orthopyroxene and Mg-rich orthopyroxene. Most of Ab-rich plagioclase and Fe-rich orthopyroxene in the inclusions show reverse zoning. Sr isotopic ratio (87Sr/86Sr) of the inclusion is slightly lower than that of the host dacite.

From these results, it is presumed that magma mixing occurred between silicic magma and mafic magma in Fujiyama. Silicic end-member might have been close to in composition to the host Fujiyama dacitic magma, and mafic end-member might have been basaltic magma having similar composition to the products erupted during the earliest stage in activity of Takahara volcano. Therefore, it is suggested that the mafic inclusions were formed from resultant andesitic magma by the magma mixing.

Origin of voluminous andesite - dacite in the Hohi Volcanic Zone : Role of basaltic magma, SW Japan

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Adakites are erupted related to subduction of the Philippine Sea Plate (PSP) on the Quaternary volcanic front of the Chugoku region tothe norteast Kyushu from Pleistocene time (e.g. Kimura et al., 2005). However, in the Hohi Volcanic Zone (HVZ) in northern Kyushu, a large amount of andesite - dacite continuous erupted from about 6 Ma, basaltis rare. Therefore, magmatism of the HVZ has been studied of a small amount of basalt (Nakada and Kamata, 1991). So, it is important to clarification the origin oh andesite - dacite in the HVZ. It also can be to identify the evolutionof PSP subduction. In this study, we have examined th Futago volcanoe group (2.0 -1.0 Ma), the Usa volcanic rocks (6.6 -2.7 Ma) and the Hikosan volcanic rocks (4.8 -3.8 Ma) distributed in Hikosan from Kunisaki peninsula located in the northern part of the HVZ.

The initial activity in the HVZ, High-Nb andesite with high-K_2O produced in the forearc side of the Usa volcanic rocks of about 6 Ma. The trace element pattern of High-Nb andesite is similar to alkali basalt - basanite. It is indicating that the alkali basalt - basanite magma may contribute to the genesisof the High-Nb andesite (Nagao et al., 2001). In addition, andesite - dacite of the Usa volcanic rocks are incmpatible element (K_2O, Nb, Zr) decreases with increasing SiO_2, and continuously changes to the island arc andesite composition. this compositional trend can not be wxplained by crystallization differentiation. this compositional change suggests High-Nb andesite magma was AFC of the crust and/or mixing with felsic magma by melting of the lower - middle crust. Around 4.5 Ma, primitive tholeiitic basalt erupted in a back-arc side Hikosa volcanic rocks, show OIB-like signature. Also andesite - dacite of Hikosa volcanic rocks, it consider to mixed with tholeiitic magma and felsic magama indicate a linear compositional trend. In the Pleistocene, OIB-like tholeiitic basaltis including with mafic enclave in Futago volcane group from 2 Ma. These are heated and remobilized mashed adakitic magama in the crust. But, in the Quaternary volcanic front, volcanic activity dominated by the adakitic magma.

The important things are that the amount of andesite - dacite (Usa volcanic rocks : 83 km^3; Hikosan volcanic rocks : 111 km^3) are erupted at HVZ, it is the need for large amounts of basaltic magma is likely to be derived from fertile mantle characteristic of the back-arc side of geochemical characteristics. therefor, there is a possibility that the fertile mantle wasa flowing up by 6 - 3 Maunder the mantle of the HVZ.

Co-Variation of Sr-Nd-Pb-Hf Isotope Chemistries of the Quaternary Lavas and the Basement Granitoids, Northeastern Japan arc

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Sr-Nd-Pb-Hf isotopic ratios were determined for the frontal-arc lavas and for the Cretaceous to Paleogene granitoids occurring in the Northeastern Japan arc in order to examine the genetic relationships between the young magmas and their basement rocks. Frontal-arc Nasu and rear-arc Chokai volcanic chains develop in response to the - 90 to -180 km depth contours of Wadati-Benioff zone of the Pacific Plate slab. Previous studies showed that the Sr-Nd isotopic compositions of the rear-arc lavas have a common depleted source, whereas the frontal-arc lavas have various enriched sources with increasing Sr and decreasing Nd isotope ratios from north to south.The isotopic variations of the frontal-arc lavas almost correlate with that in the basement granitoids, which also have increasingly radiogenic Sr from north to south. We newly present Sr-Nd-Pb-Hf isotope ratios for the representative frontal-arc lavas and the basement granitoids. Frontal-arc lavas examined were from Hakkoda, Akita-komagatake, Iwate volcanoes from the northern area, Zao and Azuma from the central area, and Nasu and Takahara from the southern area. Basement granitoids were analyzed for the Kitakami belt (north area), the Abukuma belt (central area), and the Ashio/Mino belt (south area). All the Sr-Nd-Pb-Hf isotope data confirmed increasingly enriched source from north to south for both the Quaternary lavas and the basement granitoids. Multi-isotope plots show discrete quasi-linear mixing arrays consisting of the lavas at each volcano suggesting mixing of endmember magmas from depleted and enriched sources. The depleted source is, the most likely, originated from a common Indian MORB mantle affected by the slab components from the Pacific Plate. In contrast, the enriched sources for the lavas vary and the source at each volcano appears to correlate with the underlying basement granitoids in terms of isotope geochemistry. This suggests either crustal assimilation of the upper crustal granitoids or deep assimilation of the lower crustal amphibolite which was the source of the basement granitoids. The isotopic evidence clarified that the Quaternary lavas in the Northeast Japan arc were fundamentally derived for a common mantle source but severely affected by the various crustal materials.

Relationship between seismic structure and magma migration during the 2011-2012 El Hierro (Canary Islands) eruption

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The submarine eruption in El Hierro island started on 10 October 2011 and was preceded by intense seismic activity that continued throughout the eruption and after it finished on March 2012. Seismicity was monitored by a 9-station seismic network that allowed to locate more than 10,000 earthquakes. The distribution of these earthquakes and stations is very suitable for studying the P-wave structure of the island down to 20 km with travel-time local-earthquake tomography. Using a subset of well distributed and recorded earthquakes we have obtained a three-dimensional P-wave velocity model of the island that is well resolved beneath its central and western part. The most prominent feature of this model is a high-velocity anomaly in the center of the island that at shallow depths coincides with the edifice of the Tanganasoga volcano. This anomaly dips to the south extending from the surface to 10 km depth, and seems to have great importance in the migration of magma that fed the 2011-2012 eruption. Two seismic zones converge at the base of this anomaly, while the seismicity inside the anomaly is very low. The first seismic zone dips very steeply (> 60 degrees) to the north and extends approximately to 25 km depth below the El Golfo area. The second zone dips more gently to the south below El Julan, reaching a maximum depth of 20 km, coinciding with the center of the inflation determined from GPS data. This seems to indicate that magma ascended from the south and/or north deep seismic zones reaching the base of the anomaly where its ascent was stopped. After this first period seismicity and presumably magma started to migrate south, always at the base of the high-velocity body, until it erupted 2 km offshore of the southern tip of the island. These results are consistent with thermobarometric and petrologic studies of young erupted rocks in El Hierro that suggest main fractionation of magma at 19-26 km depth, and also the existence of multi-stage ascent with small, isolated magma pockets where mixing of distinct magma batches may occur.

Geochemical study of the mafic rocks from Hokkaido, northern Japan: Spatial variations in the wedge mantle and the magma-generation processes at an arc-arc junction

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Hokkaido Island is a junction between the Northeast Japan (NEJ) and the Kuril arcs, where the extensive arc volcanism has continued at least since late Miocene. We newly investigate the spatial geochemical variation of mafic rocks (<1.7Ma). We focus on the rocks with SiO_2<54% for avoiding the effect of crustal assimilation. Based on the spatial compositional variations of the volcanic rocks, the junction can be divided into four volcanic regions: the trench (T-SWH) and the rear (R-SWH) sides of the southwestern Hokkaido in NEJ arc, and the central Hokkaido (CH) and the eastern Hokkaido (EH) in Kuril arc. Across-arc compositional variations of the rocks, such as the increase of K_2O contents from low-K to medium-K rocks toward the back-arc side, can be clearly recognized in SWH and EH. The low-K rocks from these regions are characterized by the obvious Pb and Ba spikes in spidergrams and flat REE patters. However, low-K rocks in the EH show extreme negative anormaly of Nb and Ta, and depletion of LREE. On the other hand, there exist no low-K rocks in CH. In addition, across-arc variations are not clearly recognized. In a Nb/Y-Zr/Y diagram, the rocks from four regions show distinct linear and parallel trends, respectively, and can be divided into three groups, T-SWH, R-SWH and CH, and EH. This indicates that there exists compositional heterogeneity of the wedge mantle, which cannot be explained by the degree of melting from a single mantle source. The degree of depletion in the mantle increases from T-SWH to EH. According to these Nb/Y values at similar Zr/Y, we assume the Enriched-DMM (depleted MORB mantle), DMM and Depleted-DMM of Workman and Hart (2005) for T-SWH, R-SWH and CH, and EH as the source mantle compositions, respectively. Then, degree of melting (F) for primary magmas in each region is calculated by the contents of fluid-immobile elements. Next, using these F values, we determine a metasomatized mantle source compositions for each region. Contents of fluid-mobile elements of a metasomatized mantle source show positive, various correlations in Th and U vs. F diagrams. These data indicate that there exists the difference of subduction components among these regions.

Four volcanic regions in Hokkaido can be extended to the main parts of NEJ and Kuril arcs. In NEJ arc, two distinct regions similar in Hokkaido continue to northern Honshu. Thus, the wedge mantles are distinct between the trench and rear sides in NEJ arc. On the other hand, the rocks from Kuril Islands have similar or more depleted composition compared with those from EH. Thus the wedge mantle slightly changes to become more depleted in Kuril Islands. Although low-K tholeiitic rocks occur in trench-side volcanoes of both arcs, the origins of these rocks are different. Low-K rocks are produced by lower degree of melting more depleted mantle in Kuril arc and by higher degree of melting of enriched mantle in NEJ arc.

Crustal structure beneath Aso caldera, Japan, as derived from receiver function analyses of waveform data from densely distributed stations

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Aso volcano, which is an active volcano, rises in the Kyushu district, Japan. It erupted over 600 km^3 of pyroclastic deposit 90 thousand years ago and formed a caldera with dimensions of 18 km by 25 km. After the huge eruption, small eruptions formed the central cones. Abe et al. (2010, JVGR) estimated the crustal structure beneath the caldera with receiver function (RF) analyses. They obtained a low velocity layer whose S-wave velocity is 2.4 km/s at depths between 15 km and 21 km beneath the western part of the caldera. They did not estimate the crustal structure beneath the eastern part because of the lack of seismic stations.

We set 5 stations in the eastern part of the caldera in July 2009, and started observation. We used waveform data obtained at these temporal stations and permanent stations established in and around the caldera by Aso Volcanological Laboratory, Kyoto Univ. and National Research Institute for Earth Science and Disaster Prevention, and examined the crustal structure beneath the whole of Aso caldera with RF analyses.

We used waveform data of teleseismic events (epicentral distances: 30-90 degrees, Magnitude: greater than 5.5) for calculating RFs with the extended-time multitaper method (Shibutani et al., 2008, BSSA), and estimated the S-wave velocity structure with genetic algorithm inversion of the RFs (Shibutani et al., 1996, GRL).

We revealed that low velocity layers whose S-wave velocities are 2.2-2.6 km/s exist between 8 km and 28 km in depth beneath Aso caldera except the northern and southern rim. Considering a study by Takei (2002, JGR), we estimated from the S-wave velocity structure that these low velocity layers contain 15% of melt or 30% of water at maximum. If the low velocity layers contain melt, its amount is 300 km^3 at maximum, which is about the same amount as magma erupted at the last huge eruption: 200 km^3 (Kaneko et al., 2007, JVGR). Beneath the eastern flank of the central cones, a low velocity layer whose S-wave velocity is 2.6 km/s exists only at depths of 8-15 km. Beneath the same area, a swarm of low frequency events exists at 15-25 km in depth according to a hypocentral catalog by Japan Meteorological Agency, and Geographical Survey Institute (2004, Report of Coordinating Committee for Prediction of Volcanic Eruption) detected a sill-like deformation source at 15 km in depth. Fluid movement just beneath the low velocity layer would cause low frequency earthquakes and crustal deformation. We can expect that melt is intruding through the swarm of the low frequency earthquakes, accumulating at the deformation source, and melting the crustal material above it.

Origin of spatial compositional variations of volcanic rocks from Northern Kurile Islands: Geochemical studies of active volcanoes on Paramushir, Atlasova, Antsiferova islands and submarine volcanoes

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The Northern Kurile Islands form the part of Kurile-Kamchatka volcanic arc. The Pacific plate has subducted beneath the islands since the late Miocene to cause arc-type volcanism. We newly determined major and trace element compositions, Sr-Nd isotopic variations of Quaternary rocks from 7 subarial and 3 submarine volcanoes. Analysis of new and previous publications indicate that the Northern Kurile Islands belong to typical volcanic island arc. About it there are indicated Ta, Nb minimum on the spider diagrams and naturally enriched of the LILE, LREE and depleted of the HFSE, HREE from front to back arc zone. Peculiarities of petrography and whole-rock chemistry enable us to divide all volcanoes into three main zones: frontal, intermediate and rear ones. Frontal zone include Chikurachki, Tatarinova, Lomonosova, 1.3 volcanoes. The rocks are Ol-Cpx bearing Opx basaltic andesite. Fuss, Antsiferova volcanic group and Ebeko volcano locates at the intermediate zone. Hbl-Cpx-Ol-bearing Opx andesite are commonly characterized by the presence of hornblende phenocryst. Alaid, Grigoreva volcanic group locate at the rear zone. Ol-bearing Cpx basalts and basaltic andesite are typical. In addition, Alaid and Grigorev volcanic group is characterized by the largest eruptive volume (150 km^3). Frontal zone is characterized by lowest contents of incompatible elements (Rb, Ba, K) and LREES (Nd, Ce). Isotopic variations have the highest value of $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ as 0.7031-0.7034. In the opposite, rear and intermediate zones show narrower lower contents of $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ as 0.7029-0.7031. The rocks of rear zone show highest contents of LILE (K, Rb), LREES (La, Gd, Nd, Sm) and HFSEE (Nb, Ta). Both $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ ratios of the rocks from intermediate and frontal zones increase with increasing of silica contens. These suggest that andesitic and dacitic rocks from these zones are possibly affected by crustal component. In contrast, crustal assimilation might be minor process in the case of the rear zone, because basaltic rocks are predominant in the zone. Geochemical features of the mafic rocks investigate the spatial difference in magma sources of three zones. Rocks from rear zone are systematically enriched in Nb/Y, Th/Yb, Ta/Yb, Nb/Yb, La/Yb ratios. These data are implied by the fact that magma in the rear zone more enriched with comparing depleted frontal zone. In addition, chemical variations of fluid-mobile elements (Cs, Ba, U, Th, Sr) and immobile elements (Nd, Nb, Zr, Hf) of the mafic rocks will be explained by different types of subduction components.

In summary, the following parameters have mainly affected the observed geochemical zonation across the arc in the primary magma; variably depleted and enriched mantle source: the different type fluid flux from the slab to the mantle wedge.

$^{40}Ar/^{39}Ar$ and U-Pb zircon ages provide new constraints on the history and magmatic evolution of the central Aleutian arc

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New $^{40}Ar/^{39}Ar$ and U/Pb zircon ages from Adak, Kanaga, and Great Sitkin Islands supplement existing geochronologic data and provide new information on the history and evolution of the central Aleutian arc. A clast from a volcanic sequence in southeastern Adak in the Finger Bay Volcanic Formation, interpreted to be the oldest unit on central Aleutian islands, yields an age of 38.19 $\pm$ 0.53 Ma. This age is similar to previous ages from this unit. However, all of the ages from the Finger Bay Volcanics are indistinguishable from the from $^{40}Ar/^{39}Ar$ and U/Pb zircon ages of ca. 38 Ma from the tholeiitic Finger Bay pluton, which intrudes the Finger Bay Volcanics. So, either the volcanism and plutonism were contemporaneous or the ages of the volcanics have been reset due to low grade metamorphism during emplacement of the pluton. The latter scenario is likely because the metamorphic imprint of the pluton is similar to the observed overprint in the volcanics. It is also important to note that the Finger Bay Volcanics on Adak are not related to the initiation of the central Aleutian arc as these rocks have meteoric not sea water alteration and thus the arc must have been built above sea level when these lavas erupted. Lavas from the Finger Bay Volcanics on west-central Kanaga and southern Great Sitkin islands are much younger, ranging from 10.2 to 3.2 Ma, suggesting that previous geologic interpretations on these islands need to be re-evaluated. A new $^{40}Ar/^{39}Ar$ age of 34.35 $\pm$ 0.05 Ma for a granodiorite in the calc-alkaline Hidden Bay pluton on Adak is in accord with new U/Pb zircon ages in this sample, which also importantly shows no evidence of older zircons. Two mafic dikes cutting the Hidden Bay pluton give ages of 33.36 $\pm$ 0.27 Ma and 32.80 $\pm$ 0.42 Ma. The central Adak Gannett Lake pluton, which was assumed to have an age like the 14 Ma Kagalaska Island pluton to the east, yields an age of 31.68 $\pm$ 0.06 Ma. Thus, the new age determinations indicate that calc-alkaline plutonism lasted for more than 3 Ma on Adak. The similarity of the trace element and isotopic signatures of the volcanic and plutonic rocks on Adak and Kanaga suggests that central Aleutian primitive arc magmas have changed little since at least 50 Ma except for increases in Ba/La and Th/La ratios after 2 Ma, which are attributed to subduction of glacial sediments that flooded the trench after 3 Ma. The near constancy of the mafic magma chemistry, the presence of calc-alkaline plutons dominated by granodiorite after 35 Ma and a lack of low-K island arc tholeiites and boninites paints a very different picture for the evolution of the central Aleutian arc than for western Pacific arcs.

A petrological and isotopic study of volcanic rocks from Mt. Arakurayama and other areas, North Fossa Magna, Central Japan

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The Arakurayama andesitic volcanic rocks (Pliocene) can be divided into the lower volcanic rocks, submarine fan deposits (sandstone and siltstone of the Takafu formation), and the upper volcanic rocks. The lower volcanic rocks consist mainly of hyaloclastite associated with pseudo-pillow lava and intraclastic siltstone. Some massive lavas and agglomerate deposits including bombs are distributed in the central part of the lower volcanic rocks as proximal facies. The upper volcanic rocks consist mainly of subaerial massive lavas.

The lower and upper volcanic rocks are andesitic in composition and contain phenocrysts of plagioclase, clino- and orthopyroxene, $\pm$ hornblende. The lower volcanic rocks have a wide range of bulk SiO_2 contents (52-60 wt%) compared with the upper volcanic rocks (56-58 wt%), which may reflect contrasting P-T conditions of crystallization between the two magmas (i.e., of the lower and upper magmas, respectively). Geothermobarometry using the chemical compositions of hornblende phenocrysts indicates that the lower magmas underwent polybaric crystallization in deep (989-806 MPa, 1062-1034 ℃) and shallow (374-174 MPa, 940-836 ℃) chambers, whereas the upper magmas crystallized in a single chamber at intermediate depths (789-387 MPa, 1033-928 ℃). The narrow range of SiO_2 contents of the upper volcanic rocks indicates a simple fractional crystallization in a single magma chamber, whereas the variable SiO_2 contents of the lower volcanic rocks indicate complex magmatic processes such as the mixing of magmas with different compositions in the deep and shallow magma chambers.

The Arakurayama volcanic rocks exhibit constant $^{143}Nd/^{144}Nd$ and variable $^{87}Sr/^{88}Sr$ ratios, showing a horizontal trend in Nd-Sr isotopic systematics. This trend (i.e., the Arakurayama trend) is typical of volcanic rocks from the eastern and western margins of the Fossa Magna, including the Quaternary Myoko and Kurohime volcanoes (from the western margin, near the Itoigawa-Shizuoka Tectonic line), the Yoneyama area, and the Quaternary Naeba volcano (from the eastern margin, near the Kashiwazaki-Chiba Tectonic line). A different trend is apparent for igneous rocks from the central part of the Fossa Magna region, including Miocene-Pliocene granites and the Asama volcano. This trend exhibits higher $^{143}Nd/^{144}Nd$ ratios than the Arakurayama trend. In a diagram of Nd-Sr isotopic systematics, rock samples with the least radiogenic Sr isotopes in each trend are distributed in different parts of the mantle array field, indicating two different mantle components (i.e., pre-existing mantle and newly injected asthenospheric mantle beneath the Fossa Magna area).

Santorini Volcano plumbing system: constraints from melt inclusion volatile contents

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Santorini Volcano has a long history of explosive volcanism, involving alternations of plinian and interplinian eruptions, in two 180,000 year explosive cycles. At least four plinian eruptions generated calderas, the last occurring in the late 17th century BC (Minoan eruption).

We have measured H20 and CO2 contents of melt inclusions trapped in phenocrysts from the rhyodacitic products of the Minoan eruption, from an eruption of primitive basalt discharged prior to the Minoan, and from the dacitic products of the post-Minoan Kameni intracaldera volcano. The analyses were carried out by Secondary Ion Mass Spectrometry and/or by micro-Raman spectroscopy on melt inclusions that were carefully chosen to ensure (1) complete isolation from the crystal exterior, and (2) an absence of any textural evidence for leakage.

Six melt inclusions in Fo85 olivines from the pre-Minoan basalt contain 2.8 to 3.2 wt percent H20 and 240 to 390 ppm CO2. Twenty eight melt inclusions trapped in plagioclase (An37-60) from the four explosive phases of the Minoan eruption contain 3.3 to 6.1 wt percent H2O and 15 to 90 ppm CO2; the highest H2O contents are preserved in melt inclusions from the first eruptive phase, and the lowest from the fourth phase. Four inclusions in plagioclase (An48-56) in pumices from the 726 AD eruption of the Kameni volcano yielded 2.6 to 3.8 wt percent H2O and about 10 ppm CO2. All the analysed inclusions give H20+CO2 saturation pressures within a limited range (1.0 to 2.3 kb), showing that all the magmas concerned were stored in the mid to upper crust prior to eruption. However, these pressures are minimum estimates of total pressures, since they assume volatile saturation. Indeed the data for the Minoan eruption suggest that the rhyodacitic magma was undersaturated in H20+CO2, as also concluded from a recent phase-equilibria study (Cadoux et al, 2013). The highest saturation pressure for Minoan magma comes from melt inclusions from the first eruptive phase, whereas the lowest pressures come from inclusions from the fourth phase. Assuming top-downward magma withdrawal during the eruption, the simplest interpretation is that the Minoan rhyodacite was undersaturated in H2O+CO2 at all but perhaps the uppermost (first-erupted) levels. Analyses of other units from the second explosive cycle are in progress, and will be presented as part of a growing database on Santorini volatile contents and compositions.

Three-dimensional seismic velocity structure of the upper crust beneath Kirishima Volcanoes derived from local earthquake data

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Sub-Plinian and successive Vulcanian eruptions of Shinmoe-dake, Kirishima Volcanoes, started at January 2011. Before the eruptions, inflation of the volcano edifice had been observed by GPS monitoring network (GEONET of GJI). Combining the data of GEONET and temporal GPS observations, Nakao et al. (2012, submitted) located a pressure source (Mogi model) at 10km depth beneath northwestern part of the volcanoes (5km northwest of the Shinmoe-dake crater) for the period of magma accumulating process before the eruptions. Assuming incidence of plane P waves from regional hypocenters and dividing a target volume into blocks of constant velocity, Yamamoto and Ida (1994) calculated P-wave velocity perturbations on each block. The other previous studies did not map the velocity distributions deeper than about 5km depth by limitations of ray paths. The aims of the present research are to show three dimensional P- and S-wave velocity models below 5km to 15km depth derived from data of local earthquakes and to discuss the obtained seismic velocity structure and relation to the pressure source.

305 earthquakes with 15,221 P phases and 13,649 S phases recorded by 67 seismic stations (Kagoshima Univ., Kyushu Univ., JMA, and NEID in and around southern part of Kyushu) during the period from 2001 to 2012 were selected to perform this analysis. In the 3-D inversion, we applied methods of grid model (Thurber, 1983), ray tracing with Pseudo-bending (Um and Thurber, 1987), Parameter separation (Pavlis and Booker, 1980), and Damped Least Squares (Aki and Lee, 1976). We also referenced results of checkerboard tests and diagonal elements of resolution matrix (DERMs) to delineate velocity models of only areas where the relative reliable velocity distributions seemed to be obtained.

As a result of the 3-D inversions, we obtained reliable P- and S-wave velocities at the depth range of 5-15km beneath the area in and around the volcanoes. Characteristics of the velocity structure at 10km depth are summarized as follows: (1) relative high P-wave velocities (high-Vp, 6.8-7.0km/s) distributed widely beneath the northwest, southwest, and southeast flanks of the volcanoes. The increases of Vp were 10-13 percent, (2) relative low P-wave velocities (low-Vp, 5.3-5.5km/s) areas, 11-15 percent decreases, were delineated beneath the whole areas of the volcano edifices, (3) an obvious low S-wave velocity (low-Vs, 2.7-3.2km/s) area, 10-26 percent decrease, located beneath the northwestern part of the volcanoes. The values of Vp/Vs for the characteristic low P- and S-velocity area were 1.9-2.1 (high-Vp/Vs). The obvious low velocity area contains the pressure source (Nakao et al., 2012, submitted). These features, low-Vp, low-Vs, high-Vp/Vs, and containing the location of the pressure source before the eruptions, suggest that a significant volume of magma accumulation existed at the low velocity area and its environs.

Ar-Ar dating for volcanic rocks from Bowers Ridge, Bering Sea at site U1342A and U1342D

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Basement rocks were drilled down to ca. 42 m into the volcanic sequence directly underneath the sedimentary section at Site U1342 on Bowers Ridge during the IODP Expedition 323 to the Bering Sea. This provided us an opportunity to describe the details of the sequence and to decipher the virtually unknown origin and evolution of the Bowers arc massif. There are two contrasting hypotheses for the origin of the arc, which include formation in the Pacific Basin well to the south of its present location during the Cretaceous and in-situ formation within the Bering Sea in Eocene.

The volcanic sequence recovered from Site U1342D was divided into six major lithological units: Unit 1, vesiculated andesitic lava flow; Unit 2, interbedded volcanic sandstones and polymict volcanic conglomerates; Unit 3: monomict volcanic conglomerates; Unit 4, interbedded volcanic sandstones and polymict volcanic conglomerates; Unit 5, monomict volcanic conglomerates; and Unit 6, polymict volcanic conglomerates. Units 3 and 4 represent hydroclastic volcaniclastics, while units 2, 4, and 6 are epiclastic volcaniclastics (Kawabata et al., 2011). We used the single grain Ar-Ar dating method by step-wise laser fusion for Unit 1 basaltic andesite rocks.

We collected basement volcanic rock samples from U1342A 9x section and U1342D 7x 19x sections. The vesiculated porphyritic basaltic andesite at U1342A 9x and U1342D 7x- (Unit 1) and the porphyritic basaltic andesite at U1342D 8x (Unit 1) are fresh samples and are good for single grain method of step-wise laser fusion Ar-Ar dating. We distinguish for the first time two stage (age groups) of activity (34-32Ma and 28-26Ma) from our Ar-Ar data, coupled with those from Wanke et al., (2012).

"Hot Zone" development beneath a long-lived andesite stratovolcano: Temporal evolution of the Mt. Taranaki (New Zealand) magmatic system

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Mt. Taranaki (Egmont Volcano) in the western North Island of New Zealand is a high-K andesite volcano with an eruptive history extending over more than 200,000 years. Past petrological research has concentrated mainly on the post-10 ka record of the modern edifice due to poor stratigraphic control of the older deposits. The earlier history is recorded in 14 major pre-7 ka debris-avalanche deposits, which formed as a result of a catastrophic collapse of the edifice at the time. The clast assemblages of 12 of these deposits were sampled to provide insights into the chemical compositions of magmas erupted during the earlier stages of activity of the volcano and form the basis for a more complete chemo-stratigraphic analysis of the Mt. Taranaki volcanic succession.

Throughout the volcanic history of Mt. Taranaki, similar eruptive styles produced a similar range of lithologies, indicating a long-term sustainability of the volcanic system. However, sample suites from the studied debris-avalanche deposits show a progressive enrichment in K_2O and LILE, reflecting a gradual evolution to high-K andesite. The early (pre-100 ka) magmatic system produced a wide range of compositions, including relatively primitive basalts and basaltic andesites with a more distinct mantle signature. These rocks contain phenocryst assemblages that indicate crystallisation within the lower crust or mantle, including a broad range of clinopyroxene compositions, high-Al_2O_3 hornblende, olivine and phlogopite. The compositional variation observed for the more primitive compositions also reflect a heterogeneous mantle source for primary Taranaki magmas. A higher proportion of high-silica compositions in the younger sample suites and the appearance of late-stage low-pressure mineral phases, such as high-TiO_2 hornblende, biotite and Fe-rich orthopyroxene, reflect a gradual shift to more evolved magmas with time.

These results are interpreted to reflect a multi-stage origin for Taranaki andesites. Parental magmas were generated within a lower crustal "hot zone", which formed as a result of repeated intrusions of primitive melts into the lower crust. The geochemical and mineralogical evidence indicates that prior to 100 ka this zone was relatively thin and cold, allowing primitive magmas to rise rapidly through the crust without significant interaction and modification. As the hot zone evolved, larger proportions of intruded and underplated mafic material were partially remelted, and interaction of these melts with fractionating mantle-derived magmas generated progressively more K- and LILE-enriched compositions. A complex and dispersed magma assembly and storage system developed in the upper crust where the hot-zone melts were further modified by fractional crystallisation and magma mixing and mingling.

Crustal structure of preexisting Mesozoic basement beneath the Northern Izu-Bonin Arc

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The Izu-Bonin Arc is widely regarded to be a typical intra-oceanic arc, with the oceanic Pacific Plate subducting beneath the Philippine Sea Plate, an evolving complex of active and inactive arcs and back-arc basins. However, little is known about the proto-Philippine Sea Plate, which existed along with the Pacific Plate at the time of subduction initiation and before the formation of back-arc basins.

To investigate the crustal structures of the proto-Philippine Sea Plate, we conducted manned-submersible SHINKAI6500 surveys during cruise YK10-04 of the R/V YOKOSUKA in April 2010 at the Daito Ridges. The Daito Ridges comprise the northwestern Philippine Sea Plate along with what are regarded as remnants of the proto-Philippine Sea Plate. Submersible observations and rock sampling revealed that the Daito Ridges expose deep crustal sections of gabbroic, granitic, and metamorphic rocks, along with volcanic rocks ranging from basalt to andesite. Jurassic to Cretaceous magmatic zircon U-Pb ages have been obtained from the plutonic rocks, and whole-rock geochemistry of the igneous rocks indicates arc origins. Furthermore, mafic schist collected from the Daito Ridge has experienced amphibolite facies metamorphism, with phase assemblages suggesting that the crust was thicker than 20 km at the time. These finds show that the Daito Ridges represent developed crustal sections of the Mesozoic arc that comprises part of the proto-Philippine Sea Plate, and, together with the tectonic reconstruction of the proto-Philippine Sea Plate (Deschamps and Lallemand 2002, JGR), they suggest that subduction of the Izu-Bonin Arc initiated at the continental margin of the Southeast Asia, possibly correlating with the Mesozoic island-arc and ophiolite complexes exposed in the southwest Pacific margins, such as those in the Philippine Islands.

Furthermore, detrital zircon ages from volcaniclastic sandstones collected from northern Izu-Bonin forearc, counterpart of the Daito Ridges, yield Mesozoic to Paleozoic ages, indicating that similar Mesozoic basement may even exist beneath the present Izu-Bonin Arc. To confirm this hypothesis, we have conducted a SHINKAI6500 survey on the landward slope of the northern Izu-Bonin Trench during cruise YK11-07 of the R/V YOKOSUKA in September 2011. The collected samples are dominantly andesite with two diorite samples, and preliminary zircon U-Pb dating of the diorite sample yielded Cretaceous (100 Ma) magmatic age as well as abundant Paleozoic to Proterozoic detrital zircons. Preliminary whole-rock geochemistry of the andesite and diorite samples show clear arc-signatures, confirming that a preexisting basement composed of Mesozoic arc crust underlies at least part of the present northern Izu-Bonin Arc.

These new insights on the crustal structure of the proto-Philippine Sea Plate and the discovery of preexisting Mesozoic arc basement beneath the Izu-Bonin Arc raise serious doubts about the intra-oceanic nature of the Izu-Bonin Arc.

Imaging rapidly deforming ocean island volcanoes in the western Galápagos archipelago, Ecuador

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Using finite-difference body-wave tomography methods to determine 3D seismic velocity structure, we imaged, for the first time, the plumbing system of Sierra Negra volcano, Galapagos, as well as parts of the island platform. This volcanic chain overlies a hotspot track and includes some of the fastest deforming volcanoes in the world, making this an ideal location for studying shield volcano plumbing systems. We inverted P- and S-wave arrivals recorded on a 15-station temporary array, SIGNET, installed between July 2009-June 2011 and used a minimum 1-D velocity model constrained by offshore refraction studies. Owing in part to seismicity from nearby volcanoes in the chain, as well as the frequent earthquakes along the caldera ring fault system, the model resolution is good between depths of 3km and 15.5 km beneath Sierra Negra, and adjoining Cerro Azul. Our results indicate that a shallow melt sill below the caldera, interpreted from geodetic data, must be shallower than ~4 km subsurface. The 10 km wide Sierra Negra caldera and ring fault systems are underlain by two small (<50 km^3) low-velocity zones, one just east of the caldera and one to the west. Another small (~70 km^3), shallow low-velocity zone is imaged beneath a line of eruptive centers with shallow earthquakes. We image a high-velocity zone around the site of a lower crustal magma intrusion in June 2010. Here, the steepest velocity gradients are ringed by the intense earthquake swarms, suggesting that the intrusion occurred at a petrological and/or thermal boundary. The crustal velocity beneath the northern flanks of Sierra Negra and the platform between Alcedo volcano to the north is lower than the initial 1-D model. Although resolution is poor at depths greater than ~15 km, we find no evidence for a velocity increase marking the base of the crust, suggesting that the crust is thicker than implied from earlier gravity models. Our results, interpreted in light of results of geodetic and petrological studies, provide tests of models for the construction and evolution of ocean island volcanoes, and help constrain the processes of oceanic platform construction above mantle plumes.

Mingling-induced crystallization from Saruana Lava, Chokai, Tohoku Japan, and the origins of end member magmas

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Crystallization process during magma mixing was investigated for Saruana lava, West Chokai, Tohoku Japan, by extensive petrological analyses on phenocryst minerals. Examined rocks are basaltic andesite containing phenocrysts of cpx, opx, olivine, plagioclase, magnetite, spinel, apatite, and minor hornblende. Magma mixing is suggested by petrological evidence such as: disequilibrium relation of Fe-Mg partitioning in mafic minerals, complex chemical zoning, dissolution textures, heterogeneous compositions in a single lava, etc. Basic cores of mafic minerals, calcic part of plagioclase, and chromian spinel were derived from the mafic end member magma (high Mg-basalt), whereas Mg-poor pyroxene cores, sodic plagioclase cores, magnetite, and apatite were from the felsic end member (crystal-rich andesite). Each phenocryst crystallized in at least two different host magmas in terms of large variations in Mg-values of mafic minerals and An in plagioclase. In a cpx crystal that have an Mg-rich core (Mg-values:85-87), the core is surrounded by an oscillatory-zoned intermediate margin with polygonal growth bands surrounded by an Mg-poorer thin rim. In an Mg-poor-cored pyroxene, a round Mg-poor core (Mg-values:65-67) is surrounded by an Mg-richer margin of which zoning pattern is similar to the Mg-rich-cored cpx. The oscillatory zoning was formed in the cooled and partially hybridized mafic magma during the thermal equilibration between the magmas. The shape of the core is rounded and this implies dissolution of the Mg-poor pyroxenes by heating of the host felsic magma or by incorporation of the Mg-poor phenocryst into a hot mafic magma. All complex zoning profiles of the orthopyroxene and the plagioclase phenocrysts can be accounted for by the similar process with that for cpx. Whole-rock chemistry and isotopic compositions provided further insight into chemical natures of end member magmas and their origins. Major element composition of the felsic end member is similar to that of the underlying lava, which is a typical calc-alkaline andesite. The mafic end member is an Mg-rich high-K basalt of which composition is similar to that of the basaltic lava occurred in a drillhole near the vent of Saruana lava. Sr, Nd, Pb, and Hf isotopic analyses imply that the source of the basaltic magma is as depleted as MORB source. The isotopic nature of the source mantle is different from those for the volcanic front where the source mantle is more enriched.

The initiation of crustal recycling processes in island arcs: insights from the Soufriere Volcanic Centre, Saint Lucia

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Extensive intermediate pyroclastic flow deposits, lava flows, domes and block-and-ash-flow deposits from the Soufriere Volcanic Complex (SVC), Saint Lucia, collectively represent a conspicuous shift in composition and eruption style for this island arc segment. Compositionally, these dominantly silicic (61.6 to 67.7 wt. percent SiO2) SVC deposits are distinct from older more mafic deposits in Saint Lucia. They contain accessory zircons, and many of the most recent rocks have phenocrystic quartz. SVC deposits occur in and around the Qualibou Depression, a c. 10 km diameter wide sector collapse structure of poorly constrained age. Here, we re-investigate the onset of silicic volcanism in Saint Lucia, and the relationship between individual SVC pyroclastic flows and the sector collapse through (U-Th)/He, U-Th and U-Pb zircon chronostratigraphy, aided by mineralogical and geochemical correlation.

The oldest SVC units comprise pyroclastic deposits at Micoud (640+/-8 ka), Bellevue (264+/-8 ka), Anse John (104+/-4 ka) and La Pointe (59.8+/-2.1 ka), and at Anse Noir and Piaye (undated). These were all previously grouped with or associated with the so-called Choiseul tuff, whereas our chronology demonstrates that the units represent individual periods of activity spanning a range of ages. Choiseul pumice at the type locality has yielded a (U-Th)/He zircon age of 515+/-61 ka, overlapping with the age for Morne Tabac (532+/-42 ka), a dome truncated by the depression escarpment. Younger SVC units comprise Morne Bonin (273+/-15 ka), Gros Piton and Petit Piton (71+/-3 ka and 109+/-4 ka, resp.), Belfond (13.6+/-0.4 ka) and Terre Blanche (15.3+/-0.4 ka). The younger units are clearly domes within the Qualibou Depression whereas the nature of Morne Bonin (dome or mega-block) remains poorly constrained. Belfond and Terre Blanche have whole rock geochemistry and mineral assemblages similar to the Belfond pyroclastic flow deposit, the most recent widespread pyroclastic flow with nearly-concordant (U-Th)/He and 14C ages of 20 ka. The Belfond and Terre Blanche domes possibly represent late-erupted degassed portions of the magma that produced the Belfond pyroclastic flow.

The geochemical characteristics and similar zircon age distributions of the silicic lava domes and pyroclastic flows of the SVC suggest that these share a common magma source beneath the Qualibou depression. The onset of activity from this proto-Qualibou centre occured much earlier than previously thought (by c. 500 k.a.), and marks a change from largely quartz- and zircon-free andesitic magmatism to more evolved magma compositions. We interpret crystal recycling in SVC magmas, and the presence of co-genetic plutonic enclaves, to indicate the progressive build-up of a mid-crustal batholith, and thus a major change in the crustal structure of this island arc segment.

Primary boninite magmas explored from melt inclusions

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Boninite melt inclusions were analyzed in Cr-spinel collected from beach sand from Mukojima, Chichijima, Anijima and Ototojima, Bonin Islands. The common constituents of the inclusions are quenched glass, daughter minerals which grew after trapping, and euhedral crystals of olivine, orthopyroxene and clinopyroxene that were trapped with the surrounding melt, and shrinkage bubbles. We classified the inclusions into 6 types (Type-A–F) based on the combination of the constituents and their textures. The difference in these inclusion types inherited from the melt compositions and the cooling history dependent on the mode of occurrence of the host rocks. Because of the homogeneity of the glass in inclusions and the host spinel adjacent to the inclusion walls, the bulk compositions of quench glass with or without quench crystals (Type-A, B, E and F) are considered to represent the liquid compositions when captured by the host spinel. Major and trace element compositions of melt inclusions show a wide range of boninitic compositions with SiO_2 53-63 wt.%, TiO_2 0.02-0.25 wt.%, Al_2O_3 6-13 wt.%, MgO 8-23 wt.%, CaO 4-11 wt.%, Zr/Ti 0.01-0.04, Gd/Lu 2.4-7.2 and Gd/La 0.24-0.87. We classified the compositions of melt inclusions into five types. BIC (Boninite Inclusion Compositions)-1 is characterized by a low-SiO_2 trend and belongs to high-CaO boninite series. It has a subhorizontal chondrite-normalized pattern with high REE abundances. These features are similar to low-Si boninite by Kanayama et al. (2012). BIC-2 is characterized by relatively high CaO content and low Zr/Ti, which resembles to high-Si type 2 boninite by Kanayama et al. (2012). BIC-3 shows a low-Ca and low-SiO_2 trend. BIC-4 and BIC-5 are typical low-Ca boninite with high Zr/Ti ratios and high SiO_2 contents. However, BIC-4 has a lower Al_2O_3 content than BIC-5 and a U-shaped chondrite-normalized REE pattern and is mostly sampled from Mukojima. On the other hand, BIC-5 shows a characteristic V-shaped chondrite-normalized REE pattern. In general, BIC-types show a systematic relationship with the host Cr-spinel compositions. BIC-1, 2 and 3 are hosted by low-Cr# spinel, whereas BIC-4 and 5 are hosted by high-Cr# spinel. I have estimated the pressures and temperatures for the most primitive melt inclusions in each BIC type to have been in equilibrium with the mantle peridotite under anhydrous or hydrous conditions by using the olivine-liquid geothermometer by Putirka et al. (2007) and the olivine-orthopyroxene-liquid geobarometer by Putirka (2008). As a result, it is shown that BIC-1 type was generated in higher pressure condition than other BIC types.

None of us belong: crystal chemistry of andesites in Dominica, Lesser Antilles

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As the simplest subduction setting, island arcs provide a unique chance to study the magmatic processes involved in andesitic eruptions. Located in the centre of the Lesser Antilles arc, Dominica has been the site of andesitic volcanism for >500,000 years. Eruptions from the island produce dominantly porphyritic andesite with a phenocryst assemblage of plagioclase (An54-92), clinopyroxene (En64-69), orthopyroxene (En52-58) and Fe-Ti oxides with less common amphibole and olivine. Microprobe spot and profile analyses were undertaken on all phenocryst phases in order to constrain petrogenetic and ascent processes. While single plagioclase and amphibole profiles within individual units lack core to rim zonation, each mineral population within the units displays significant chemical variability. Combined with the lack of equilibrium between phenocrysts and melt, this indicates a mineral-melt decoupling which may be the result of magma mixing or the accumulation of crystal cargo during ascent from source to surface. The homogenous crystal profiles seen in all mineral phases across all units suggest the existence of locally homogeneous magma reservoirs in the crust. Amphibole pressures and the rhyolitic nature of matrix glass suggest that such reservoirs were relatively shallow (3-5 km). Model temperatures calculated for individual phases and equilibrium phase pairs also support mineral-melt decoupling, with Fe-Ti oxides (avg. 800℃), amphiboles (avg. 750℃), and high-An plagioclase (avg. 950℃) displaying different temperatures. Our findings suggest that the phenocryst assemblage in the Dominican andesites is the result of near-equilibrium crystallization in evolved and primitive melts, followed by subsequent mixing which resulted in a non-equilibrium crystal cargo. U-Th zircon geochronology provides further evidence for recycling, with most lava samples showing multiple crystallization events prior to eruption. This work provides evidence for widespread disequilibrium between magmas and their crystal cargo, which can be explained by a long-lived crystal mush beneath the silicic centers in Dominica. These centers, which only recently emerged compared to the overall longevity of the arc, thus may indicate the initiation of a batholithic crust of continental affinity in an island arc.