

the prolonged water-rock interaction including the dissolution of sedimentary (evaporitic?) sulfates, the reduction of sulfate to form H₂S, the CO₂ degassing and associated calcite precipitation, and the re-oxidation of H₂S to SO₄. We consider that the geothermal system responsible for both MTW and BTW are located nearer to a deep heat source, compared to the other geothermal systems found in South Korea. The application of silica and various cation geothermometers as well as multi-component geochemical modeling suggests the temperatures of a deep thermal reservoir of up to about 120 to 130 degree in centigrade. Accordingly, a potential geothermal anomaly (40-85 mW/square meters) is expected to exist beneath the Magumsan and Bugok area.

V12E MC: 304 Monday 1330h

Trench to Subarc: Diagenetic and Metamorphic Mass Flux in Subduction Zones (GERM/MARGINS Subduction Factory Session) II (joint with OS, T, MR)

Presiding: G E Bebout, Lehigh University; J Ryan, University of South Florida

V12E-01 1335h

Comparative Thermal Structures of Circum-Pacific Subduction Zones

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Subduction zone thermal structure influences Benioff Zone (BZ) seismicity, slab dehydration/metamorphism, geochemical fluxes, and arc magma production. To evaluate effects of relative differences in slab-surface temperature (SST), we have simulated thermal structures of ten circum-Pacific cross-arc transects (Andean, Central American, Cascades, E Aleutian, Kurile, NE Japan, and Mariana arcs) showing large variations in slab age (9-134 Ma), convergence rate (2-10 cm/yr), duration (40-226 Ma), slab length (200-1200 km), and slab geometry.

A finite-element method was used to simulate mantle convection and a finite-difference solver used to compute heat transfer. A staggered grid for discretization enhanced accurate modeling of mantle convection. All models assume realistic curved slab geometries as constrained by BZ earthquake hypocenters. Shear-heating is evaluated using rheology of wet quartzite to simulate the presence of a veneer of subducted sediment near upper slab surfaces. Error propagation analysis indicates that the major uncertainty in SST profile is associated with (1) uncertainty in thickness of the overriding lithospheric plate, which determines the size of the convecting wedge domain, and (2) shear-heating contributions. Assuming constant lithosphere thickness (100 km), we estimate a nearly two-fold range in SST (300 to 600 °C) at BZ depths below the respective volcanic fronts. Moreover, for most transects similar SSTs (800±50 °C) are predicted at depths of the deepest BZ earthquakes. Even where slow subduction of young slabs occur, Ts approaching the wet solidus of oceanic crust or sediments are predicted only if the lithospheric lid is relatively thin or there is very strong shear-heating. Thus, we consider direct melting of subducted materials unlikely in any of the model transects.

Assuming that highly fluid-mobile B is derived largely from subducted slabs, B-enrichment data help constrain our thermal models. We show that B-enrichment (e.g., B/Zr ratios) in arc volcanic rocks is anti-correlated with SSTs at 100 km depth. This relation is consistent with progressive loss of fluids and fluid-mobile elements as descending slabs warm, and with variation in slab thermal structure from arc to arc.

V12E-02 1350h INVITED

Quantification of Subduction Zone Metamorphic Devolatilization From Computed High Pressure Phase Equilibria

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Devolatilization in subduction zones is essential to arc magmatism, seismicity and volatile recycling. A premise of our research is that realistic modeling of metamorphic devolatilization of subducted lithologies is only possible with phase equilibria for chemical systems that closely approximate actual bulk compositions. Volatile components are introduced into subduction zones by three contrasting lithologies: marine sediments, and hydrothermally altered mantle ultramafic rocks and oceanic metabasalts. Using free energy minimization (Perplex programs - web address: erdw.ethz.ch/~jamie/perplex), phase equilibria were computed to 6 GPa (~160 km) to quantify the evolution of CO₂ and H₂O by prograde metamorphism of these lithologies. Geotherms for NW and SE Japan [1] were adopted as thermal extremes along the tops of subducted slabs. The following summarizes our conclusions regarding the correlation between the depth of devolatilization, bulk rock composition and P-T locations geotherms. Serpentinites: for carbonate-bearing serpentinites (ophicarbonates) little CO₂ is released; for high-temperature (high-T) geotherms complete dehydration occurs under forearcs, and for low-temperature (low-T) geotherms major dehydration occurs under subarcs. Siliceous limestones: little devolatilization for all geotherms. Marls: with high-T geotherms devolatilization is complete under subarcs; in contrast, little devolatilization occurs with low-T geotherms. Carbonate-free pelites and turbidites: with high-T geotherms most dehydration occurs under forearcs, whereas along low-T geotherms substantial H₂O is released under subarcs. Carbonate-bearing oceanic metabasalts: decarbonation is negligible along low-T and intermediate-T geotherms and is limited along high-T geotherms; dehydration is complete under forearcs for high-T geotherms, significant under subarcs for intermediate-T geotherms, and very limited along low-T geotherms. Carbonate-free oceanic metabasalts: dehydration is complete under forearcs for high-T geotherms, and widespread under subarcs for intermediate-T and low-T geotherms. Metamorphic devolatilization of subducted metabasalts and metasediments is continuous; thus, we do not expect pulses of fluid release (corresponding to univariant devolatilization) for these lithologies. Our study emphasizes that because of differences in the bulk compositions of volatile-bearing lithologies and in the P-T location of geotherms, generalized modeling of subduction zone volatile recycling is questionable.

References: [1] Peacock, S.M. and Wang, K. (1999) Science, 268, 937-939.

V12E-03 1410h

The influence of subduction zone thermal structure on arc magma chemistry: B and fluid-mobile elements

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It is postulated that contents of B and other highly fluid-mobile elements (HFMs) in primitive arc lavas are sensitive to thermal structures of subducting slabs (sensu lato), which are the principal sources for these elements in subduction zones. Initial slab HFM inventories may be variably depleted in proportion to progressive fluid release as a consequence of gradual warming and metamorphism of descending slabs. Also, some variation in the rate of slab heating is expected from arc to arc due to differences in subduction rate, slab age, Benioff Zone (BZ) geometry, etc. Thus, a greater fraction of the initial slab HFM inventory will be available to modify subarc mantle domains in relatively cool subduction zones, and vice versa. Nearly 100-fold variation in B-enrichment (e.g., as monitored by B/Zr or similar ratios normalized to constant B content) is observed for volcanic front (VF) basalts from arcs worldwide. B-enrichment is highly correlated with the above measurable subduction parameters and with other temperature-sensitive parameters such as slab length (= down-dip extent of BZ seismicity). B-enrichment is also well correlated with slab-surface temperatures (SSTs) below the VF, as determined from numerical models (Huang et al., this volume). These relations suggest that slab HFM fluxes are strongly influenced by slab thermal history, and probably controlled by stability of HFM host minerals as well as the availability of fluid transport media. Different behavior is expected for various elements depending on their fluid-solubility and/or P-T stability of relevant host phases in which case geochemical fractionations are readily feasible and may explain some of the geochemical variability among arc magma suites. Moreover, B/Zr and similar ratios potentially can be used to infer aspects of slab thermal structure. However, care must be taken that the ratios are representative of the most primitive mafic magmas and not modified

by shallow crust-level processes. For example, interaction with lower crust rocks can lower normalized B/Zr values for relatively evolved lavas.

V12E-04 1425h

Mineral Solubility in Aqueous Fluids at High Pressure: Implications for Metasomatism in Subduction Zones and the Mantle Wedge

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Subduction zones are regions of profound fluid-controlled mass transfer (metasomatism). However, the physical chemistry of fluid-rock interaction in this environment remains poorly understood because there are few measurements of mineral solubility at the relevant pressures and temperatures. We have carried out a program of experimental and theoretical studies of mineral solubility in H₂O-NaCl-HCl-H₂S fluids at 5-20 kbar and 350-900 °C. Experiments are performed in a piston-cylinder apparatus; mineral solubilities are determined based on weight changes of encapsulated minerals or analysis of extracted quench fluids. When combined with theoretical predictions, these studies provide a basis for modeling metasomatism in subduction zones and the mantle wedge.

Experimental studies on quartz, diaspore, corundum, albite-paragonite-quartz, calcite, forsterite and enstatite show that, as a general rule, mineral solubility increases strongly with pressure at constant temperature in pure H₂O. In some cases solubility is 3-4 orders of magnitude higher at subduction zone conditions than in shallow crustal environments. Silica, alkalis, and Al dominate the solute load relative to alkaline earths and transition metals. NaCl profoundly enhances the solubility of calcite and Al and other metal oxides, but decreases SiO₂ solubility significantly. Studies of HCl dissociation show it to be a weaker acid at >5 kbar than anticipated from low-pressure experiments. H₂S does not strongly influence the solubilities of Si, Al, and Na, but is expected to enhance metal solubility. Experimental results agree well with theoretical predictions of solubility based on the observation that the quantity ΔV_r/βH₂O RT is isothermally constant with increasing pressure. This gives a foundation for predicting thermodynamic properties of aqueous species that have not been studied experimentally. Results of our studies confirm that aqueous subduction-zone fluids will be rich in alkalis, Al, and Si. Metal contents will be low, unless additional components (NaCl, HCl, H₂S) are present.

V12E-05 1440h

Experimental Study of Slab-Mantle Geochemical Exchange in Subduction Zones

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Aqueous fluids derived from subducting oceanic crust play an important role in the material transport leading to the production of arc lavas, and in the long-term chemical evolution of the Earth's mantle and crust. In order to determine the geochemical evolution of both the subducting slab and the overlying mantle wedge, a series of dehydration/hydration experiments was carried out at conditions of 0.8-4.0 GPa and 650-900 °C appropriate for subduction zones. Blueschist facies rocks/minerals, and olivine (Fog₁) were used for starting materials, as analogue materials of slab and mantle, respectively. Finely ground metabasalt (H₂O = 5.9 wt%) and glaucophane (H₂O = 2.3 wt%) were separately sealed in gold capsules with an olivine grain (1mm diameter), and then run in a piston-cylinder apparatus. Polished sections of run products were observed and analyzed for major element compositions with an electron micro-probe. Trace elements of selected run-products were determined using an ion probe (Cameca-5f).

At subsolidus conditions, the metabasalt was transformed into amphibolite-facies mineral assemblages

containing Mg-ilmenite at <1.5 GPa, and eclogite-facies assemblages containing rutile at >1.5 GPa. Glaucophane was transformed into the mineral assemblage of Na-Cpx, Opx \pm garnet. Garnets formed in the slab portion show low-LREE/HREE and higher-HREE contents when compared with the starting materials. In all subsolidus experiments, Al-rich silicate glasses, which could be quenched aqueous fluids, were observed between mineral grain boundaries in the slab portions. The fluids at 3.0 GPa show high-LREE/HREE, and higher-LILE and lower-HREE contents. In contrast, the quenched fluids for <1.5 GPa, which did not co-exist with garnet, do not show strong depletion in HREE. Negative Nb anomalies were observed in the quenched fluids in the metabasalt experiments, but this anomaly does not appear to exist in the glaucophane experiments. The behavior of the HREE and HFSE is consistent with the existence of garnet and Ti-oxides (rutile and ilmenite) in the slab portion of the experiments. The fluids should therefore be enriched in SiO₂, LILE and LREE. Mineral zones were observed on olivine grains near the initial olivine-slab interface. These reaction zones consisted of talc and enstatite layers at < 800°C, and an enstatite layer only at > 800°C. Because the enstatite layers are strongly LILE and LREE-enriched compared with the primary olivine, the reacted layers are thought to have been formed by chemical interaction between olivine and SiO₂-riched aqueous fluids which were capable of also delivering these other trace elements. As a consequence of this transfer, the chemical compositions of the descending slab and the overlying mantle could be considerably depleted and enriched, respectively, in SiO₂, LILE and LREE during the process of subduction.

V12E-06 1455h INVITED

Element Fluxes From Subducted Slabs: Constraints From High-Pressure Metamorphic Rocks

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High-pressure metamorphic rocks in paleo-subduction and collision zones are the exhumed equivalent of subducted crust in modern subduction zones. The variable maximum P-T conditions of high-P terranes represent an opportunity to study kinetics, fluid flow, element partitioning and element fluxes during dehydration or melting reactions at various depth levels in subduction zones. Several conclusions from many metamorphic and stable isotope studies of high-P terranes are important for the study of element fluxes in subduction zones: (1) disequilibrium between phases is prevalent to temperatures of 600 – 700°C, (2) metabasites and metasediments in most terranes show evidence for dehydration and fluid flow, however no evidence for partial melting at high P, (3) fluid flow appears to be focused in fractures. Quantitative studies of the major and trace element budget and element mobility in high-P rocks are still scarce. Particularly scarce are data for key elements that are important to model the long-term isotopic evolution of mantle and crust (K, Rb-Sr, U-Th-Pb, Sm-Nd). It has been shown that quantitative constraints on the efficiency of removal of fluid-mobile elements can be obtained by normalizing the abundances of such elements to abundances of elements that are much less soluble in fluids (e. g., Nb, Ta, Zr, HREE, Be). This seems to work well in metabasites in which the protolith chemistry can be reasonably well constrained from major element and Sr-Nd isotopic compositions. The data on eclogites can be used to construct a preliminary model for the composition of dehydrated altered MORB in mantle recycling models. This composition agrees well with predictions based on the composition of HIMU ocean island basalts. Similar approaches for high-P metasediments may work for specific elements but are problematic for others because protolith compositions are much more variable. Smartly designed experimental studies may fill these gaps. Future trace element studies of eclogites from moderate- to high-temperature terranes should help to improve existing model compositions for dehydrated altered MORB. A major limitation on any flux model is the uncertainty on the significance of unaltered oceanic crust for the water and element flux into arcs.

V12E-07 1535h

Slab-related Boron Isotope Signatures in arc Volcanic Rocks From the Central Volcanic Zone (CVZ) of the Andes

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This study uses the geochemical and isotopic behavior of boron as a tracer for mass transfer and the generation of arc magmas in the southern part of the CVZ. Investigations were made on andesitic to dacitic arc lavas between 20 and 26°C.

B isotopic ratios were measured using the Cs₂BO₂⁺-graphite method and are reported as $\delta^{11}\text{B}$ values in ‰ relative to NBS 951. The total B concentrations of investigated rocks range from 10 to 54 ppm and $\delta^{11}\text{B}$ values vary between +4 and -7 ‰, whereby the trench-side locations show systematically higher $\delta^{11}\text{B}$ values and B contents. The wide range of $\delta^{11}\text{B}$ values and B contents is the most striking feature of the presented dataset.

Potential source reservoirs for B and their assumed compositions in this setting include: Altered oceanic crust (5ppm; $\delta^{11}\text{B}$: +4 ‰), marine sediments (100ppm; $\delta^{11}\text{B}$: -10 ‰), mantle (1ppm; $\delta^{11}\text{B}$: -3 ‰) and continental crust (15ppm; $\delta^{11}\text{B}$: -10 ‰). The contribution of subducted marine sediments in the CVZ is negligible.

Assuming these compositions, positive $\delta^{11}\text{B}$ values can neither be explained by incorporation of mantle-derived B nor by B from the crust. For these samples, a ¹¹B rich slab-derived component dominated by altered oceanic crust must be the major source. This implies that B and possibly other mobile elements were effectively transferred via fluids from the subducted slab into the mantle wedge where generation of arc magmas took place.

Various experiments indicate a temperature dependent fractionation of B isotopes between rock and fluid. Using published fractionation factors, $\delta^{11}\text{B}$ values of the subduction zone fluids would decrease from ca. +12 ‰ at 150°C to ca. -6 ‰ at 750°C with increasing depth to the slab. The range of observed $\delta^{11}\text{B}$ values can be explained with the fractionation effect. The correlation of decreasing $\delta^{11}\text{B}$ values and B contents with distance to the trench and depths of the subducted plate suggests that the total boron budget is dominantly controlled by slab-derived B. If this is true, decreasing B contents toward the back-arc indicate a decrease in the mass flux of B and perhaps other fluid mobile elements with increasing depths of the slab. Deviations from the general across-arc variation may be due to locally variable degrees of crustal contamination. Two component mixing models of $\delta^{11}\text{B}$ with Sr and Nd isotopic compositions indicate an addition of 15 to 35 % crustal material to the initial magma.

V12E-08 1550h

Amount of Sediment-Derived Fluid in Mantle Wedge Beneath Northeast Japan Arc: Comparison Between B and Other Element Contents in Japan Trench Sediments and Those in Iwate Lavas

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From the Japan Trench, the Pacific Plate descends to the deep mantle. Parts of the plate, the altered oceanic crust (AOC) and overlying sediments, release hydrous fluids at the deep mantle, and these slab-derived fluids would be added to the mantle wedge beneath Northeast Japan arc. In order to estimate the weight percent of the fluid in the mantle wedge, we determine boron and other element contents of 42 sediments from Japan Trench and 29 lavas from Iwate volcano on Northeast Japan volcanic front. The Japan Trench sediments are typical trench-fill sediments mainly consisting of pelagic clay. 15 Iwate lavas belong to the tholeiite series and 4 Iwate lavas belong to the calc-alkali series. The tholeiite lavas have uniform B/K, indicating these lavas were formed by melting of a single magma source. B/K of the calc-alkali lavas is lower than that of the tholeiite lavas. Also, B/K ratios are distinctly more variable in the calc-alkali lavas, suggesting we have to consider more than two magma source. Trace element contents of the trench sediments are used to estimate those of the sediment-derived fluid, and previously reported trace element contents of the AOC (Smith et al., 1995, Chem. Geol., 126, 119-135) are used to estimate those of the AOC-derived fluid. Examination of mobile/immobile element

ratios (B/Sm, Ba/Sm, K/Sm, B/Zr, Ba/Zr, K/Zr) of the two slab-derived fluids and Iwate tholeiite lavas, indicates a mixing ratio between the AOC-derived fluid and the sediment-derived fluid is 90 : 10 in the mantle wedge beneath the Northeastern Japan arc. Based on the element ratio diagrams, weight fraction of the total slab-derived fluid in the mantle wedge is estimated to be less than 1 wt %. When we combine the above two estimations, the amount of the sediment-derived fluid in the mantle wedge is estimated to be less than 0.1 wt %.

V12E-09 1605h INVITED

Lithium Isotopic Compositions of South Sandwich Arc and Southwest Washington Cascades: A Comparative Study of Arc Processes

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Lithium isotopes constitute a relatively new tracer for island arc processes. Published results show that arc lavas are generally enriched in Li and isotopically heavier compared to mid-ocean ridge and ocean island basalts. This enrichment is attributed to addition of Li from subducted oceanic crust and sediments to the mantle source. We report new data from the South Sandwich (SS) and Southwest Washington Cascades (SWC) arcs, which demonstrate greater diversity of Li isotope systematics among arc lavas.

SS basaltic lavas are moderately enriched in Li (Li/Y = 0.29 to 0.37) with $\delta^7\text{Li}$ ranging from (1.3 to 7.6‰). Local diatomaceous ooze and clay-rich sediments (ODP Site 701) have largely constant $\delta^7\text{Li}$ (2.7 to 4.8‰) that closely resemble MORB (3.4 to 4.7‰). On the other hand, oceanic crust altered by seawater can have $\delta^7\text{Li}$ as high as 20‰. $\delta^{11}\text{B}$ of the lavas are distinctly higher than local sediments. These observations suggest that the subduction component is mainly derived from altered oceanic crust with little contribution from the sediment. The low $\delta^7\text{Li}$ may indicate addition of light Li from hydrothermally altered crust or some isotopic fractionation process in the subduction environment.

The Cascades arc is characterized by the subduction of young and hot oceanic crust. Li/Y of the forearc and the volcanic front including Mt. St. Helens and Indian Heaven are elevated (up to 0.60) but $\delta^7\text{Li}$ of the enriched lavas are remarkably constant (2.5 to 4.0‰). This suggests that the subduction component has an isotopic composition of about 3‰. The MORB-like signature of the enriched lavas may be explained by (1) a relatively weak isotopic signal of the subducted oceanic crust due to its young age, and (2) sediment compositions that are indistinct from the mantle, much like those near the South Sandwich Trench. The later will be verified by analyses of sediments on the Juan de Fuca plate. Normalized B/Li ratios decrease from forearc eastward, indicating early loss of B by slab dehydration. Behind the front at Mt. Adams and Smicoc, there is little enrichment in Li and the isotopic composition is mantle like. Apparently Li is also stripped from the deeper slab. Because of high temperatures of this subduction zone, fluid plays a relatively unimportant role in magma generation under the Cascades arc.

The main implication of this comparative study is that Li-rich subduction components can exhibit a range of isotopic compositions from arc to arc and the cause of this variability is in part related to the thermal structure of the subducting lithosphere.

V12E-10 1625h

Lithium Budget and Isotopic Characterization of Materials Entering the Izu-Mariana Subduction Zone

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We present lithium-isotopic data for alteration products entering the Izu-Mariana subduction zone, as part of a larger study of the Li flux balance across the margin. Sediments and altered basaltic crust samples were collected during ODP Leg 185 at Site 801C, Pigafetta Basin outboard of the Mariana arc, and Site 1149, Nadezhda Basin outboard of the Izu arc. Dramatic variability between the two sites has been observed in sediment lithology and basement petrology, architecture and alteration styles. This study will address the extent to which these factors affect the along-strike heterogeneity of the Li-content and isotopic ratios of subducting material.

A small, preliminary, data set shows that whole rock samples (altered alkali and tholeiitic basalt, altered basalt rich in smectite, or in early or late stage celadonites etc.) are characterized by Li concentrations ranging from 8 ppm to greater than 30 ppm and $\delta^6\text{Li}$ values of -3‰ to -14‰ . Many weathered samples appear to fall on a mixing line first observed by Chan et al. (EPSL, 1992, 108, 151-160) between fresh MORB and authigenic phyllosilicates in equilibrium with seawater. Deviations from this trend are observed for alkalic basalts and late stage celadonitic samples. The alkalic basalts may possess greater initial Li concentrations than tholeiitic basalts, but the intrusive nature of the alkalic basalts into sediments must contribute to their enhanced Li content and elevated $\delta^6\text{Li}$ values. Preliminary results suggest that early celadonites are characterized by Li-systematics similar to smectite, while low Li-concentrations and extreme isotopic ratios characterize late-stage celadonites. $\delta^6\text{Li}$ depletions may be the result of higher temperature fluids, but considered in light of low Li concentrations we suggest that this mineral phase formed in equilibrium with previously reacted, relatively low-temperature seawater component.

V12E-11 1640h

Light Li Isotopic Composition in Subducting Slabs: Evidence From Alpine Eclogites

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As the Li isotopic compositions of various regions of the Earth become known, a mass balance problem is emerging: the $\delta^7\text{Li}$ value of oceanic mantle-derived basalts is 3-5 per mil, which is thought to be representative of the upper mantle. Oceans and sediments are heavier than this (32 and 9-23 per mil, respectively). Arc lavas have variable $\delta^7\text{Li}$, ranging from 2 to 11 per mil, with the heavier values interpreted as resulting from addition of a heavy, slab-derived component (sediments or sea-water altered oceanic crust). Few rocks have been measured with light $\delta^7\text{Li}$ values. If the heavy $\delta^7\text{Li}$ in arc lavas derive from slab fluids, it is possible that the dehydrated slab is isotopically light, and provides the light Li reservoir needed to balance the heavy surface rocks to make a bulk Earth $\delta^7\text{Li}$ of ~ 4 . High pressure metamorphic rocks from Trescolmen (Swiss Alps) are an analogue to subducted oceanic crust. Eclogites from this locality have geochemical characteristics of MORB that experienced low temperature hydrothermal alteration (Zack et al., 2001, J. Petrol.). Surrounding eclogite-facies garnet mica schists were once pelitic sediments. Although tectonic reconstructions place these rocks in a passive margin setting, they nevertheless experienced metamorphic conditions similar to those in a subducting slab (ca. 650°C and 2 GPa). Li concentrations in the eclogites are all significantly higher than MORB, implying overprinting by post-magmatic processes (sea-floor alteration, metamorphism and exchange with the surrounding metasediments). Interestingly, $\delta^7\text{Li}$ values range from -10 to 5 per mil, with all but 2 samples having $\delta^7\text{Li}$ values < 0. The uniquely light values for these samples cannot be explained by sea-floor alteration or eclogite-sediment exchange and must be related to the dehydration reactions accompanying high pressure metamorphism. These data provide the first evidence that the Li isotopic compositions of subducted slabs may be light, and thus has implications for storage of slabs in the mantle and their subsequent incorporation into mantle plumes.

V12F MC: 305 Monday 1330h

Experimental Volcanology: Sturtevant Memorial II (joint with G, P, T, MR, HG)

Presiding: M Ichihara, Tohoku University; D B Dingwell, University of Munich

V12F-01 1330h

PIV measurement of granular flow speeds: implications for volcanic flows

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The avalanching of granular material at slope angles between the angle of repose and the angle of maximum stability, such as within a block and ash flow or on the flank of an active scoria cone, typically produces droplet-shaped flows that consist of a well-defined head at the front. We have performed the first experiments on such flows using the particle-image velocimetry (PIV) technique, in which we have studied avalanching flows of sand for different surface properties. Our results suggest that the presence of a layer of loose or erodible particles on the surface is a necessary condition for the occurrence of these flows. We measured the surface-velocity field in avalanches propagating at angles between the angle of repose and the maximum angle of stability, and observed a transition in the flow behavior with downstream distance, from an inertial (?) flow of particles above the bed surface to a compressing, frictional (?) flow of particles within the bed that has the characteristics of a shockwave propagating through the bed. Particle-speed measurements of the transition confirm that it occurs within a limited spatial region. Particle and flow speed measurements seem to indicate that the features of the transition between these regimes depend on the inclination angle of the surface in the small range between the two critical angles. The results suggest that block and ash flow deposits and scoria cone flanks, for example, are formed by flows that in their upper reaches propagate as an inertial flow of particles above a bed surface, and in their lower reaches propagate as a shock wave within the uppermost part of the debris pile.

V12F-02 1345h

Experiments on Gas-Fluidized Granular Flows: Implications for Pyroclastic Flow Mobility

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We carried out experiments on fluidized granular flows and report characteristics of their deposits. The experimental apparatus (8 cm wide x 50 cm deep x 150 cm long) consists of a fluidization reservoir and a horizontal channel. Particles are fluidized in the reservoir by introducing an air flux with velocity U through a porous plate, and are released into the channel by means of a sliding gate. We used glass beads of grain size 45-90 μm , 106-212 μm , and 600-800 μm corresponding respectively to groups A, B, and D of Geldart's classification (1973). We studied the influence of the initial bed height ($H=10$ to 20cm) and the degree of fluidization on the flow mobility as measured by the distance traveled by the flows (L), and the deposit slope.

The distance L increases as soon as the initial bed in the reservoir is aerated (at $0 < U < U_{mf}$, where U_{mf} is the minimum fluidization velocity). Once the bed

is fluidized (at $U > U_{mf}$), L rapidly reaches a constant maximum value, then showing that the extent of the flow does not vary with U. L also increases with H and decreases with the grain size. A graph using the parameter $L/H^{1/2}$ as a function of U/U_{mf} shows a good collapse of the data, except for group A particles for which $L/H^{1/2}$ increases with H. Compared to their non-fluidized analogues, the mobility of the fluidized flows is increased by factors of 1.7-2.3, 1.7, and 1.2 for the group A, B, and D particles respectively. The deposits are characterized by a front wedge with a small and constant downstream slope of 2° (group A) to $3-5^\circ$ (groups B and D). This frontal wedge represents 45-65 %, 25-40 %, and 20-30 % of L for deposits of group A, B, and D particles respectively. The slope of the body of the deposits is larger than that of the front for group B and D particles ($5-10^\circ$). Particles of group A commonly slope upstream ($1-2^\circ$). The ratios L/t (t: maximum thickness) of the deposits are 25-45, 10-20, and 7-10 for group A, B, and D particles respectively. This corresponds to an increase by a factor of 6-10 (group A) and 3-5 (groups B and D) compared to the non-fluidized state.

Pyroclastic flow deposits commonly have show slopes of few degrees. Similarities between field deposits and those obtained in our experiments suggest that laboratory fluidized granular flows are suitable analogues for the study of pyroclastic flows mobility. Our experiments might suggest that, irrespective of the degree of fluidization, pyroclastic flows propagating on a horizontal surface could reach a fixed maximum distance from their source. Pyroclastic flow deposits commonly have large amounts of group A particles (grain size of 20-30 to 150-200 μm) as these form their matrix. As our experiments showed that flows of group A particles were the more mobile, we infer that these particles have controlling effect on the commonly observed large mobility of pyroclastic flows.

V12F-03 1400h

Experimental Validation of Two-phase Flow Model for the Analysis of Gas-Particle Volcanic Flows

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Laboratory experiments represent a fundamental tool to empirically investigate the dynamics of a system. At the same time, they represent an extraordinary opportunity to validate theoretical fluid-dynamic models aimed at the description of the process. This is particularly relevant for volcanic processes, for which the lack of control on the system and the large uncertainty on initial and boundary conditions make the validation using real events particularly difficult. In this work we validate our transient two-dimensional kinetic-theory-based two-phase flow code by using experiments of gas-particle flow along the riser of a circulating fluidized bed. Riser hydrodynamics has been extensively studied, both theoretically and experimentally, by numerous research group and represents an ideal test-case for the investigation of gas-particle flows of volcanic interest. Numerical results show that the dynamics of particles flow in the riser is in the form of clusters. However, the time-averaged particle concentrations and fluxes give us the core-annular flow regime in agreement with measurements. The computed clusters produce major frequencies of density oscillations in quantitative agreement with measurements. The kinetic theory model and the fluid-dynamic code compute also granular temperature and viscosity distributions in a qualitative agreement with data. For volume fraction around 3-4%, which is the average particle concentration in the riser, the computed solid viscosity agrees with our experimental measurements. The successful comparison between model predictions and data gives us further confidence in the model, and it is very promising for the future investigation of pyroclastic flow dynamics and gas-particle flow along volcanic conduits.

V12F-04 1415h

Analogue Study of Clastes Transport and Sedimentation in Pyroclastic Density Currents

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