older than non-radioactive cases with the same dissipation, because the low efficiency of radioactive heating requires a much larger heat flow at the core mantle boundary. Although the age of the inner core is controlled by the heat flow at the CMB, the ohmic dissipation to be maintained is the constraint that makes it low.

T31G-05 1140h

The power requirement of the geodynamo from scaling Joule dissipation in numerical models

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In order to contrain models of the thermal evolution of the core, the nucleation time of the inner core and possible requirements for core heat sources, the power needed to maintain the geomagnetic field against Joule dissipation must be known. Here I use results from a large number of convection-driven spherical shell MHD dynamo models to derive a systematic scaling of the magnetic decay time τ, defined as the time-average of magnetic energy over Joule dissipation. The magnetic Reynolds number Rm covers the range between 50 and 1000, Ekman numbers are between 3×10^{-4} and 10^{-5}, and magnetic Prandtl numbers Pm between 0.25 and 3. The results are fitted fairly well by a simple relation of the form $\tau \sim Rm^{-1}$. A weak dependence on the magnetic Prandtl number may exist and a two-parameter fit of the form $\tau \sim Rm^{-1}Pm^{1/6}$ reduces the scatter somewhat. I use a ratio of ≈ 7 between the mean field strength inside the fluid shell and at its surface, taken from a model with a particularly Earth-like field, to estimate the magnetic energy density in the core as $3J/m^3$. For $Rm = 500$ the simple scaling of magnetic decay time predicts a Joule dissipation of $3\times10^{11}W$ in the core. When a dependence on the magnetic Prandtl number is assumed, this figure rises to $3\times10^{12}W$. While the former value can be easily accommodated in the energy budget of the core, the second one puts severe constraints on its thermal history and energetics.

T31G-06 1155h

Numerical and Parameterized Modeling of the Earth's Thermal History: Effects of Heat Producing Elements in the Core

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Thermal convection in the Earth's mantle regulates the rate at which heat is lost from the Earth's interior. Factors affecting the vigor of that convection, such as the viscosity of the mantle and barriers to convection such as the 660-km endothermic phase transition, as well as the rate of radioactive heat generation within the planet determine the rate at which the Earth is cooling. In this presentation, we will describe a suite of simulations of the Earth's thermal history using both parameterized and numerical (fluid-dynamical) modeling of convection in the Earth's mantle. The core is modeled, in both cases, as a heat reservoir which is used to set the temperature boundary condition at the CMB for the numerical model. We investigate the effects of varying the concentration of heat producing radioactive elements in the core by varying the degree of internal heating in this region. We find that the inclusion of modest amounts of heat producing elements in the core results in simulations that fit modern constraints on temperature in the mantle as well as surface heat flow while geochemically derived mantle radioactive abundances of heat producing elements are used.

T31G-07 1210h

The Effects of Radiogenic Heating in Geodynamo Simulation

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Recent studies have suggested that potassium-40 may be present in the Earth's fluid outer core. The presence or absence of this radiogenic isotope may have an effect on magnetic field generation. This study examines the consequences of radiogenic heating on the character of a simulated magnetic field. The Glatzmaier-Roberts geodynamo model is used to test the effect of different levels of radiogenic heating with both homogeneous and tomographic core mantle boundary (CMB) heat flux conditions. Zero to fifty percent of the simulated CMB heat flux is generated by radiogenic heating. The total heat flow through the CMB is prescribed to be the same total amount in every case. Preliminary results show variation in the velocity, magnetic field, and temperature structures in the different cases.

T31H MCC: 3007 Wednesday 1020h

Izu-Bonin-Mariana Arc Processes and Progress II *(joint with S, V)*

Presiding: **S Klemperer,** Stanford University**; J Gill,** University of California, Santa Cruz

T31H-01 1020h

Marine Magnetotelluric Experiment for the Mariana Subduction System

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A marine magnetotelluric (MT) experiment was carried out in the central Mariana area from 2001 to 2002 to elucidate electrical structure of the subduction-arc-back arc system. The electrical conductivity is mainly subject to temperature, partial melt, and volatiles such as water in the mantle. 10 ocean bottom electromagnetometers (OBEMs) were deployed along the line crossing the central Mariana trough during the cruise YK01-11 in October 2001. This OBEM array covers from the Pacific plate to Parece-Vela basin through Mariana trough. 5 of them were successfully recovered during the cruise using R/V M. Ewing in April 2002 and during the cruise KR02-14 in October 2002. The MT analysis has been carried out using the data at the 5 sites and another 3 sites. These additional data were collected by past experiments (Filloux, 1983; Seama et al., 2003) and the sites locate near the survey line of our experiment. Goto et al. (2003) analyzed 3 MT data sets around Marina islands and showed no thick conductive layer in the mantle wedge beneath the arc and fore arc region. In this study, we analyzed the 5 MT data sets in Mariana trough and Parece-Vela basin, so far. The MT responses were first corrected for the topographic effect which is significant especially for marine MT data. Then, the corrected responses are separated to TE and TM modes and then inverted in two-dimensional (2-D) model space independently. The responses for the each mode is sensitive to electric current flowing either parallel or perpendicular to the 2-D strike. Obtained 2-D models for both modes have common feature that the mantle resistivity decrease from several hundreds or more to several tens or less ohm-m at the depth of 60-70 km. The mantle below 60-70 km is, however, more conductive for the model of the TM inversion than that of the TE inversion. This may indicate anisotropy that is more conductive in the direction along the profile. These features are seen in the mantle beneath southern East Pacific Rise and interpreted that the upper resistive mantle is result from drying out of olivine due to partial melting and lower conductive and anisotropic feature is manifestation of the alignment of olivine crystals to the mantle flow direction in wet condition (Baba et al., 2003). The same interpretations may be possible for the Mariana back arc basin. In addition, further analysis is now on going, which we invert all the data to obtain the model for the whole 2-D transection. The result will be presented in the meeting.

T31H-02 1035h

The Causes of Melt Differentiation at the Izu Arc Volcanic Front

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While it is common consensus that mafic arc magmas (basalts to magnesian andesites) are partial melts of the upper mantle, the provenance of the evolved arc magmas (dacites and rhyolites) remains much contested. Classic models suggest either fractional crystallization or partial melting of the upper plate crust, or a combination of both, as causes of melt differentiation. Unfortunately, it is difficult to test such models in natural systems since most arc volcanic rocks are fully crystallized, and liquid compositions cannot be directly compared to their cogenetic phenocrysts. Such possibilities, however, arise from the Cenozoic fallout tephras from the intraoceanic Izu Bonin arc. The tephra melts originate from similar mantle sources as the low-K Quaternary Izu arc front (Izu VF) volcanic rocks. Individual fallout layers from single eruptions are commonly zoned and frequently contain a range of basalt to rhyolite glass shards together with plagioclase (An_{42-96}), clinopyroxene (En_{34-75}), orthopyroxene (En_{41-73}) and titanomagnetite (Usp_{14-50}). Trace amounts of Cl-apatite (Cl=0.8-2.4 wt%) are confined to high-silica tephras, whereas olivine is absent despite its presence in the Izu VF basalt lavas. The Cenozoic tephra glasses (approximately 1500 individual glasses from 43 layers) display coherent elemental systematics through time. At any given age, the tephra glasses display a distinct bimodal distribution, with maxima at 53-54 wt% SiO_2 (basaltic andesitic) and 70-72 wt% SiO_2 (rhyolitic), respectively. Basaltic andesitic glasses overlap widely with the Izu VF lavas, whereas the dacitic-rhyolitic pole is almost exclusively represented by the tephra. Chemical and petrographic evidence of melt mixing is ubiquitous in all tephras, indicating melt mixing as important generic process. The incompatible element K varies by a factor of two in abundance at any given SiO_2. The linear mixing trends of K_2O vs. SiO_2 in individual fallout tephras, however, always have similar slopes with K_2O being always more enriched in the more siliceous glasses. It is this uniformity of the K_2O zoning, that effectively rules out that the zoned tephra melts formed by mixing of mafic and siliceous component melts that originate from either mantle and upper crustal sources (i.e. mixing of mantle melts with crustal partial melts), or by mixing of derivate melts that stem from different batches of mantle melts. Therefore, the only viable process of upper crustal differentiation appears to be mixing of cogenetic basaltic-andesite and dacitic-rhyolitic component melts that evolved by fractional crystallization from a single batch of mantle melt, and that became mixed during eruption. However, quantitative models cannot reproduce the intra-layer tephra zonation by fractional crystallization processes. Therefore, I suggest that the subducting slab may possibly play a role in the generation of the siliceous Izu VF melts. A scenario in where mafic mantle melts mix incompletely with hydrous, K_2O-bearing siliceous fluids from the slab appears be able to explain many of the chemical and petrographic features observed in both the IzuVF tephra and lavas.

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T31H-03 1050h

Coexistence of Highly-Depleted Wet Basalts and Depleted Dry Basalts in Sumisu Caldera, Izu-Bonin Arc, Japan

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The northern Izu-Bonin arc consists of 11 Quaternary volcanoes and eight Quaternary submarine caldera volcanoes. Sumisu caldera (31.5° N, 140° E), which is 8 × 9 km in diameter and has 600∼700 m high inner walls, is one of the best developed submarine calderas along the Izu-Bonin arc and has been studied and sampled during the R/V Natsushima NT02-10 and the R/V Kairei KR02-16 cruises in Sept.-October and December, 2002, respectively. The ROV Dolphin 3K, the manned submersible Shinkai 2000 and dredge hauls were used for sea-floor sampling. Both basalt-basaltic andesite (<55 wt % SiO_2) and dacite-rhyolite (66-74 wt % SiO_2) are clearly predominant eruptive products, but rocks having SiO_2 contents of 61∼66 wt % are absent. Basalts (49∼53 wt % SiO_2) from Sumisu caldera and Sumisu island contain 4∼8.5 wt % MgO; variations of major and trace element compositions are relatively large in the basalt-basalt intervals. They ubiquitously bear plagioclase phenocrysts and some contain >4 % olivine and augite, but others are free of olivine and/or augite phenocrysts. Many parent-daughter sets within the basalts were examined by least squares mass-balance calculations using phenocryst phases. It is suggested that fractionation alone of phenocryst phases from the most magnesian basalt (8.5 % MgO) cannot explain even the major element variations of the daughter basalts. These discrepancies, however, disappear if the parent basalts were to assimilate small amounts of rhyolite, together with fractional crystallization (AFC). Unfortunately, however, incompatible trace element concentrations, such as Zr and Ba, are not always compatible with these AFC models. The most-magnesian basalt, as well as some of the other basalts, contain low Zr (20∼30 ppm), which cannot yield basalts containing much higher Zr (30∼40 ppm) through fractionation and/or assimilation. Moreover, low-Zr basalts have more light-REE depleted patterns than high-Zr basalts and olivines in low-Zr basalts are more magnesian at a given NiO content than those in high-Zr basalts, suggesting higher degrees of melting of the source mantle. On the other hand, we recognised that high- and low-Zr basalts have different mineral assemblages; low-Zr basalts contain up to 5 vol % augite phenocrysts, but most high-Zr basalts are free of augite phenocrysts. Thus, the former and the latter assemblages are OL + CPX + PL and OL + PL, respectively. H_2O will retard crystallization of plagioclase. Hydrous basalts will crystallize olivine followed by augite and plagioclase, producing the former assemblage, but plagioclase will appear on the liquidus just after olivine in the dry basalts, yielding the latter assemblage without augite. Moreover, low-Zr basalts are enriched in the fluid mobile element Ba, suggesting a larger fluid content was necessary to produce greater degrees of partial melting. We suggest that there existed dry and wet primary basalts in the Sumisu magmatic system, each having different trace element concentrations and mineral assemblages, which would have been caused by differences of water content in the source mantle and basaltic melt. The lower content of Zr in the wet basalt could then have resulted from higher degree of partial melting of a hydrous source mantle.

T31H-04 1105h INVITED

Processes controlling along-arc isotopic variation of the Izu-Bonin arc

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We present along-arc variation of isotopic and trace element composition for >2000km section of the Izu-Bonin arc including new high-precision Pb isotope measurements. New data mainly come from the southern Izu-Bonin arc, where the Sofugan Tectonic Line (Yuasa, 1985) intersects the volcanic front and is characterised by intra-arc rifting and thinner arc crust compared to the north. The lavas studied are mostly low-K tholeiitic basalt and basaltic andesite. Exceptions are highly alkaline shoshonitic rocks from Iojima and the surrounding volcanoes. Most of the volcanoes have been active in late Quaternary. A southward decrease in $^{87}Sr/^{86}Sr$ and increase in $^{206}Pb/^{204}Pb$ is observed in the northern section of the arc and this continues into the southern arc as far as 27°N. In Pb-Pb isotope space volcanoes plot systematically closer to the NHRL from north to south. The decoupled behavior Sr and Pb isotopes led us to propose an along-arc mantle wedge heterogeneity prior to the addition of the slab-derived component. In terms of the slab-derived component, the overall correlation between $^{87}Sr/^{86}Sr$ and fluid-mobile element enrichment implies a contribution of fluid from altered oceanic crust and pelagic sediment in the section between 35 and 27°N. South of 27°N, the along-arc isotopic trend changes dramatically. Sr isotopic ratio increases southward from 27°N, and the $^{206}Pb/^{204}Pb$ becomes highly radiogenic (19.5). This isotopic signature requires involvement of component with high $^{206}Pb/^{204}Pb$ with low Δ8/4.The volcaniclastics of the oceanic islands on the subducting Pacific Plate are a possible candidate to introduce such a component into the mantle wedge. Lack of correlation between Nd isotopic composition and Th enrichment relative to Ce implies that fluid, not melt, has played a major role in the source magma compositions in this segment of the arc. South of 25°N, in the vicinity of the Iojima, the isotopic characteristics again changes significantly. $^{143}Nd/^{144}Nd$ decreases down to 0.51280 but the high $^{206}Pb/^{204}Pb$ and low Δ8/4 signatures are retained. The remarkable Th enrichment associated with low $^{143}Nd/^{144}Nd$, Δ8/4 and Δ7/4 implies that melt of a high μ subducted volcaniclastics is required. In this respect the samples from ODP Hole 801, located outboard of the Mariana arc, have a high μ volcanic sequence, and may provide a potential source for high μ signature in the arc south of 27°N.

T31H-05 1125h

HFSE-REE systematics of Neogene IBM lavas

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Hf-Nd isotope ratios and REE+Hf concentrations have been measured for representative lavas from the Izu and Mariana arc, and can be compared with similar results for Mariana Trough basalts. Isotopes for all three suites define a trend parallel to the Terrestrial Array but displaced to its high-Hf side, as for Indian Ocean MORB. The Izu arc volcanic front lies at the most depleted end of the array whereas the Izu rear arc overlaps the Mariana volcanic front. The overall isotopic pattern is qualitatively consistent with arc and back arc magmas being mixtures of Indian-type mantle plus small amounts of subducted sediment. However, the slope of the isotope correlation requires a mantle-like Nd/Hf ratio for the sediment component that is much lower than in most IBM sediment. Izu rear arc lavas also lack the expected negative Ce and Hf concentration anomalies. Together the data indicate substantial intrinsic isotopic heterogeneity in the IBM mantle wedge, and small amounts of LREE>Hf addition from the slab, least at the Izu volcanic front.

T31H-06 1140h

Acidic Plutonism in the Izu-Ogasawara (Bonin)-Mariana (IBM) Arc and Growth of Arc Crust: Petrological and Geochemical Characteristics of the Tonalite at the Komahashi-Daini Seamount and Difference From the Tanzawa Plutonic Complex

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Recent seismic refraction and reflection data suggest that the continents are underlain by mafic lower crust and felsic middle crust. Petrogenesis of granitic middle crust layers is important for understanding the formation and evolution of continental crust. In modern tectonic regimes, tonalitic rocks and chemically equivalent volcanic rocks occur in island arcs and active continental margins. Thus, the petrogenesis of tonalite and related rocks in intra-oceanic arc settings is of great importance in understanding the processes of both recent island arc and continental crust formation. The Komahashi-Daini Seamount, in the northern Kyushu-Palau Ridge in the northern Philippine Sea plate, was investigated by the Japanese Geodynamics Project (GDP) cruises in the 1970's, and by the R/V Tansei-maru (Ocean Research Institute, University of Tokyo) in the 1990's. Plutonic rocks were dredged from the seamount, and have great importance for understanding the processes of island arc and continental crust formation. The petrographical and geochemical characteristics of the Komahashi-Daini Seamount tonalite are summarized as follows: (1) These tonalites are classified into biotite-hornblende tonalite and hornblende tonalite. Phenocrysts, especially plagioclase, show common lamellar twins and oscillatory zoning patterns; (2) This tonalite show low content of bulk LILE, and classified into low-K calc-alkaline, 1 to 8 wt.% MgO with 55 to 75 wt.% SiO_2; (3) This tonalite shows roughly parallel and increasing total REE content with increasing SiO2 content, except for increasingly strong negative Eu anomaly at higher SiO2. These factors indicate that the Komahashi-Daini Seamount tonalite was produced by fractional crystallization. The parent magma of this tonalite is considered lower than 56 wt.% SiO2. Based on this relationship, we concluded that the source for the parental magma was arc mantle peridotite. We compared these tonalites with typical tonalite, i.e., Tanzawa Complex, central Japan. The Tanzawa complex is considered to represent the lower-middle crust of the IBM arc. One of the characteristics of these tonalites is that cumulate textures are common in the mafic rocks. And HFSE and REE vs. SiO2 diagrams of Tanzawa tonalites show inflection trends at 62 wt.% SiO2. This tonalite was derived from an intermediate (62 wt.% SiO2) parent magma by crystal fractionation (felsic part) and accumulation (basic part). The parent material of the intermediate magma is basaltic lower crust, and the gabbro is restite from the partial melting process (Kawate and Arima 1998). Differences between Komahashi-Daini Seamount and Tanzawa tonalite are; (1) Cumulate textures are not observed in the tonalite from the Komahashi-Daini Seamount; (2) Komahashi-Daini Seamount tonalite shows linear variation of Zr and REE vs. SiO2. These data and observations also support the interpretation that tonalite in the Komahashi-Daini Seamount was produced from basaltic magma. We suggest that this process of primary felsic plutonic activity predominated during the early stage of oceanic island arc activity, and later shifted to secondary granitoid activity, i.e., crystal fractionation and accumulation from andesitic magma derived from partial melting of basaltic lower crust, as represented by the tonalite in the Tanzawa Complex.

T31H-07 1155h

Anatahan Eruption of May, 2003: Integrated Response of the MARGINS Community

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Following the May 10 eruption, the MARGINS office responded by authorizing helicopter surveillance of the eruption and ship deployment to visit Anatahan. The helicopter flights allowed for (a) visual inspection of the impact of the eruption, (b) identification of the source of the eruption (east crater), (c) collection of bombs and tephra from the eruption, and (d) deployment of a seismometer. The ship visit followed, and consisted of (a) maintenance and data retrieval from a previously-deployed seismic station, (b) collection of more samples, and (c) deployment of COSPEC instrumentation (for volatile flux measurement). The eruption has therefore presented the MARGINS community with an unique opportunity to integrate geophysical, geochemical and volcanological observations of an active, SiO_2-rich volcano located on a targeted margin. This presentation will highlight on-going studies of the May event which will be presented in detail in the accompanying special session. Topics to be presented include (1) seismicity associated with the eruption, which was well monitored by a PASSCAL broadband seismograph fortuitously installed on Anatahan 4 days prior to the eruption, (2) geochemistry of the erupted products. This includes ICP analysis of the major and trace element chemistry, electron microprobe analysis on selected mineral phases, plus the isotope systematics (Sr-Nd-Pb-Hf-O-U-series) of selected samples, (3) volcanological observations on eruption initiation and evolution plus estimates of volatile flux rates within 11 days of the start of the eruption, and (4) hazard assessment of the eruption and mitigation strategies.