T32A MCC: Level 2 Wednesday 1330h

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

Presiding: **J Gill,** University of California, Santa Cruz**; Y Tamura,** IFREE/JAMSTEC

T32A-0902 1330h POSTER

Detailed analysis of the spreading history of the Parece Vela and Shikoku Basins: Implications for Philippine Plate Rotation

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The Philippine plate, located between the Pacific and Eurasian plates, is the world's largest marginal basin plate. Its motion history is poorly understood as it is almost entirely surrounded by subduction zones. Hence, the rotation of the Philippine plate through time has only been constrained by palaeomagnetic data, and estimated to be 34 degree clockwise between 25 and 5 Ma . Here, we present a comprehensive analysis of geophysical data from two Oligocene to Miocene back-arc basins, the Parece Vela and the Shikoku Basin, located along the eastern margin of the Philippine Plate. By means of their seafloor spreading record, these basins provide independent constraints on the rotational history of the Philippine Plate. Our detailed plate model is based on a joint analysis of all available magnetic, gravity and bathymetric data in the region. Subduction occurred along the proto-Izu-Bonin-Mariana trench and led to trench roll-back, arc rupture and back-arc rifting in the Parece Vela and Shikoku Basins at 30 Ma. A northward and southward propagating rift developed from the extremities of the basin inward, and seafloor spreading in both basins developed by chron 9 (28 Ma) and possibly by chron 10 (29 Ma). The spreading orientation in the Parece Vela Basin was initially E-W, as opposed to ENE-WSW spreading in the Shikoku Basin. The ridges joined by chron 6B (23 Ma) and formed a R-R-R triple junction to accommodate the difference in spreading orientations in both basins. At approximately 20 Ma, the direction of spreading in both basins changed dramatically, from E-W to NE-SW in the Parece Vela Basin and from ENE-WSW to NE-SW in the Shikoku Basin. This change was accompanied by a marked decrease in spreading rate. Cessation of back-arc opening occurred at 15 Ma, a time of regional plate reorganisation. The dramatic change in spreading rate and direction at 20 Ma is interpreted to be an expression of Philippine plate rotation, a rotation which was previously thought to have occurred at 25 Ma as a result of a global change in plate motions. Our results suggest that the Philippine Plate rotated clockwise by about 4 degrees between 20-15 Ma about a pole located 35oN, 84oE. This implies that most of the 34 degree clockwise rotation inferred from paleomagnetic data to have occurred between 25 and 5 Ma may have been confined to the period between 15 and 5 Ma. The mechanisms that drive this rotation remain uncertain, but we speculate that changing boundary conditions result in edge driven rotation.

T32A-0903 1330h POSTER

Overlapping Spreading Centers, Ridge Jumps and Ridge/Hotspot Interaction: the Northwestern West Philippine Basin as Study Example

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We conducted a geophysical cruise, including ROV dives, in the northwestern part of the West Philippine Basin (WPB) in April-May of 2003. Our survey indicates that the well-established spreading center (uncorrectly known as the Central Basin Fault) of the WPB is relayed in the northwest by a series of at least seven overlapping spreading centers (OSC) that align against the Luzon-Okinawa Fracture Zone. We observe systematic southward ridge jumps with propagating rifts to the south and failed ones to the north. These OSCs reveal the continuous interaction - and cyclic effects - between a propagating spreading center and the hotspot that has produced the Benham Rise (and its derivative Urdaneta Plateau) during Middle and Late Eocene and what could be the present-day Manus hotspot. Fresh basalts and dolerites were collected using ROV Kaiko at the northernmost margin, northern Urdaneta Plateau, and the failed rifts. We thus expect to get soon chronological constraints on rates of ridge propagation and ridge jumps in relation with the simultaneous northward drift of the growing Philippine Sea plate, in addition to geochemical characteristics of source mantle(s).

URL: http://www.whoi.edu/science/GG/people/adeschamps/

T32A-0904 1330h POSTER

Fate of an Oceanic Island-arc at the Collision Zone: Insight From a Modern Case at the Izu Collision Zone, Central Japan

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Arc-arc or arc-continent collision zone, which separates an arc crust into materials to be left on the earth's surface and to be returned to the mantle, is regarded as the final disposal place of the subduction factory product. Mass balance across the collision boundary, therefore, should have great significance in the processes of continental growth and mantle evolution. The Izu Collision Zone (ICZ) located at the conjunction of the Honshu arc and the Izu-Bonin arc (IBA), is a place of ongoing orthogonal arc-arc collision, where the middle to upper crust of the northern IBA is exposed on land as accretionary terranes. The IBA-ICZ system is much advantageous for elucidating the mass balance, because that the product is simple and fresh and the flow from manufacture to disposal is quite clear. Across arc variation of buoyancy and rheological state of the lithosphere controlled principally by geothermal gradient would regulate the regime of collision tectonics. Crust-scale accretion is taking place associated with conspicuous crustal shortening and thickening in the central ICZ where the active arc that is about 100 km wide and 20 km thick is colliding. By contrast, almost the whole arc crust is subducting, leaving the off-scraped sediments as accretionary prisms in the eastern and western areas where the inactive forearc and backarc, totally 200 km wide and averagely 14 km thick, are colliding. Based on the land geology and existing seismic structure, crustal volume of the accreted IBA is estimated for the line along the axis of the ICZ and another line passing through the Tanzawa Terrane situated eastward 30 km apart from the axis. The estimation indicates that the volume of the Tanzawa line is significantly smaller (16 %) than that of the axis, in spite of being very close. This difference is explainable, if the Philippine Sea Plate slab including expected aseismic part is accompanied with 7 km thick subducted arc crust. This result of calculation implies that the lower crust delamination is occurring beneath the Tanzawa Terrane and the major part of the central ICZ. As a consequence, survival rate of an arc crust in an orthogonal arc-arc collision zone like the ICZ can be estimated at about 70 % of the active arc and 30 % of the whole crust. Furthermore, taking a preexisting 6 km thick oceanic crust into account, the survival rate of arc magmatic products in this pattern of collision can be calculated at about 50 %.

T32A-0905 1330h POSTER

Three Dimensional Slab Structure of the Izu-Bonin-Mariana Arc

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Recent studies on slab structure in the northwest Pacific have imaged inconsistent geometries of the subducted ocean lithosphere along the plate margin. Below the Mariana arc portions of the subducted Pacific plate penetrate into the upper mantle vertically while in areas below the Izu-Bonin arc the slab appears to lie horizontally. This large variation in geometry is particularly well visualized in three dimensions using a combination of seismic tomography and earthquake data. One important feature that has been identified from this multidisciplinary approach of studying the three-dimensional structure and tectonic history of the northwest Pacific margin is a subhorizontal tear in the Pacific slab at the southern end of the Izu-Bonin arc. This visualization has inspired new tectonic reconstructions and insight into the evolution of the subducting Pacific plate and the development of its current geometry.

T32A-0906 1330h POSTER

Long Term Seismic Observation in Mariana by OBSs : Activity of Deep Earthquakes

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In order to obtain the deep arc structural image of Mariana, a large-scale seismic observation by using 58 long-term ocean bottom seismometers (LTOBS) has been started since June 2003 for about one year. It is a part of the MARGINS program (US-JAPAN COLLABORATIVE RESEARCH: MULTI-SCALE SEISMIC IMAGING OF THE MARIANA SUBDUCTION FACTORY), and the aim of this observation is the crustal and mantle structure modeling by using passive and active seismic sources. The 50 and 8 LTOBSs are owned by LDEO and ERI, respectively, and they were deployed during the cruise of R/V Kaiyo (Jamstec), KY03-06. Prior to this experiment, we made a pilot long-term seismic array observation in the same area by using 10 LTOBSs, deployed in Oct. 2001 by R/V Yokosuka (Jamstec) and recovered in Feb. 2003 by R/V Kaiyo. This LTOBS has been developed by ERI, which has the PMD sensor (WB2023LP) and a titanium sphere housing (D=50cm) and was already used in several long-term observations (ex. trans-PHS array observation presented at the AGU fall meeting, 2000, S51B-02). Two of 10 LTOBSs could not be recovered due to malfunction of the releasing system, and one recovered had a trouble in the sensor control unit. But, seven others have obtained more than 11 months long data continuously. As passive source studies of these observations use characteristic deep earthquakes in this area, the activity of them will be introduced in this presentation, from the data obtained just above them. At the first step, difference of hypocenters of known events, listed on the PDE catalog, is examined. There are 59 events of epicenters within a circular area centered at 19°N, 145°E with radius of 1000km from the catalog during the observation. P and S arrivals are picked by using the WIN system, and the iasp91 model (only V_P with $V_P/V_S = 1.732$) is used for the hypocenter determination. Station corrections are applied only for the sediment layer, estimated from several arrival time data of P and P-S converted phase at the sediment-basement interface below the OBS. The major result is a systematic shift of epicenters with about 200km depth to SE direction below the island chain, and those relocated hypocenters show concentration.

T32A-0907 1330h POSTER

Crustal architecture of the Mariana arc

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In 2003, we carried out deep wide-angle seismic experiments using a large airgun array with a total capacity of 12,000 cu. in. and total 152 ocean bottom seismographs (OBSs) by R/V Kaiyo of Japan Marine Science and Technology Center (JAMSTEC) around the middle Mariana area (KY03-01 and KY03-06 cruises), in collaboration with JAMSTEC, Earthquake Research Institute, University of Tokyo and Stanford University. To understand structural nature of the Mariana arc - back arc system, we performed airgun shooting along a main line (700 km length) across whole of the arc - backarc system from the serpentinite seamount on the forearc to the Parece Vela backarc basin though the Mariana arc, the Mariana trough and the west Mariana ridge. The airgun signals were also recorded by a 12-channel hydrophone streamer towed from the vessel. We summarize information of these seismic experiments, introduce obtained seismic data, and report the preliminary results from the forearc to the Mariana trough. Data qualities of vertical components of almost OBSs are good and the first phases can be traced until a distance of about 200 km. Those of horizontal components are also good to trace airgun signals until a distance of about 100 km. Reflection records indicate thick sediments beneath the forearc region and between the Mariana arc and the Mariana trough and diffractions due to intrusive materials beneath the western part of the Mariana arc, the eastern Mariana trough and the West Mariana ridge were also identified and the oceanic Moho was also traced beneath the Parece Vela basin. Using above reflection records and wide-angle data, a seismic structure was modeled by a 2-D ray tracing (Zelt and Ellis, 1988) and a tomographic inversion method (Zelt and Barton, 1998). The main characteristics of the preliminary velocity structure are as follows. (1) Crustal thicknesses of the Mariana arc and troughs are about 20-25 km and 6 km, respectively. (2) A middle crust with a P-wave velocity of 6km/s exists beneath the arc region and the thickness is about 5 km. The topography has severe variation and indicates intrusive materials from the middle crust. (3) A lower crust of the arc has P-wave velocity of over 7.0 km/s and the thickness is about two or three times of that beneath the trough area. (4) The lower crust of the arc - backarc transition zone indicates fast P-wave velocity of 7.0-7.6 km/s. (5) The P-wave velocities of the upper and lower crusts seems to be slow beneath a serpentinite diapir at the eastern end of the forearc region.

T32A-0908 1330h POSTER

Carbon and Nitrogen Input Fluxes in Subducting Sediments at the Izu-Bonin and Central America Convergent Margins

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We are investigating the N and C contents and isotope ratios in subducting sediment sections in the two MARGINS Subduction Factory focus sites, the Izu-Bonin (IB) and Central America (CA) convergent margins (using samples obtained on DSDP/ODP Legs 125, 170, 185, and 205). The sediments from IB (Site 1149, and Leg 129) contain 5 to 661 ppm N with $\delta^{15}N_{Air}$ values of +2.5 to +8.2 per mil (weighted average +4.6 per mil). Reduced-C concentrations range from 0.02 to 0.35% with $\delta^{13}C_{PDB}$ values from -28.1 to -21.7 per mil. Calcite in carbonate-rich layers has $\delta^{13}C$ of +1.7 to +2.8 per mil and $\delta^{18}O_{VSMOW}$ of +28.5 to +29.7 per mil. In comparison with IB, the CA sediment section (Site 1039) has far higher N content (663 to 2380 ppm N with $\delta^{15}N$ of +3.9 to +7.1 per mil; weighted average +5.6 per mil). Calcite in Site 1039 carbonate-rich layers has$\delta^{13}C$ of +0.1 to +3.0 per mil and $\delta^{18}O$ of +29.9 to +32.1 per mil. At Site 1149, down-section decrease in N content, accompanied by decrease in $\delta^{15}N$ and C/N, is thought to reflect diagenesis, whereas at Site 1039, down-section decrease in N content (near 2000 ppm at surface, near 1000 ppm at 150 km) occurs without an obvious shift in $\delta^{15}N$ (reduced C data not yet available). Based on the C-N concentration data we've obtained, sediment C-N input fluxes are estimated at, for the IB margin, 2.5×10^6 g/km.year for N, 1.7×10^7 g/km.year for reduced C, and 9.2×10^8 g/km.year for oxidized C. For the CA margin, we estimate input fluxes of 8.9×10^6 g/km.year for N, and 1.3×10^9 g/km.year for oxidized C (work on reduced C is underway). Our input fluxes for C and N differ significantly from previously published input fluxes for the two margins based on estimated subducting sediment C-N concentrations, but errors are large. For the CA margin, the sediment-only N input flux of 9.8×10^9 g/year (for the entire 1100 km trench length), based on our results for Site 1039, can be compared with the arc volcanic output flux of 8.1×10^9 g/year of Fischer et al. (2002, Science; N input flux of 6.4×10^9 g/year estimated by those authors), indicating the incomplete return of subducted N to the surface in arcs. The magnitude of the N input flux in altered oceanic crust remains unknown (work on AOC N-$\delta^{15}N$ is underway) but should also be considered in such comparisons. All estimates of this type assume uniformity in the incoming sediment section along-strike in active trenches (known not to be the case). Shifts from $\delta^{15}N$ values measured for the two sediment sections to values near +7 per mil for the deeply subducted sediment component as suggested by studies of volcanic gases (e.g., Fischer et al., 2002; Hilton et al., 2002) could be accomplished by moderate loss of isotopically light N during metamorphic devolatilization across forearcs.

T32A-0909 1330h POSTER

Chemistry of Springs Across the Mariana Forearc Shows Progressive Devolatilization of the Subducting Pacific Plate

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Upwelling pore water fresher than seawater has been sampled from serpentinite mud volcanoes on six cruises to the Mariana forearc in 1987-2003: ODP Legs 125 and 195, Alvin and Shinkai-6500 diving cruises in 1987 and 1996, and two cruises in 1997 and 2003 using piston and gravity coring and the ROV Jason. Low-chlorinity water has been sampled at ten sites on nine serpentinite mud volcanoes from 13o47'N to 19o33'N, ranging from 50-90 km from the trench axis, corresponding to depths to the top of the subducting slab of 15 to 29 km below the seafloor. Another six seamounts failed to yield freshened water, probably because we failed to hit the right spots. We achieved this success rate using high-resolution bathymetric and sonar maps generated on the same cruises. The freshened waters show systematic variations in composition across the forearc. Near the trench, at 50-56 km distance, springs have high Ca (47-75 mmol/kg) and Sr (310-920 umol/kg) and low alkalinity (3 meq/kg). Farther from the trench, at 70-90 km, springs have high carbonate alkalinity (35-56 meq/kg) and near-zero Ca and Sr, apparently because carbonate dissolution has joined dehydration as a major process at the top of the subducting plate. Sulfate, Na/Cl, K, Rb, Cs, and B all increase regularly with distance from the trench, from values less than in seawater to greater, in response to increasing temperature at depth. All of the waters have high pH and are heavily depleted in Mg, Si, and F relative to seawater. Springs with high carbonate alkalinity also have high CH4, which feeds microbial communities in the shallow subsurface that reduce sulfate to bisulfide at pH 12.5. Chlorinity ranges from 235-538 mmol/kg but does not vary systematically with distance from the trench, because of either variable supply at the source or variable uptake of H2O by serpentinization along the flow path. Volatile elements and compounds including H2O and CO2 thus are progressively leached from the sediment and altered oceanic crust at the top of the subducting Pacific Plate, probably in response to increasing temperature over a range of 100-250oC. Based on leaching of K, the 150oC isotherm is crossed approximately beneath Big Blue Seamount at a depth of 22 km below the seafloor, 70 km behind the trench. The systematic and sharp chemical gradients across the forearc imply that the aqueous solutions carrying these volatiles rise vertically from their source region at the top of the subducting plate rather than traveling long distances along the decollement before ascending.

T32A-0910 1330h POSTER

Mapping the Mariana Seismogenic Zone Through the Measurement of Geochemical Tracers in Serpentinite Seamounts

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The Mariana forearc contains tens of seamounts up to 2 km high and 20-50 km in diameter. These seamounts were formed by serpentinite mud volcanism, sometimes in combination with uplift of serpentinized forearc mantle blocks, in which fluids driven off of the subducting slab infiltrated the overlying mantle and serpentinized the harzburgite and dunite rocks creating a density imbalance within the mantle. The resulting fluid-rock matrix flows along faults and exposes mantle-sourced serpentinite muds, blueschist facies metamorphosed mafic clasts, and slab-sourced fluids at the seafloor. The protrusion of these materials allows direct observation of active subduction zone components that are elsewhere buried beneath kilometers of rock and sediment. A multi-disciplinary survey of the Mariana Forearc was conducted in the spring of 2003 to study the biogeochemical properties of this mud volcanism. Seven different seamounts were sampled using shipboard and subsea coring techniques employing RV Thomas G. Thompson and ROV Jason II, respectively. Pore waters were extracted from these sediment cores and analyzed for several chemical constituents at sea. The measured values were consistent with preliminary work from 1997. Systematic trends in chemical composition of these high pH fluids (up to 12.3) are observed with distance from the trench (proxy for the depth to slab). These trends include low alkalinity and high Ca near the trench (e.g., Blue Moon Seamount; 0.26 mmol alkalinity/kg and 55 mmol Ca/kg), and high alkalinity and low Ca further from the trench (e.g., Big Blue Seamount; 69 mmol alkalinity/kg and 0.14 mmol Ca/kg) consistent with carbonate dissolution at the top of the plate between depths of 17 km and 22 km. Here we report results from trace element analyses that similarly show trends across the forearc region. For example, fluids upwelling at Baby Blue Seamount have; 58 μmol Sr/kg, 31 μmol Li/kg, 1.4 μmol Rb/kg, 10 nmol Cs/kg, 0.2 μmol Ba/kg, 0.1 μmol Mo/kg, 0.6 nmol U/kg, and 5 nmol Y/kg. In contrast, fluids from Big Blue Seamount, only 23 km away, have; 10 μmol Sr/kg, 0.7 μmol Li/kg, 6 μmol Rb/kg, 0.2 μmol Cs/kg, 60 nmol Ba/kg, 0.1 μmol Mo/kg, 0.2 μmol U/kg, and 0.1 nmol Y/kg.Trace element analyses for a host of chemical species and for each of the sampled seamounts offer insight into the conditions and interactions currently occurring within the Mariana seismogenic zone.

T32A-0911 1330h POSTER

Variability in Mineralogy of Mariana Serpentinite Mud Volcanoes: Source Compositions and Relationships to Fluid Release From the Subducted Slab

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Sediments from active serpentinite mud volcanoes on the Mariana forearc reveal considerable variability in mineralogy across and along strike, as well as with time. This suggests a complexity in source material and possibly in eruptive processes. As shown previously, several seamounts are bringing up high-pressure, low-temperature lithic clasts. Others lack these lithics, however, and even within individual seamounts some mud flows contain these mafic components while others lack them. This indicates variable sources for the muds even within a given seamount. The variability in mud composition contrasts with a more regular pattern of composition of slab-derived pore fluids at active seeps on the seamounts. It has been established that there are systematic changes in slab-derived fluid composition (Mottl et al., this volume) with distance from the trench and thus with depth to slab. Carbonate alkalinity is lower near the trench, but is higher farther away. Ca concentration is higher nearer the trench. As alkalinity increases Ca is removed via CaCO3 precipitation. Authigenic carbonate (e.g., aragonite, calcite, sjogrenite group minerals), formed by the interaction between seawater and upwelling slab-derived fluids, were collected by coring and ROV sampling in the shallow subsurface of several serpentinite mud volcanoes at various distances from the trench. Both spatial and temporal variability in the pore fluid composition may play a part in the isotopic concentrations of d13C

and d18O in these carbonates. The muds erupting from the seamounts probably derive from varying sources beneath the edifices through time; in contrast the compositional snapshot presented by the active seeps suggests that the extraction of fluids from the slab is depth controlled. The range of isotopic concentrations of the carbonates suggests that there may be factors controlling the release of fluids from the slab that vary with time. Recent sea-floor mapping with the DSL-120 high-resolution sidescan sonar system and detailed seafloor observations with the Jason 2 ROV indicate a far greater degree of complexity in the processes of formation of these seamounts than previously observed (see Fryer et al., this volume).

T32A-0912 1330h POSTER

Complexities of Eruptive Processes at Mariana Forearc Serpentinite Mud Volcanoes and Implications for Serpentinite Mélange Development

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Detailed DSL120 side-scan sonar surveys and Jason2/Medea ROV observations of the summit areas of several serpentinite mud volcanoes on the eastern half of the Mariana forearc reveal vent dimensions and information about the size and dynamics of mud protrusions emanating from the vents. Some vents appear to be small (a few km in diameter), which suggests narrow conduits beneath the mud volcanoes. Other sites of mud flow emanation appear to be along fissures a few tens to hundreds of m long. New high-resolution bathymetry of the seamounts shows details of the seamount flanks that confirm multiple lobes of mud protrusions and show evidence of catastrophic collapse events, possibly associated with pulses of larger-volume fluid egress. The collapse events scour channels in the sides of the edifices and in some instances distribute large volumes of material about the base of the seamounts. The debris shed from the edifices can extend for tens of kilometers outward from the flanks of the edifices. The seamounts are clearly subject to large-scale episodic disruption. Some bear fault traces throughout the edifices. Shallow earthquake activity in the Mariana forearc is largely confined to the outer 100-km zone of faulting and serpentinite seamount formation. Fault zones in the outer forearc control canyons that probably channel debris from the seamounts toward the trench axis. The wide-spread distribution and reworking of debris shed from the mud volcano edifices and from fault-exposed serpentinite provides a model for the formation of complex serpentinite mélange deposits in exotic terranes, such as the Franciscan of California.

T32A-0913 1330h POSTER

New Mapping of Mariana Submarine Volcanoes with Sidescan and Multibeam Sonars

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An expedition in February/March 2003 on the R/V Thomas G. Thompson mapped more than 18,000 km^2 with the towed MR1 sidescan sonar and almost 28,000 km^2 with an EM300 hull-mounted multibeam system along the Mariana volcanic arc. The expedition was funded by NOAA's Office of Ocean Exploration (more on the expedition can be found at: http://oceanexplorer.noaa.gov/explorations/03fire/welcome.html). The MR1 sidescan surveys began at the northern end of a 2001 R/V Melville MR1 survey at 16° N and extended to Nikko Volcano at 23°05'N. A portion of the southern back-arc spreading center and the arc volcanoes south of 16°N were mapped using the EM300 system. Of 43 submarine arc volcanoes surveyed that have basal diameters of 10 km or greater, 17 have summit calderas or craters. Of these, however, only 5 have diameters more than 2 km. In an accompanying survey of hydrothermal activity along the arc, CTD casts and/or tows were conducted over more than 50 individual volcanoes. The 11 volcanoes with active hydrothermal systems found in the course of these surveys appear to be about equally divided between those with and without summit calderas or craters (for additional information, see Baker et al., Resing et al., and Lupton et al., this session). The flanks of the submarine volcanoes and islands of the central and northern Mariana Arc consist largely of volcaniclastic flows. Most of the larger edifices have high-backscatter spoke-like patterns that probably represent coarser and/or younger flows from the summits. Higher relief high-backscatter areas, also commonly exhibiting a radial pattern, are found on many of the volcanoes' flanks. These are probably lava flows erupted along radial fissures. The Mariana Arc volcanoes are shedding large volumes of volcaniclastic material westward into the back-arc basin through a series of deep-sea channels oriented transverse to the arc that are in many places fed by flows from several volcanoes. On many of the volcaniclastic aprons of the islands and larger submarine volcanoes, sediment waves with wavelengths of up to 1.0 km and amplitudes up to 50 m commonly occur. Their crests are almost always oriented parallel to regional contours, indicating a formation mechanism related to down slope flow. In some places clear transitions occur between mass flows on the volcanoes' steeper flanks and the sediment waves on the gentler slopes of the apron. A preliminary interpretation is the sediment waves form during the transition from channelized to unconstrained flows. Sediment waves of similar scale are commonly observed on the levees of deep-sea channels and on deep-sea fans. The location and shape of the arc volcanoes are often controlled or influenced by tectonic control. Within the southern part of the Central Island Province, from about 15°50' N to 18°00' N, volcanoes often line up and/or are elongated in an E-W or an E-NE direction. There are several cross-chains of volcanoes in this region that penetrate 10's of kms into the back-arc basin. Along the northern part of the arc (the Northern Seamount Province), where the convergence direction is roughly parallel to the arc front, the structure is more complex. Several active volcanoes occur at the intersection of two or more structural lineaments northwest of Farallon de Pajaros Island. There are several volcanoes in the northern area that are narrow ridges striking in a S-SW trend 9 (arc-orthogonal).

T32A-0914 1330h POSTER

Discovery of Active Hydrothermal Sites Along the Mariana Volcanic Arc, Western Pacific Ocean

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Some 20,000 km of volcanic arcs, roughly one-third the total length of the global midocean ridge (MOR) system, rim the western Pacific Ocean. But compared to 25 years of hydrothermal investigations along MORs, exploration of similar activity on the estimated 600 submarine arc volcanoes is only beginning. In February 2003, as part of the Submarine Ring of Fire project funded by NOAA's Ocean Exploration Program, we made the first systematic survey of hydrothermal activity along the 1270-km-long Mariana intraoceanic volcanic arc, which lies almost entirely within the US EEZ. Prior fieldwork had documented active (but low-temperature) hydrothermal discharge on only three volcanoes: Kasuga 2, Kasuga 3, and Esmeralda Bank. During the cruise, we conducted 70 CTD operations over more than 50 individual volcanoes from 13°N to 23°N, plus a continuous CTD survey along 75 km of the back-arc spreading center (13°15'N to 13°41'N) adjacent to the southern end of the arc. We found evidence for active hydrothermal venting at 11 submarine volcanoes with summit (or caldera floor) depths ranging from 50 to 1550 m. Two additional sites were identified on the back-arc spreading center. Ongoing analyses of collected water samples could increase these totals. Our results confirmed continuing hydrothermal activity at Kasuga 2 (but not Kasuga 3) and Esmeralda Bank, in addition to newly discovered sites on nine other volcanoes. Many of these sites produce intense and widely dispersed plumes indicative of vigorous, high-temperature discharge. The volcanoes with active hydrothermal systems are about equally divided between those with and without summit calderas. The addition of the Marianas data greatly improves our view of hydrothermal sources along arcs. The 20,000 km of Pacific arcs can be divided between 6380 km of intraoceanic (i.e., mostly submarine) arcs and 13,880 km of island (i.e., mostly subaerial) arcs. At present, ∼15% of the total length of Pacific arcs has been surveyed thoroughly: 2550 km of intraoceanic arcs and 350 km of island arcs. Along the carefully studied intraoceanic arcs, 36 of 104 surveyed submarine volcanoes are hydrothermally active. Projecting these results along the unsurveyed intraoceanic arcs yields an expected total of an additional 54 active volcanoes. Island arcs will add additional sites, but are too poorly studied to admit a helpful estimate. For Pacific intraoceanic arcs, the predicted frequency of active volcanoes, about 1/66 km of arc length, is similar to the frequency of hydrothermal fields found along slow and ultra-slow MORs.

T32A-0915 1330h POSTER

Geochemical Characterization of Hydrothermal Plumes Above Hydrothermally Active Volcanos on the Mariana Arc

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During February-March, 2003, a comprehensive survey of hydrothermal plumes and their geochemistry was made along 1200 km of the Mariana Arc from 13.5°N to 22.5°N. Eight of the 50 submarine volcanoes surveyed had intense hydrothermal emissions indicated by extremely elevated levels of Fe, Mn, ΣCO_2, H_2S, particulate sulfur, particulate Fe, and/or particulate Al (PAl). The geochemical signature in the plumes above each of the eight volcanos was distinctly different, with elevated levels of Fe being the most common feature. Hydrothermal activity was found at another three volcanos but the chemical anomalies at these sites were much smaller. Of particular geochemical interest were elevated levels of PAl that were observed at three sites of intense activity with the NW Rota site having PAl > 1100nM. SEM-IXRF analysis of the particles found in the plumes revealed them to be Natroalunite, $(K,Na)Al_2(SO_4)_3OH_6$. Elevated Al levels have been observed only rarely in hydrothermal systems and their plumes (e.g., in the Manus Basin by Gamo et al., 1993) and have never been observed along the mid ocean ridges. The elevated Al must arise from SO_2- or sulfuric acid-rich hydrothermal fluids stripping Al from the host rocks resulting in the pervasive argillic alteration found in various arc and back arc settings. This interpretation is supported by elevated Fe:Mn ratios which are closer to those found in the host rocks than those found in MOR hydrothermal fluids. End member hydrothermal fluids that might support the Al levels found in the plumes have never been found, suggesting that the fluids producing this type of alteration are rare. The total Fe concentrations above the eight most active volcanos ranged from 90 to 2300 nM Fe, averaging > 700nM. Of these volcanos, two are within 200 m of the surface of the ocean while another four were within 450m, thereby making these volcanos potentially large sources of the trace nutrient Fe to the surface oceans. The elevated levels of Fe also have important implications for the geo-chemical cycle of other elements (e.g., P) that are scavenged from the oceans during Fe oxidation and particle formation. Scavenging may be the ultimate removal mechanism for these elements from the oceans, suggesting that arc hydrothermalism may provide an important sink for these elements in their oceanic geochemical cycles.

T32A-0916 1330h POSTER

Hydrothermal Helium Plumes over Submarine Volcanoes of the Marianas Arc

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During February-March, 2003, as part of the Submarine Ring of Fire project funded by NOAA's Ocean Exploration Program, the R/V T.G. Thompson conducted a comprehensive survey of hydrothermal activity along 1200 km of the Mariana Arc from 13.5°N to 22.5°N [see Embley et al., EOS Trans. AGU, 2003]. Plume surveys were conducted in the water-column above 50 submarine volcanoes using a CTD/rosette system. A total of 70 CTD casts were completed, and discrete water samples were collected for analysis of a variety of hydrothermal tracers, including ^{3}He, CH_4, CO_2, H_2S, Fe, Mn, pH, and suspended particles. Although shorebased analysis of the samples is still underway, preliminary results indicate that about 11 of the 50 submarine volcanoes surveyed are hydrothermally active. Because many of the Marianas Arc volcanoes rise to within 500 m of the sea surface, hydrothermal plume signals such as light attenuation (suspended particles) and temperature anomaly have limited utility due to masking by near surface effects. For this reason ^{3}He, an unambiguous hydrothermal tracer, has been particularly useful for identifying which of the shallow arc volcanoes are hydrothermally active. Our expectation was that the water-column helium signal might be reduced at shallow depths due to ventilation into the atmosphere. However, we observed very high ^{3}He enrichments at shallow depths both at Maug Islands and at NW Rota #1 (14°36'N; 144°46.5'E). The ^{3}He enrichments were strongly correlated with changes in pH, Mn, and other hydrothermal tracers. The three Maug Islands mark the perimeter of a caldera formed by an explosive eruption, and a single hydrocast in the center of the caldera detected a robust helium plume at 120-200 m depth with δ^3He reaching a maximum of 250% at 150m depth. Analysis of the co-variation of [^{3}He] vs. [^{4}He] at Maug gave R/R_a = 6.6 for an estimate of the end-member helium isotope ratio ($R = {}^3He/{}^4He$ and $R_a = R_{air}$). This value falls well within the range of R/R_a = 5-7 generally observed for helium at subduction zone volcanic systems. At NW Rota #1, we found a strong helium plume reaching a maximum δ^3He = 320% at 460 m depth. Surprisingly, the estimate for the end-member ^{3}He /^{4}He at NW Rota gave R/R_a = 8.4, outside the range normally found at subduction zones and similar to that observed along MOR spreading centers. NW Rota #1 is located about 15 km west of the main arc and is part of a cross-arc volcanic chain. Craig et al. [EOS 68, No. 44, p.1531, 1987] found a similar value of R/R_a = 8.6 in vent fluids in the Mariana Trough back-arc system at 18°13'N. Thus the higher ^{3}He/^{4}He ratio at NW Rota may reflect an affinity to the back-arc spreading center as opposed to a pure arc component.

T32A-0917 1330h POSTER

Across-Arc Variability of Outputs From the Mariana Subduction Factory: Melt Inclusions From the 14°35'N Cross-Chain

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Olivine- and feldspar- hosted melt inclusions (MI) in lavas dredged from the cross-chain along 14° 35' N in the southern Mariana arc provide a unique means of examining the cross-arc variability of outputs from the Subduction Factory. Unlike in the shorter Guguan cross-chain near 17°20'N (Stern *et al.* this session), in the 14°35'N cross-chain lavas with phenocrysts that host primitive MI (Mg#s up to 78) have erupted both midway between the arc and back-arc and at the magmatic front. These lavas and MI presumably derived by melting of the mantle wedge and thus sample asthenosphere as it is modified during movement towards the magmatic front and at the front itself. In addition, lavas similar to back-arc basin basalts (BABB), presumably derived from shallow mantle melting, have erupted between the midpoint seamount and the arc. Melt inclusions from these BABB-like lavas then provide an opportunity to sample the cross-arc variability of the upper mantle as well. All melt inclusion compositions from the cross-chain and arc front display trace element signatures in spider diagrams characteristic of arcs and evidence of a subduction component. The latter is shown in part as an increase of Th/Yb relative to MORB and OIB at a Nb/Yb ratio of ~1. The subduction signature is less pronounced in BABB-like melts, which suggests mixing between arc-like magmas produced largely by flux melting and those derived from pressure-release melting due to upwelling. Primitive MI from the lavas at both the midpoint and arc show evidence for components derived from the mantle wedge and sediments, as well as a LILE-enriched component. The sediment component dominates in some MI from the arc front, with Pb/Ce up to 0.44 at ~5.7 ppm Pb, while the LILE enriched component is more prominent in some MI from the midpoint seamount. The most LILE enriched MI from the midpoint seamount contain ~0.7-1.5 wt% K_2O, ~28 ppm Rb, and ~153-163 ppm Ba at Mg#s of 64-66, and ~1000 ppm Cl. The highest degrees of melting, based on trace-element systematics (e.g. Zr/Y vs. Y; Nb vs. Yb), are recorded in MI from the primitive arc front lavas. HFSE are more depleted in the primitive arc MI relative to the primitive midpoint MI. The BABB-like MI are less depleted in HFSE than the primitive midpoint and arc MI, however these are still depleted relative to MI from the Marianas Trough back-arc spreading axis. These data show that arc melts are composed of mantle wedge components mixed with a sediment-derived component (either sediment melt or sediment-derived fluid) and a LILE enriched component. These magmas may also mix with melts derived from shallow pressure release melting due to upwelling. We also suggest that some of the HFSE depletion observed in arc lavas can be attributed to prior melting in the back-arc and along a cross-arc chain. This HFSE depletion is present in the upper mantle as well as deeper in the mantle wedge. We are currently gathering volatile data via FTIR with which we will be better able to assess to role of fluxing in producing the various components and the origins of fluids themselves.

T32A-0918 1330h POSTER

Pickling Peridotites in the IBM Mantle Wedge: Inferences from the Guguan Cross-Chain, Mariana Arc

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Variations in lava compositions observed in arc cross-chains' reveal chemical and isotopic gradients resulting from 'pickling' of convecting asthenosphere by fluids and melts from the descending slab. This can be studied using lavas from arc cross-chains. We report geochemical and isotopic data for basalts and basaltic andesites from the Guguan cross-chain at 17°15'N in the Mariana Arc, comprising the active volcanic island Guguan (and submarine cone N. Guguan) along the magmatic front (125 km above the subducted slab) and two seamounts to the west, W. Guguan (150km) and Guguan II (230 km). Guguan lavas represent the fluid-dominated' endmember of Mariana arc lavas, and comprise fractionated basalts, basaltic andesites, and subordinate andesites (Mg# = 35-51, Ni<30ppm). Lavas from N. Guguan seamount consists of less fractionated basalts (Mg# = 52, 50ppm Ni). Basalts from W. Guguan (Mg# = 61, 60-80 ppm Ni) and Guguan II (Mg#= 63-75, 100-400 ppm Ni) are much less fractionated. Guguan, N. Guguan, and W. Guguan lavas straddle the Low- to Medium-K boundary on a K2O-SiO2 plot, whereas Guguan II lavas are slightly more enriched and plot in the Medium-K field. Strong enrichments in K and other LIL elements observed for the Kasuga cross-chain farther north in the Mariana arc are absent. Olivine Fo decreases and plagioclase An increases towards the magmatic front. These relations suggest that water contents increase towards the magmatic front in the Guguan cross-chain. Spider diagrams for Guguan cross-chain lavas show the characteristic elemental enrichments of arc lavas, most notably LIL elements (Rb, Ba, Th, U, K, Pb, and Sr); similar but muted enrichments are found in basalts formed by seafloor spreading in the Mariana Trough (MTSB). Trace element variations observed across the Guguan cross-chain indicate that the fluid-dominated Subduction Component' diminishes away from the magmatic front and is replaced by a component that manifests either sediment melt or the MTSB mantle source. Ba/La vs. La/Yb systematics show that magmatic front lavas plot near the fluid-dominated endmember whereas Guguan II plots along the trends inferred for sediment melts. Similarly, Th/U doubles across the cross-chain, from 1.5-2.0 along the magmatic front (consistent with U-rich fluids from altered oceanic crust, AOC) to 2.5-3.0, similar to that of MTSB and approaching values for sediment melts. On a plot of Zr/Nb vs. Th/Nb, lavas from along the magmatic front (esp. Guguan) show the high Zr/Nb expected for depleted mantle that is fluxed by hydrous fluids. W. Guguan and Guguan II show lower Zr/Nb and Th/Nb that trend towards sediment and MTSB. Surprisingly, there is little systematic variation in Sr/Nd and Pb/Ce across the chain. There is no systematic variation in Pb isotopic compositions across the arc. There is a marked gradient in 87Sr/86Sr, decreasing from 0.7035 along the magmatic front to 0.7032 for W. Guguan and 0.70317 for Guguan II. These values approach the mean of 0.70291±0.00015 found for MTSB. 143Nd/144Nd also decreases slightly, but 176Hf/177Hf decreases slightly from the magmatic front to the rear. Coupled isotopic and trace element variations are difficult to reconcile with suggestions that cross-arc variations result from increasing participation of sediment melt with distance from the magmatic front.

T32A-0919 1330h POSTER

Mineral Chemical Records of Subduction Factory Metamorphism and Devolatilization in UHP Eclogites From the Italian Alps

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Across-arc geochemical studies indicate progressive changes in the magnitude and character of slab-derived fluids with depth. However, the precise nature of fluid chemistry as a function of metamorphic reaction history in subducting slabs is poorly constrained. Blueschists, eclogites, and other metamorphic products exhumed from ancient subduction zones have been the subject of mostly whole-rock geochemical studies to evaluate the results of fluid processing during subduction, but such studies suffer from an inability to provide the continuous geochemical records necessary to evaluate progressive changes in the metamorphic fluid flux to the mantle wedge. Furthermore, many of these records are partly (to completely) obscured by overprinting during exhumation or are limited to samples that reflect forearc depths (<50 km) in subduction zones and do not appear to record fluid histories occurring beneath the sub-arc mantle. To partly address the shortcomings of the present SubFac metamorphic record, we have applied *in-situ* high spatial resolution electron- and ion-microprobe methods to HP eclogites from Monviso and coesite-bearing UHP eclogites from Lago di Cignana, both located in the western Italian Alps and together record peak *P-T* conditions of up to 630°C and 2.9GPa (Reinecke, 1998). Garnets from Cignana are generally >3mm and record initial growth in the blueschist facies from inclusion mineral assemblages of Na-amphibole, paragonite and clinozoisite in garnet cores. Cignana garnets preserve prograde growth zoning for major elements, HREEs, and Li and are highly LREE-depleted (Chondrite-normalized, $La_N/Yb_N < 10^{-3}$) and, in some metamafic eclogites, coesite occurs as inclusions near garnet rims. Reactions liberating REEs within the eclogite facies appear to be recorded in garnet as abrupt positive deviations from growth zoning profiles for Gd to Lu; the relative magnitude of enrichment is stronger for the MREEs than for the HREEs. This suggests decomposition of a L- and

MREE-enriched phase such as clinozoisite, but incompatibility of the LREEs in garnet precludes a record of changes in LREEs directly from garnet. Depletions in the LREE and HREE about MREE such as Gd in matrix CPX reflect the influence of growth coeval with garnet and the general compatibility of REEs in the CPX structure. Corroborating such inferences, CPX inclusions in garnet generally display higher HREE contents than matrix CPX. Fluid-mobile elements such as the LILEs and B are generally hosted by white micas in these eclogites. Both phengite and paragonite are present in the eclogites and record distinct TE partitioning. Phengite is the primary host for Cs and Ba, with Ba/Sr ratios >20, while Sr is more strongly partitioned into paragonite, with Ba/Sr ratios <0.1. While Li contents for paragonite and phengite are indistinguishable, B preferentially resides in paragonite, creating B/Li ratios of ∼10 in paragonite versus ∼1 in phengite. These data indicate that mobility of individual LILEs during devolatilization in the eclogite facies will be strongly controlled by the stability of distinct phases. Our results indicate eclogite-facies minerals can provide detailed geochemical information regarding trace element behavior during metamorphism and, when combined with traditional thermobarometric data, will provide a powerful record of devolatilization in subduction zones. Our approach also allows characterization of overprinting mineral parageneses and trace element redistribution related to the complex exhumation histories of these rocks.

T32A-0920 1330h POSTER

Hydrothermal Venting in the Southern Most Portion of the Mariana Backarc Spreading Center at 12.57 Degrees N

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The southernmost portion of the Mariana Trough is a complex zone of deformation and magmatism. The centerpiece of the trough is the Malaguana-Gadao Spreading Center Ridge, which has a morphology that is inflated relative to all of the other spreading segments in the Mariana Backarc Basin. This inflated morphology is similar to that of the EPR and is consistent with a high rate of eruption. Samples of lavas from the spreading center are island arc tholeiites, which typically contain higher concentrations of CO2 relative to MORBs. In February 2003 the NOAA VENTS program conducted two CTD tow-yos in this area, revealing a hydrothermal plume consistent with the presence of a high temperature hydrothermal site. In May 2003 we used the ROV Jason II to survey a hydrothermal site at 12 degrees 57.214'N, 143 degrees 37.147'E in a water depth of 2860 m. Here we collected vent fluids, sulfides, basalt, microbial mats, and macrofauna. Two styles of venting were identified within an 80 m by 70 m area. Higher temperature venting was located in cracks among extinct mounds that were 2-5 m high and wide and are nearly monomineralic (sphalerite) in composition. The exterior is soft and vuggy in contrast to the interior that has crystalline layers with bladed habit lining the orifices. Maximum temperatures of 248 degrees C were recorded 30 cm into these cracks, which were covered with abundant large provannid snails, Alvinoconcha Hessleri, and crabs. In contrast, lower temperature diffuse venting (77 degrees C) emanated from mounds that have a porous structure that is composed of amorphous iron oxide and opal. These mounds are covered with microbial mats, which exhibit a high degree of biomass as detected by Cyto-13 nucleic acid epifluorescent staining. Filament and amorphous particulate morphotypes are observed in association with microbial cells, but sheaths have not been detected. These mats have a morphology that is similar to that of neutrophilic Fe-oxidizing bacteria. Fluid chemistry is consistent with a single source and with other back-arc derived hydrothermal fluids that are enriched in alkalinity relative to bottom seawater. Extrapolated concentrations per kg of seawater are 0 mmol Mg, 36.2 mmol Ca, 7.3 mmol alkalinity, 544 chlorinity, 414 mmol Na, 32.2 mmol K, 0 mmol sulfate, 165 umol Sr, and 575 umol Li. Additional analyses are ongoing.

T32B MCC: Level 2 Wednesday 1330h

Causes and Consequences of Lateral Heterogeneity in the Earth's Mantle II Posters *(joint with S, V, MR, DI)*

Presiding: **C Lithgow-Bertelloni,** University of Michigan**; L Stixrude,** University of Michigan

T32B-0921 1330h POSTER

Geophysical Signatures of Chemical Depletion in Slave Cratonic Peridotite.

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Variously depleted peridotites of the Slave craton (Northwest Canada) provide an excellent natural laboratory that allows us to investigate effects of depletion on the chemical and physical characteristics of rocks. We computed seismic velocities for the variously depleted peridotites of the N and SE Slave based on single-crystal elastic moduli and volume fractions of constituent minerals. The depleted peridotites enriched in MgO have lower Vp and higher Vs, where lower Poisson's ratios are due to orthopyroxene enrichment. The predicted effect on seismic wave speeds would be up to 0.05 km/s, or 0.6 rel.% of Vp. The correlation observed on the Slave craton contradicts the established view that peridotite depleted in basaltic magmaphile elements has higher seismic wave velocities. However, evidence amassed in the past 15 years suggests that cratonic mantle peridotite is chemically distinct from off-cratonic peridotite. In cratonic peridotite, the Mg-number of olivine is negatively correlated with its mode, and Ni in olivine is positively correlated with orthopyroxene mode and olivine Mg-number. These patterns hint that depletion in the cratonic mantle may have a distinct seismic signature compared to the off-cratonic mantle. Our data suggest that chemical depletion of peridotites should also affect their redox state. The shallow, more depleted spinel peridotite of the N Slave shows a distinctly lower bulk Fe2O3 abundance and lower Fe3+ concentration in spinel, consistent with a lower oxygen fugacity. Moreover, different types of peridotite that coexist at a given depth have different redox states, and the redox state of peridotitic mantle changes sharply between the layers with different bulk compositions and oxide mineralogies. Such a pattern of oxygen fugacity is expected if oxygen is controlled intrinsically by Fe equilibria. In an Fe-buffered peridotitic mantle, domains depleted in Fe3+ following partial melting should be more reduced and therefore should contain more elemental carbon. A larger abundance of graphite may explain the higher EM conductivity of the ultra-depleted layer mapped in the Central Slave mantle.

T32B-0922 1330h POSTER

Invisible Slabs: The Influence of Phase Boundary Deflection on Velocity Anomalies of Stagnant Slabs in the Transition Zone

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A primary constraint on the dynamics of subducting slabs comes from images produced by seismic tomography. The interpretation of the seismically fast anomalies in tomographic models as being cold bodies allows a comparison of behaviours in geodynamic models and the Earth's mantle. However, the inference of seismic anomalies as purely thermal in origin neglects the contribution of olivine phase changes in the transition zone to the seismic manifestation of subducted slabs. To demonstrate the potential importance of phase change effects, we use a numerical routine to simulate the sinking of subducted lithosphere in a convecting mantle. We pay particular attention to the behaviour of the slab around the endothermic phase change associated with the 660-km seismic discontinuity. The time-dependent temperature fields from the flow simulation are used to derive perturbations from a radially stratified seismic velocity model. We show that the positive velocity anomalies of the cold descending slabs may be significantly decreased at the phase change owing to the slab-induced downward phase boundary deflection and associated velocity discontinuity across the boundary. The slab may be completely or partially rendered seismically undetectable, depending on the amount of phase boundary deflection. Gaps in the seismic images of subducting slabs (van der Hilst [1995]) may reflect this effect. These results have implications for the observation and interpretation of the dynamics of subducted slabs in the transition zone.

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Receiver Function Imaging of the upper mantle seismic discontinuities beneath the Japan Islands and the Korean Peninsula -Lateral variation in the depths and the Ps amplitudes-

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In the Japan Islands, high density short-period and broadband seismic networks have recently been installed. In this study, we apply Receiver Function (RF) analyses to teleseismic P-wave coda portions observed at 63 J-array, 64 F-net, 4 IRIS and 7 KIGAM (Korea) broadband stations and investigate the detailed structure of the upper mantle velocity discontinuities beneath the Japan Islands and the Korean Peninsula. The results indicate that there are large lateral variations in visibility of the 410 km discontinuities, and the 410, 660 km discontinuities are affected by the subducting Pacific (PAC) slab.

We examine the observed waveforms from the teleseismic events with the magnitudes greater than 5.5, which occurred during a period from 1998 to 2003. We discard almost 35,000 RFs with low signal-to-noise ratios, and finally keep a total of 8,825 RFs from 389 events.

RFs are constructed through frequency domain division of radial components by vertical ones with a water level of 0.01. The low-pass Gaussian filters of 0.1, 0.3, 1.0 Hz are also applied to examine the frequency dependence of the visibility of the discontinuities. Assuming the phases in RFs are produced by Ps converted ones at depths, we transform the time domain RFs to the depth domain ones using recent P- and S-wave tomographic velocity models. Then, SVD filtering is applied to the depth domain RFs. We keep largest 6 eigenimages to construct SVD-filtered RFs. Finally, we construct 2-D stacked RF images projected on cross-sections along several profiles to see the detailed velocity discontinuity structure.

Beneath the Japan Islands, the dipping positive RF amplitude traces can be recognized to a depth of 200 km or more, which coincides with the distribution of deep earthquakes occurring within PAC. In contrast, the Philippine Sea slab has not been confirmed clearly. 660 km discontinuity is confirmed clearly and uniformly beneath the whole Japan Islands. Similarly, 410 km discontinuity is detected clearly in Kanto area (central Japan). However, in Tohoku (northern Japan) and southwest Japan area, 410 km one is not detected clearly. We consider that the reasons are both the density differences of the stations and the regional differences of the thickness of the 410 km discontinuity. Also, the 410 and 660 km discontinuities are undulated due to the subducting cold PAC slab. That is, in our results, the 410 km discontinuity seems to be locally affected where the PAC penetrates, and the 660 km discontinuity is broadly and gradually downwarped westwards by 50 km, which is consistent with the stagnated PAC on the 660 km discontinuity.

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