

We discuss the processes taking place in the experiments and the effect that conduit inclination could have on eruptive style for volcanoes with similar degassing rates.

V11A-11 1120h

### Gas-Driven Eruptions, and Speculation for Methane-Driven Ocean Eruptions

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Brad Sturtevant was a central player in experimental simulations of various types of eruptions, including those driven by the exsolution of gas initially dissolved in a liquid (referred to as gas-driven eruptions, including explosive volcanic eruptions, lake eruptions and eruption of Champagne), and those driven by the evaporation of a liquid (such as geyser eruption, or evaporation waves). The experimental simulations helped to bring together the general understanding of different eruptions. Among gas-driven eruptions, explosive volcanic eruptions are the most familiar and spectacular type. Lake eruptions were recognized only in the 1980s. The underlying principles of the two types of eruptions are similar although there are some difference in the role of the conduit and buoyancy.

The main purpose of this report is to speculate on a possible but yet unrecognized type of gas-driven eruptions, methane-driven water eruptions in oceans. In marine sediment, huge amount of CH<sub>4</sub> is stored either as gas or as methane hydrate. (The gas pockets might burst, resulting in mud volcanos.) Under some unusual circumstances such as marine landslides or earthquakes, a large amount of CH<sub>4</sub> may be released from sediment to seawater. Depending on the local pressure-temperature conditions, and depending on the kinetics of the various chemical reactions, the released methane gas might lead to gas-driven explosive eruptions. This type of eruptions would be similar to CO<sub>2</sub>-driven lake eruptions, except that the gas is CH<sub>4</sub> instead of CO<sub>2</sub>. Although no such eruptions have been reported and they are expected to be rare, theoretically they are possible. Because CH<sub>4</sub> gas is less dense than air, erupted CH<sub>4</sub> gas cloud is expected to rise high into the atmosphere instead of forming ground-hugging flows for CO<sub>2</sub> gas flows. Hence, the danger to life on the ground is smaller. Satellite imaging might be able to detect such eruptions.

V11A-12 1135h

### Dry Particle Aggregation in Volcanic Plumes

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Understanding the deposition of fine grained silicate particles from volcanic plumes is key to interpreting ash fall deposits and predicting hazards for future eruptions. The importance of particle aggregation for the 'premature' deposition of ash grade tephra was demonstrated in the 1980 eruption of Mount St. Helens during which delicate, dry aggregates were collected 390 km from the volcano. This type of aggregate is thought to be bound mainly by electrostatic forces and consequently has little or no preservation potential in a deposit. The generation and physical characteristics of dry aggregates have not been previously investigated. We have carried out laboratory experiments with small, dry silicate particles produced by repeatedly colliding two samples of Mount St. Helens pumice. Extensive aggregation was observed in the column of falling particles below the samples and, in the absence of any liquid phases, this process was driven solely by fall velocity differences and the electrostatic charges generated on particles during fragmentation. For particles falling distances of ~1 m, images of in-flight aggregates show that they commonly have irregular shapes and are up to ~800 μm in size. Fall velocity measurements suggest that most aggregates have densities of ~100 to 200 kg m<sup>-3</sup>. During experiments in which falling particles and aggregates were horizontally dispersed within a gentle airflow, bimodal particle size distributions were produced, similar to those observed in the May 18, 1980 Mount St. Helens deposits. These particle size distributions suggest that aggregates were comprised mainly of particles <70 μm in diameter. The dispersal experiments confirmed the earlier aggregate density measurements and suggest that the plan view of landed aggregates represents a reasonable aerodynamic area from which the fall velocity of equivalent spheres can be estimated. Our experimental data are in agreement with aggregate size and density estimates previously used within several theoretical plume sedimentation models in order to explain some features of natural ash deposits. The results have consequences for

remotely sensed data, numerical models of plumes and for the interpretation of ash fall deposits.

V11B MC: 304 Monday 0830h

### Trench to Subarc: Diagenetic and Metamorphic Mass Flux in Subduction Zones

(GERM/MARGINS Subduction Factory Session) I (joint with OS, T, MR)

**Presiding:** G E Bebout, Lehigh University; H Becker, University of Maryland

V11B-01 0835h

### Mass Flux of Continental Material at Cenozoic Subduction Zones—New Global and Trench-sector Calculations Using New Geological and Geophysical Observations

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**INTRODUCTION:** A decade ago, then available geophysical and geological data implied that more than 65 percent of ocean floor sediment entering most subduction zones (SZ) accompanied the oceanic crust to the mantle (= sediment subduction or SS). The underthrusting slab also eroded the margin's crustal framework and conveyed this material to the mantle (= subduction erosion or SE). Globally, the mass of continental material recycled to the mantle was estimated at 1.3-1.8 km<sup>3</sup> / yr (SS = 0.7 km<sup>3</sup> + SE = 0.6-1.1 km<sup>3</sup>). **SEDIMENT SUBDUCTION:** New and enhanced seismic reflection data, new drilling observations, and reevaluation of older information stress that the efficacy of SS is higher than earlier assessed. In detail, it appears that 100 percent SS occurs at non-accreting margins (19,000 km), at least 80 percent at accreting margins (16,000 km) where small to moderate size accretionary prisms (width=5-40 km) are forming, and 40-45 percent where larger prisms are accumulating (8,000 km). At Cenozoic SZs (43,000 km), it is now estimated that the long-term (i.e., >10 Myr) rate of SS is at least 1.0 km<sup>3</sup> / yr (solid volume).

**SUBDUCTION EROSION:** New and reassessed seismic, drilling, subsurface, coastal mapping and arc-retreat observations suggest a higher long-term rate of SE than formerly estimated at 30 km<sup>3</sup> / Myr / km of trench. We now estimate that, except perhaps where large accretionary bodies are forming, the long-term rate of forearc erosion averages at least 40 km<sup>3</sup> / Myr (range = 28-62), which corresponds to a global recycling rate of 1.4 km<sup>3</sup> / yr. The matching average rate of landward truncation of the submerged forearc is 2.5 km<sup>3</sup> / Myr (range = 1.8-4.2).

**SUMMARY:** The late Cenozoic rate at which continental crust is recycled at SZs is currently estimated at 2.4 km<sup>3</sup> / yr (ss=1+ se=1.4) +/- 25 percent, which is basically that now approximated for arc magmatic additions. It can thus be inferred that at Cenozoic SZs rates of crustal addition and recycling have been in general balance. This quasi-stasis may be applicable to the Phanerozoic.

V11B-02 0850h INVITED

### Production and Fluid Flow at Shallow to Intermediate Forearc Depths: An Overview

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A variety of physical and chemical processes lead to the production and eventual expulsion of fluids from subduction forearc regions at shallow to intermediate depths. Many processes, such as compaction and some of the stress (in the case of smectite) and thermally induced dehydration reactions, are relatively well understood, at least at a general level. However, much remains uncertain about the depth and temperatures

at which water comes to be released, expulsion mechanisms, and pathways to the surface. For example, because most/all systems have a highly heterogeneous permeability distribution it is not known what proportion of the input fluids come to be expelled laterally either along the subduction thrust or through the oceanic basement, or by more vertical pathways through the forearc itself (via faults, diapirs, and diffuse flow). Indeed, a recent benthic flux meter study of the Costa Rican forearc suggests that diffuse flow may account for a significant proportion of the expulsion flux, with the potential that there is only limited lateral focused expulsion along the decollement.

Predicting the depth at which fluids originate is also difficult because even though the consolidation behavior of sediments can be determined experimentally, the development of overpressures in low permeability systems can result in a considerable extension of the depth range over which consolidation proceeds. Another factor that has to be considered in predictions of fluid origination and expulsion patterns is that even where mechanical compaction proceeds to near completion, a significant residual fluid volume (5-20 %) can remain trapped within sediment pores and in the fractured but still relatively ridged upper oceanic basement. Ultimately, however, studies of exhumed materials do suggest, that the bulk of the remaining pore fluids in sediments do come to be expelled (at least into local fracture systems) during the onset of late stage diagenesis and as pressure solution reactions pick up at seismogenic depths. The fate of pore fluids trapped within basement is less clear, however, and this region may not be a significant net source of fluids at shallow to intermediate depths. Indeed, there is the potential that much fluid remains trapped in the basement until temperatures have risen sufficiently for it lead to the additional development of hydrous minerals such as chlorite. Thus, while fluid production/expulsion within the sediments is probably intimately associated with aseismic/seismogenic processes it seems reasonable to assume that it is the basement that forms the principal source of H<sub>2</sub>O involved in magma generation.

V11B-03 0910h

### Pore pressure development and progressive sediment compaction at the toe of the Costa Rican margin wedge: Mechanical and hydrologic implications

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At subduction zones, the fate of pore fluids within underthrust sediments has important effects on the evolution of mechanical strength and structural development. Results from Ocean Drilling Program (ODP) Leg 170, offshore Costa Rica, documented the complete underthrusting of a regionally uniform sediment section, with the important implication that observed changes in sediment thickness and void ratio directly reflect the evolution of effective stress. Combining logging-while-drilling (LWD) data, down-hole physical properties data, and laboratory consolidation tests, we track the development of effective stress and pore pressure within underthrust sediments with progressive loading beneath the margin wedge. High-quality drilling data, combined with numerous laboratory consolidation tests, allows a spatially detailed investigation of down-section pore pressure evolution with progressive loading. Effective stresses inferred from laboratory experiments and those projected from observed reductions in void ratio are in excellent agreement. In both cases, the results indicate essentially undrained conditions at site 1043 (located ~0.5 km landward of the trench). At site 1040 (located ~1.6 km from the trench), our results suggest that the lower, pelagic underthrust sediments remain nearly undrained, whereas the upper, hemipelagic sediments are partially drained. An inferred minimum in effective stress developed near the base of the hemipelagic section between sites 1043 and 1040 is consistent with observed down-stepping of the decollement at ~2-3 km from the trench, and illustrates the important effects of pore pressure distribution on structural development. In comparison, pore pressures within underthrust sediments at the Nankai and Barbados subduction zones inferred from porosity data indicate that dewatering at these locations occurs more slowly than at Costa Rica. These differences can be attributed to the higher permeability and larger compressibility of near-surface sediments underthrust at Costa Rica.

V11B-04 0925h

### Boron and B Isotopes in Mud Volcanoes and Their Significance for Mobilization Depth and Global B Cycling

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Mud volcanism is a global phenomenon in mostly convergent margin settings, whose nature has long been subject to scientific investigation. However, only recently its significance has been unraveled by quantitative studies in well-investigated submarine environments, like large accretionary complexes. The fluid flux through active mud volcanoes has been estimated to exceed that of the frontal accretionary prism (Kopf et al. 2001, EPSL 189, p295-313), and may have done so in earlier Earth's history. Pore fluids as well as muds and clasts of onshore and offshore mud volcanoes all over the world have undergone a systematic geochemical study using contents and stable isotopes of the mobile element boron. When tied into results from hydrothermal geochemical experiments in the laboratory (You et al. 1996, EPSL 140, p41-52), the B geochemistry proves to be a powerful tracer to estimate the depth of fluid and mud mobilization below ground. Boron adsorbed to clay minerals is preferably donated to the fluid when either tectonic stress (vertical and/or lateral compaction) or temperature increase. Here, we report variations in B content and B isotope ratios in mud volcano deposits as a result of different history of the material prior to extrusion. Results reflect the regional geology of the study areas, ranging from dewatering of undercompacted marine sediment in accretionary prisms (Barbados, Makran, Mediterranean Sea) to diagenetic reactions in mud volcanoes of orogenic belts (Malaysia, Pakistan, Georgia, Taman Peninsula, Western Alps). Boron shows maximum enrichment in the fluid phase (owing to desorption in the mud) when faulting roots deepest and deformation is strongest. Mud domes juxtaposing out-of-sequence faults in the Caucasus orogenic wedge show mud B contents 8x marine sediment, and fluid B contents up to 25x seawater. Deep-seated, B-rich fluids liquefy clay-bearing strata to facilitate mud extrusion, allowing the clay to re-adsorb B in the process. B isotopic composition of the mud decreases with incipient stress and mobilization depth. Given the abundance and high discharge rates of mud volcanoes along subduction zones, this process generally affects chemical and fluid budgets in the subduction factory. Also, it clearly has to be considered a major backflux mechanism in global B cycling from the lithosphere to the hydrosphere.

V11B-05 0940h

### Deep Fluids from the Subducting Pacific Plate and Associated Microbial Activity on a Mariana Forearc Serpentine Seamount, ODP Leg 195

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As the Pacific plate subducts beneath the non-accretionary Mariana forearc its crust emits water and other volatiles that hydrate the mantle of the overriding plate. The resulting serpentinized rises through faults to the seafloor, along with partially altered harzburgite and the excess volatiles, to form a belt of serpentine mud volcanoes in the outer half of the forearc that have cold springs at their summits. This mass flux through the forearc represents one of the earliest returns of subducted material to the oceans. To assess this flux, Ocean Drilling Program Site 1200 was drilled on the summit of one of these mud volcanoes. South Chamorro seamount lies near 14 deg.N, 85 km landward of the Mariana trench and 27 km above the top of the subducting plate. Cold springs at its summit, discovered on Dive 351 of the Shinkai-6500 in 1996, are populated by mussels, small tubeworms, whelks, and galatheid crabs. We recovered pore waters from three holes drilled on a transect <10, 20, and 80 m from one of these springs. Composition-depth profiles for these pore waters, to a maximum depth of 71 mbsf, verify that water is upwelling through serpentinized to feed the springs. Like the upwelling water sampled on

another serpentine mud volcano, Conical seamount, at ODP Site 780 (Leg 125) near 20 deg.N, the ascending water at Site 1200 has a clear chemical signature of a deep-slab origin. It is highly enriched in a suite of elements that are virtually absent in the partially serpentinized, depleted harzburgite matrix, including (mainly carbonate) alkalinity (60; all units in mmol/kg), Na (610), Na/Cl (1.2), K (19), B (3.2), ammonia (0.22), methane (2), and C2 through C6 hydrocarbons. The fluids have a pH of 12.5, similar to the 12.6 at Conical Seamount. They are highly depleted in Mg, Ca, Sr, and Li, and have low concentrations of Si, Mn, Fe, Ba, and phosphate. They are slightly depleted in chloride (510 vs. 545 in seawater) and enriched in sulfate (by 7% relative to chloride). This chloride depletion is much smaller than that in the deep fluid from Conical Seamount, suggesting that the conduit at Conical is more heavily serpentinized and less reactive, allowing more of the H2O from the deep source to arrive at the seafloor without being lost to serpentinization along the way.

Pore water composition-depth profiles reveal that these deep fluids feed an active microbial community within the upper 20 mbsf that is oxidizing light hydrocarbons from the fluid while reducing sulfate. At pH 12.5, this is a true extremophile community. Sulfate reduction is most active at two levels. Microbes within the upper level at 3 mbsf reduce seawater sulfate that diffuses downward against the ascending flow. Those within the lower level at 13 mbsf reduce sulfate that is supplied from the subducting slab by the upwelling fluid. As organic carbon is virtually absent within the depleted harzburgite, the microbes rely on methane and the C2 through C6 thermogenic hydrocarbons for their source of organic carbon, and ammonia for their source of nitrogen. Both are supplied by the upwelling fluid. The microbial community intercepts these nutrients and traps them within the ecosystem, where they can be recycled and continually enriched. This process may explain the enrichment in organic carbon in the uppermost sediment. Iron sulfides, and CaCO3 in the form of aragonite needles and chimneys, are also enriched there, by reaction between the ascending fluid, the microbial community, and the overlying seawater.

V11B-06 0955h INVITED

### Chemical Fluxes in Subduction Zones: Implications for Forearc and Ocean Chemistry

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Subduction zone pore fluid chemical and isotopic profiles and recent modeling of the fluid flow regimes and solute fluxes indicate rapid and intense alteration of the accreted and subducted sediments and mostly episodic expulsion of considerably altered seawater (pore water) into the ocean. Fluid flow is along higher permeability conduits. The extent of alteration and the fluid fluxes involved vary, they depend on the type of sediments involved, the ratio of accreted to subducted sediments, the subduction rate, the thermal regime, and the geophysical properties of the subduction zone.

The important diagenetic and low-grade metamorphic reactions which modify the fluid compositions, and concurrently the physical and thermal properties of the solids through which they flow are: bacterial and thermal degradation of organic matter; carbonate precipitation and recrystallization; formation and dissociation of gas hydrates; dehydration and transformation of hydrous minerals, especially of clay minerals and opal-A; volcanic ash hydration and alteration, principally zeolitization and smectite formation; and higher temperature hydrous silicates formation. These fluid-sediment diagenetic and low-grade metamorphic reactions alter the sediment properties of the subduction system. The degree to which these fluid regimes influence the global chemical and isotopic systems, for example the seawater and mantle Cl isotopic compositions, are significant for some components and insignificant for others. An evaluation of the fluid fluxes and associated Li, Cl, Sr, Ca, and Mg chemical and isotopic budgets will be considered, assuming that the ocean is circulating through the global subduction zones once in 200 to 300 million years.

The fluid-sediment reactions and fluid and solutes expelled may alter the bulk chemical composition of the underthrust sediments. If so, it would alter the original concentrations of some typical sediment signatures in volcanic arcs.

V11B-07 1035h

### Clastic Intrusions and Chemosynthetic Communities in the Cretaceous-Paleocene Forearc, Panoche Hills, CA: Structural Context of a Linked Fluid System

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Modern cold-seep deposits containing carbonate structures and chemosynthetic organisms are well documented but do not expose the underlying "plumbing" systems. In the Panoche Hills, CA, outstanding exposures of an intact, Cretaceous-Tertiary cold-seep system reveal both subsurface plumbing and the surface seepage system.

The Panoche Hills occur along the western margin of the Great Valley forearc basin in central California. Regional dips in the Cretaceous-Tertiary section are basinward 35°-45° east. The base of this seep-system is defined by a network of interconnected sandstone intrusions propagating upward through the shale-rich Moreno Formation as dikes and sills. Previous investigations have indicated that the source of these intruded sands is the underlying Panoche Group sandstones. The sandstone intrusions cut through approximately 500-600 meters of section and are interpreted as being permeable pathways for fluids and gases that fed the overlying seep-related carbonates and chemosynthetic organisms. Coeval dikes and sills suggest similar magnitudes of principal stresses. A NW-SE dike maxima suggests NE-SW extension. These carbonate seep-structures contain micro and macrofossils common to cold-seep environments. The seep related organisms and carbonates are present only within a 45 meter-thick stratigraphic horizon near the upper boundary of the Moreno Formation. This stratigraphic horizon begins generally less than 100 meters upsection from the terminus of the sandstone intrusions.

These exposures define a fluid system that is, in total, about 800 m thick and that uniquely ties subsurface sandstone intrusions to carbonate-dominated cold seeps. Fluids were probably derived from an underlying overpressured section that thickened eastward towards the center of the forearc basin. Thus, the system was probably driven by subduction-imposed forearc basin architecture.

V11B-08 1050h

### Snapshots From a Tertiary Subduction Factory: Metamorphic Fluids From Fault Zones of the Low-Grade Shimanto Accretionary Prism of Southwest Japan

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We characterize the physico-chemical conditions in the Shimanto accretionary wedge by examining fluids trapped synkinematically in euhedral quartz crystals associated with late-stage reverse faults. The samples come from three areas that span the Paleogene exposures on the Muroto Peninsula of Shikoku Island. Applying microthermometric and laser Raman microsampling techniques to coeval water-rich and carbonic fluid inclusions, we constrain the fluid chemistry, pressure and temperature conditions during a widespread and kinematically distinct phase of deformation. Crosscutting relations between the faults that host the fluid inclusions and pressure solution cleavage suggest that these conditions postdate peak heating. At Cape Oyama the carbonic phase appears to be pure methane, and this enables us to constrain geothermal gradients between 24 and 77 degrees Celsius per kilometer, depending on assumptions regarding overburden. The occurrence of the fluid inclusions along faults of mm- to cm-scale thickness suggests that these structures facilitated transient and very localized fluid flow during thickening of the prism.

The evolution of the thermal structure of this low-grade accretionary wedge is revealed by comparing peak temperatures inferred from organic phases such as vitrinite to fluid trapping temperatures. The former show

a prominent southeastward increase that has been interpreted to reflect landward tilting of the Paleogene portion of the wedge after peak heating. In contrast, the latter indicate consistent temperatures during late-stage faulting across all three locations investigated. Although this result suggests minimal modification of the thermal structure that is recorded by the trapped fluids, the fluids reveal a southeastward decrease in molar proportion of methane relative to carbon dioxide that may reflect tilting adequate to differentially expose this metamorphic gradient. In total we document thermally-driven oxidation of methane relatively late (i.e., post-cleavage) in the deformation history of the Shimanto accretionary wedge.

#### V11B-09 1105h

##### Helium-Carbon Relationships in Geothermal Fluids of Guatemala: Mapping the Subducted Sedimentary Component

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As part of the Central America MARGINS initiative, we report a comprehensive study of helium isotope (<sup>3</sup>He/<sup>4</sup>He), carbon isotope ( $\delta^{13}\text{C}(\text{CO}_2)$ ) and He-C abundance relationships of geothermal fluids from 7 volcanic centres of Guatemala. Guatemala was selected to provide a contrast to on-going studies in Costa Rica (see next abstract) as the arc crust in this region is thicker and older, and (unlike Costa Rica) the entire sedimentary sequence on the down-going plate (both hemipelagic muds and underlying pelagic carbonates) likely contributes to the slab flux.

The Guatemalan volcanic centres of Amatitlan-Pacaya, Tecuamburro, Moyuta, Zunil and V. Fuego have <sup>3</sup>He/<sup>4</sup>He values which fall within the range normally associated with subduction zones (5 - 8 R<sub>A</sub> where R<sub>A</sub> = <sup>3</sup>He/<sup>4</sup>He of air). Slightly lower <sup>3</sup>He/<sup>4</sup>He values (< 3 R<sub>A</sub>) are found at San Marcos and L. Atitlan but sampling in these regions was less extensive. CO<sub>2</sub>/<sup>3</sup>He ratios vary between 5 and 81 ( $\times 10^9$ ) with  $\delta^{13}\text{C}$  values scattering between -1.4 and -5.5 ‰. Although the helium in Guatemala is overwhelmingly of mantle wedge derivation, He-C results are consistent with the bulk of the CO<sub>2</sub> having a slab origin.

Using the approach of Sano and Marty (Chem. Geol., 1995) i.e. volcanic gases can be approximated by a 3-component mixture of MORB (M:  $\delta^{13}\text{C} = -6.5$  ‰), slab-derived marine carbonate/limestone (L:  $\delta^{13}\text{C} = 0$  ‰) and (organic) sedimentary (S) endmember components, the calculated L/S ratio for Guatemala is 8 and 5 for sedimentary endmember values of -30 and -20 ‰ respectively. These values are higher than worldwide arc averages and imply preferential incorporation of carbonate into the slab flux compared to the hemipelagic muds. However, both values are lower than those found for Costa Rica which indicates that possible loss of subducting sediments (e.g. by underplating) is less pronounced in Guatemala compared with contiguous arc segments to the south.

#### V11B-10 1120h

##### Carbon and noble gas composition of the Central American Volcanic Arc: Implications on global recycling of subducted carbonates.

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Four geothermal fields in Central America were sampled for gas composition in order to determine the degree to which mantle and subducted components contribute to the present CO<sub>2</sub> flux. Subducted marine carbonates contribute 86% to 98% of the carbon dioxide emitted by volcanoes of the Central American arc system, based upon  $\delta^{13}\text{C}$  values and CO<sub>2</sub>/<sup>3</sup>He ratios. Previous investigations from active arc systems around

the world report similar proportions of recycled carbon dioxide. The highest proportion of carbonate recycling in Central America occurs in the Costa Rican segment of arc, presumably due to higher temperatures of the subducting slab. Although the subducted sediment column along the Middle America Trench system is rich in carbonate lithologies, carbon-helium relationships require that only 0.3% to 3.3% of the subducted carbon is released through devolatilization beneath the arc, roughly an order of magnitude less than other arc systems which generally contain a higher water content and lower carbon content. The lack of extensive decarbonation along the subducting Central American slab is due to insufficient mineral-bound water in the subducted sediments, as well as insufficient temperatures beneath the volcanic axis. When differences between Central America and other arc systems are accounted for, the total global flux of carbon from island arcs is only  $0.18 \times 10^{12}$  mol/a. This is much less than previous estimates, yet balances the flux of carbon dioxide gas at mid-ocean ridges and the return of subducted carbon to the mantle. Given the low flux of subducted carbon from active arc volcanoes, global models which consider arc volcanism as a substantial source of exospheric carbon should be reconsidered.

#### V11B-11 1135h INVITED

##### Isotopic and Elemental Signatures of the Forearc, and Impacts on Subduction Recycling: Evidence from the Marianas

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Trace element and B and Li isotope systematics of serpentinites from the Conical Seamount in the Mariana forearc indicate significant geochemical changes occur in the slab and mantle wedge in the earliest stages of subduction. Elevated K, Rb, Cs, B, Li and possibly Pb and As contents in fluids, clasts, and/or muds from Conical indicate transport of H<sub>2</sub>O-soluble species off the slab at < 30 km depths. Boron contents in Conical clasts correlate broadly with LOI, suggesting continuous inputs of B with progressive hydration. Abundances of Li, Rb and Cs covary mutually, but do not correlate with LOI or other elemental concentrations in Conical clasts. The alkalis may thus reflect a different (later?) stage of slab inputs in which a broader menu of species are mobilized.

Boron isotopic systematics of Conical serpentinites point to additions of fluid with uniform  $\delta^{11}\text{B}$ , irrespective of fluid-rock ratio. This fluid, at  $\delta^{11}\text{B}$  of +13 ‰, is > 10 ‰ heavier than any subducted component, indicating fractionation of B isotopes during slab fluid releases beneath forearcs. The temperatures of shallow slabs must be cool enough for B isotope fractionations to occur, which is consistent with the observed, low T serpentine mineralogy in Conical samples. The fraction of slab B recycled in the forearc depends on the model for developing high  $\delta^{11}\text{B}$  arc lavas: either slab fluids with elevated  $\delta^{11}\text{B}$  are released beneath arcs, or a hotter (and presumably lower  $\delta^{11}\text{B}$ ) fluids from the slab mix with some portion of hydrated, high  $\delta^{11}\text{B}$  mantle convected in from shallower depths.

Li isotopes in Conical serpentinites indicate more modest, if variable, slab inputs.  $\delta^7\text{Li}$  variations in these samples (from -0.5 to +11 ‰) are greater than those observed in probable slab materials, or in most arc lavas, and may indicate the development of Li isotopic heterogeneities in the Mariana forearc mantle, like those suggested by Li isotope variations in "hot" arcs (Tomaschak et al., 2000).  $\delta^7\text{Li}$  in Mariana arc lavas (at +1 to +8.5 ‰), are more diverse than observed in other arcs, but show less variation than Mariana forearc rocks, supporting contentions that Li from the mantle wedge dilutes the slab input during arc melting.

#### V12A MC: Hall D Monday 1330h Ridge Processes and Products

Presiding: R Keaten, MBARI

#### V12A-0942 1330h POSTER

##### Hf Isotope Compositions in MORB from the Arctic MAR

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We report on <sup>176</sup>Hf/<sup>177</sup>Hf for 52 MAR basalt glasses from 66 - 78°N. Spreading rate, ridge axis elevation, and degree of melting progressively decrease northwards to very low values. On southern Kolbeinsey Ridge (66 - 69°N),  $\epsilon_{\text{Hf}}$  increases from +14.5 north of Iceland to +19.5 at the Spar FZ, where typical N-MORB erupt ( $\epsilon_{\text{Nd}}=+11$ , (La/Sm)<sub>n</sub>=0.5, (Lu/Hf)<sub>n</sub>=2.8). This gradient reflects mixing of the Iceland plume with depleted upper mantle. On northern Kolbeinsey Ridge (69 - 71°N),  $\epsilon_{\text{Hf}}$  decreases steeply from +19.5 at the Spar FZ to +15 at the Jan Mayen FZ, reflecting mixing between depleted upper mantle and the Jan Mayen plume, located 160 km to the east. On Mohs Ridge (71 - 73.5°N),  $\epsilon_{\text{Hf}}$  increases abruptly from +10 at Jan Mayen platform ( $\epsilon_{\text{Nd}}=4.5$ ) to +24.3 at the intersection with Knipovich Ridge, where N-MORB erupt with  $\epsilon_{\text{Nd}}=+10$ , (La/Sm)<sub>n</sub>=0.6, and (Lu/Hf)<sub>n</sub>=1.3. The  $\epsilon_{\text{Hf}}$  gradient over Mohs Ridge reflects the northward dispersion of the Jan Mayen plume and its mixing with depleted upper mantle. Along Knipovich Ridge (73.5 - 78°N), which runs NW parallel to and on the fringe of the Barents Sea-Svalbard continental shelf break,  $\epsilon_{\text{Hf}}$  scatters between +20 and +23, a relatively small and highly radiogenic range compared to that of +7.2 to +10 for  $\epsilon_{\text{Nd}}$ . Overall, the Hf isotope latitudinal profile is similar to that of Nd and opposite those of Pb and Sr. A major distinction between the Hf and Nd isotope profiles is the magnitude of the maxima observed where N-MORB are present. The <sup>176</sup>Hf/<sup>177</sup>Hf maximum at 73.5°N ( $\epsilon_{\text{Hf}}=24$ ) is significantly higher than that at 69°N ( $\epsilon_{\text{Hf}}=19$ ), whereas the opposite is observed for <sup>143</sup>Nd/<sup>144</sup>Nd. In Nd-Hf isotope space, three distinct mixing trends are observed, stacked significantly above the global mantle array. The farthest displaced Jan Mayen-Mohs trend converges at a sharp angle with the mantle array at  $\epsilon_{\text{Nd}}=5$ . The southern and northern Kolbeinsey trends are superimposed, run subparallel to the mantle array, and intersect the Jan Mayen-Mohs trend at  $\epsilon_{\text{Nd}}=6.5$ . The Knipovich trend falls in between the Jan Mayen-Mohs and Kolbeinsey trends, intersecting the former at  $\epsilon_{\text{Nd}}=7.5$ . Small differences in the Hf/Nd ratios of the end-members of these binary mixing arrays are suggested by their slight downward concavities. The <sup>176</sup>Hf/<sup>177</sup>Hf latitudinal profile resembles that of <sup>143</sup>Nd/<sup>144</sup>Nd rather than <sup>176</sup>Hf/<sup>177</sup>Hf, indicating relatively recent decoupling in parent/daughter-<sup>176</sup>Hf/<sup>177</sup>Hf isotope systematics over the Knipovich and northern Mohs Ridges. The proximity of Knipovich Ridge to the Svalbard-Barents Sea continental break, its youth, shear-dominated spreading, and punctiform nature of volcanism, with graben-like sections invaded by turbidites, are likely the cause of this decoupling. Melting of randomly distributed sub-continental mantle lithosphere schlieren embedded in the depleted upper mantle beneath Knipovich Ridge was proposed based on Pb-Nd-Sr-He isotope systematics. The unusually radiogenic Hf isotopic signature further suggests these heterogeneities may be deep relicts from ancient melt extraction at great depth where garnet/clinoxyroxene ratios would have been high, producing residue aging with higher-than-usual (Lu/Hf)/(Sm/Nd). The slow spreading and small degree of melting characterizing Knipovich Ridge can readily account for the relatively high (La/Sm)<sub>n</sub>=1-1.5 and low (Lu/Hf)<sub>n</sub>=0.7-1 also observed in these MORB.

#### V12A-0943 1330h POSTER

##### Contrasting Geochemistry of on- and off-axis Magmatism, 26°S Mid-Atlantic Ridge

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