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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  $-3\text{‰}$  to  $-14\text{‰}$ . 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  $\sim 4$ . 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  $\mu\text{m}$ , 106-212  $\mu\text{m}$ , and 600-800  $\mu\text{m}$  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  $20\text{cm}$ ) 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  $2^\circ$  (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  $\mu\text{m}$ ) 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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Analog experiments using an aqueous lock-exchange flume were carried out to study the transport and sedimentation processes occurring in pyroclastic density currents (PDC) generating extensive sheet-like ignimbrites. Those experimental flows scaled to turbulent PDCs, focusing on: (i) a very wide range of particle sizes, and (ii) particles of two different densities (the water-immersed densities of which scaled to those of lithics and pumice in gas). A suspension, containing either one or two components of different densities (SiC:2600 kg.m<sup>-3</sup> and LB:1440 kg.m<sup>-3</sup>), with a log-normal particle size distribution, produced flows of various initial concentration (0.6 to 23 vol.%). Hydrodynamic equivalence was respected in the two-component suspension. Development of stratification and particle segregation was followed in the moving flows. Originally in a homogeneous suspension, the dense component in the one- or two-components flow displayed vertically and laterally a normal grading in the flow, latter observed in the deposit. Its mass loading and grain size distribution was insensitive to the initial concentration of the flow. Deposit from a one-component flow provides little information on particle concentration of the parental flow. The transport and sedimentation behaviour of the light component in the two component experiments was extremely concentration sensitive. For dilute currents, dense and light particles settled respecting their hydrodynamic equivalence whereas they segregated efficiently for initial flow concentration higher than a few percent. In the moving flow of high initial concentration, the light component exhibited a reverse grading vertically and laterally. Their resulting deposit showed reverse grading and the site of their maximum accumulation was progressively displaced downstream, due to some increasing buoyancy effects. Segregation between pumice (light component) and lithics (dense component) occur in a PCD, the density of which is lower than that of the pumice. Based on the study of the aerodynamic equivalence between pumice and lithics, we conclude that the principal transport system for the large ignimbrites is of low concentration. The sharp variation in the decrease of the maximum size of the lithics versus distance is explained by the distinct value of the Pn of the settling particles around Pn critical value, ruling out the hypothesis of a deflation zone. The proximal co-ignimbrite lag-breccia results from the settling of coarse clastes from the overloaded PDC.

V12F-05 1430h

### The Entrance of Pyroclastic Flows into the Sea

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Explosive volcanoes, especially in subduction-zone and ocean-island settings, can generate pyroclastic flows that enter the sea. Geologic constraints on the interaction mechanisms and hazards are poor since resulting deposits hardly survive coastal erosion.

The entrance of hot pyroclastic flows into water has been observed experimentally by letting shooting granular flows of ignimbrite ash heated to up to 420°C run down a chute into a water-filled tank. Flows of relatively cool ash, less than 150°C, impulsively displace some near-shore water generating a tsunami wave and then separate into a fine-ash over-water surge formed near shore and the main, coarser and denser material penetrating the water surface to form a turbulent mixing zone which advances downstream as long as the granular flow is maintained. Pumice floats to the surface, lithics and coarse ash fall out onto the floor, but ash remaining in suspension forms a turbidity current flowing down the tank.

At temperatures above 250°C, almost all ash is initially transported along the water surface, rather than immediately penetrating it. Transport over water is facilitated by steam explosions derived from mixing of some of the ash with water across the surface. Ash fountains throw dry ash forward before it contacts the water, triggering the next steam explosion farther away from shore where fountains collapse onto the water surface. Each time ash and heat are consumed by mixing; the distance to where explosions extend thus depends on initial mass flux and temperature. Most fine ash forms an ash-cloud surge travelling over water, losing sediment plumes that unite on the tank floor to form a turbidity current. Tsunami waves generated by coastal impact appear to be additionally driven by surface-water displacement by massive ash-input from ash fountains.

Grain size distribution is also critical in determining interaction processes. Moderately well sorted medium ash generates strong steam explosions and becomes mainly emplaced as fallout from ash fountains and plumes. Poorly sorted ash with a high content of fines generates strong ash-cloud surges and turbidity currents. Major volcanic hazards associated with the entry of pyroclastic flows into the sea include tsunamis, littoral explosions, and pyroclastic surges over water, which are generated by the interaction process rather than being derived directly from the volcano.

V12F-06 1505h

### Depressurizations of Fine Powders in a Shock Tube and Dynamics of Fragmented Magma in Volcanic Conduits and Lava Dome Explosions

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Samples of fine glass beads (mean grain size equal to 38 and 95 microns) have been suddenly depressurized within a shock tube. These short-lived, rapid decompressions simulate discrete, cannon-like vulcanian explosions and produce two-phase flows that are inhomogeneous in density in both vertical and horizontal directions. Observed flow velocities increase from approximately 2 to 12 m/s when the pressure drop increases from 200 to 900 mbar. Scaling criteria enable estimates of possible size of decompressing volcanic systems (approximately between 10 and 840 m) and possible velocities of volcanic flows (approximately between 35 and 290 m/s) that correspond to our experiments. At high pressure drops, as the mixture expands and moves up the tube the flow front becomes highly irregular and bubble-like voids form. The shape of these voids becomes also distorted and stretched in the turbulent flow. At relatively low pressure drops the samples oscillate because the fragments, after the expansion, flow back and bounce upward again. Jets with diameter smaller than that of the tube are shot out of the oscillating samples generating independent pulses. Large voids whose diameter is an important fraction of the tube diameter can also discretize the flows. A question arises then if similar mechanisms in real volcanoes can produce discrete flows within the conduit and pulse-like pyroclastic flows out of the vent. The rapid decompression of these powders results in their fluidization and for this reason we advance the hypothesis that also the fragmentation of magma within a volcanic conduit or the explosion of a lava dome results in the explosive fluidization of the generated fragments.

V12F-07 1520h

### A Momentum Scaling Law for Volcanic and Impact Erosion

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Brad Sturtevant, who is honored by this session, was not only a brilliant experimentalist, but had a unique ability to bring his experimental knowledge to problems vastly different in nature from the clean, well-defined and controlled experiments of the laboratory to the dirty, ill-defined, and usually uncontrollable events of nature, and to apply his knowledge to obtaining new data and interpretations. Based on open-ended shock tube work performed in the early 1980's Brad became a convert to supersonic flow concepts in volcanology (Kieffer and Sturtevant, JGR, 1984). In our first, and subsequent, collaborative field visits to Mount St. Helens, we observed three different kinds of erosional features. The first was the general lowering of the land surface which removed trees and soil to a depth roughly proportional to the distance from the source. The second two kinds of erosional features were nearly horizontal, quasi-periodic, 7-m in average transverse wavelength, and order of 100-m in length. These "furrows" were interpreted as scouring by longitudinal vortices resulting from flow instabilities induced by either streamline curvature, or by the cross-flow component of flow sub-parallel to ridge crests. Theoretical analysis of these features gave a boundary-layer thickness for the lateral blast (14 m at 9 km from the source), a Mach number of 3.3 and flow velocity of 235 m/s at the Central Ridge, and a momentum-scaling concept for erosion based on aerodynamic lofting theory (Kieffer and Sturtevant, JGR, 1988). The furrowing process was calculated to enhance erosion over that observed in uniform vortex-free flow by a factor of from 1.3-14. An average erosion rate for the Mount St. Helens lateral blast was 0.5 cm/s lowering of the land surface. Simonds and Kieffer (JGR, 1993) applied the same theory to the flow of a dense, fast melt sheet from Manicouagan impact crater across a bedrock landscape and determined an erosion rate of approximately 2562 kg/sq m/s. (1 m/s lowering of the land surface).

V12F-08 1535h

### Experimental study on magma fragmentation by rapid decompression

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Fragmentation of vesicular magma by rapid decompression is one of the most likely triggers for explosive eruptions. In this phenomenon the decompression rate and the viscoelastic nature of magma are considered to be key factors. In order to obtain a clear idea on the effects of these two factors, controlled fragmentation experiments have been conducted. These experiments have three advantages. Firstly, the specimen is made of a viscoelastic material with controlled porosity and geometry. Secondly, the fragmentation process is directly monitored. Finally, both the magnitude and rate of decompression are controlled.

Upon sudden decompression, the specimen was fragmented into several cylindrical segments. Each segment had angular shape right after the fragmentation and then gradually expanded with ductility. For the slower decompression, the specimen just expanded without fragmentation. It was noted that fragmentation occurred when the decompression exceeded a critical value within a critical time.

Brittle fragmentation and ductile expansion were both observed in the same porous material at different time scales. The various mechanical responses of the specimen (elastic, flow and fragmentation) were correlated with the pressure profile measured at the base of the specimen. Fragmentation was noted to occur when the decompression exceeded a critical value within a critical time. Two relevant time scales are discussed in terms of physical mechanisms of relaxation. The first is the measured glass transition time. The second is the estimated time scale for the onset of viscous bubble expansion. The observed phenomena bear several similarities with natural magma fragmentation. It is thus considered that the present results are a useful step toward constructing a model for magma fragmentation.

V12F-09 1550h

### High pressure magma-water interaction experiments: data on energy distribution into system expansion melt fragmentation and mass transport

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It is well known hydromagmatic volcanic eruptions occur by heat transfer through the magma-water interface when the magma thermal energy is explosively converted to kinetic energy. In this sense the magma-water explosive interaction (MWI) is a particular case of the molten fuel coolant interaction (MFCI) that involves the phases of hydrodynamical mixing, generation and collapse of the interface vapor film, melt fine fragmentation, water vaporization, and finally system expansion. Many intensive and extensive parameters control the amount of produced kinetic energy and its distribution as different types of work done against the magmatic system and the surrounding environment and can explain the great variety of eruptive patterns and pyroclastic deposits originated by the hydromagmatic volcanic eruptions. A pressure vessel especially designed for silicate melt water interaction experiments is described. With reference to the melt thermal energy converting into kinetic during the explosive interaction, exploratory experiments carried out at magmatic temperatures, confining pressures up to 10 MPa, and injected water pressures up to 100 MPa, on a Volcani Vulsini District le-tephritic sample, have been performed aiming at finding the parameters controlling the

distribution of the kinetic energy into sample fragmentation, system expansion and mass transport. These experiments have shown that variations in the process controlling parameters, i.e.: the multiphase system viscosity (due to the presence of the melt + crystals + bubbles) and the water injection modes (due to the water relative amount and velocity) can produce strongly different distributions of the mechanical energy produced by the water interaction. The flow regime of the injected water (injection rate and injection gradient) appears to be the most critical parameter controlling the energy distribution between the system expansion and the mass transport processes. Isobaric versus impulsive injected water experiments, in progress still, show that for the same sample composition temperature and pressure, isobaric injected water experiments favour the system expansion and melt fragmentation while the impulsive ones produce more mass transport. This latter is relevant for volcanic hazard evaluation and appears to be firstly controlled by the aggregation state of the interacting melt and then, given a fixed  $M^m/M^w$  (melt/water masses ratio), by the interaction time.

V21F-10 1605h

**Unzen Dome Dacite Density: Influence on Fragmentation Threshold.**

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Preliminary experimental investigation of the fragmentation of dome lava from Unzen volcano, Kyushu, Japan, has indicated that the fragmentation is influenced by density. Thus to apply our experimental analysis to Unzen we have conducted two field campaigns (2000 and 2001), with the aim of obtaining extensive density information for the pyroclastic flow deposits of the 1990 to 1995 eruption. This permits the characterisation of the pre-collapse dome density.

Further, such density data allow us to evaluate the effect of transport processes on the density distribution of the deposits. No evidence for simple transport-related density distribution has been found.

Experiments have been conducted to determine the fragmentation threshold for rapid decompression of hot, pressurised specimens (60 x 26mm). The energy source is pressurized gas (argon) inside the open porosity. The fragmentation bomb simulates well the conditions for volcanic fragmentation induced by rapid decompression. At 850°C dense dacite (< 25% vesicularity) requires an initial pressure difference >20MPa to overcome the threshold. Less than 20% of the dacite samples, with vesicularity > 25% exhibit a lower threshold. Using a layered model of the dome interior, derived from abundant layered blocks at the dome and in the deposits, a quantitative reconstruction of the collapse is being developed.

V21F-11 1620h

**Fragmentation Speed (FS), Sound Speed (Vp) and Fracture Velocity (FV) in Dome Dacite.**

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The fragmentation speed is a vital parameter for numerical modeling of explosive eruptions. This is because the speed of fragmentation, in combination with gas expansion influences the effusion rate during explosive eruptions. Thus, the propagation speed of the fragmentation front relative to the flow rate in the conduit has the potential to establish a dynamic situation where the fragmentation depth may be either stable, deepening or shallowing with time during the eruptive event.

Using statistically relevant density variations of pyroclastic blocks determined in the field (Kueppers et al. 2001) we have selected representative samples of varying density for experimental investigation. Two types of experiments have been performed. (1) Fragmentation speeds have been determined at constant differential pressure using the fragmentation bomb. (2) Elastic wave velocities have been determined using a cubic anvil press.

Existing empirical relationships indicate further that the fracture velocity (FV) correlates with sound speed (Vp ~ 3FV). Thus, through a combination of

Vp and FS measurements, together with the FV-Vp relationship we derive the fracture propagation speed for dome lavas and its correlation with fragmentation speed, as a function of vesicularity. In a case study of Unzen dacite, first results indicate a negative correlation between fragmentation and sound speeds. The fragmentation experiments further indicate that 5 vol% vesicularity appears as a limit in the decompressive fragmentation through bubble overpressure in these experiments under these conditions.

**V21A MC: Hall D Tuesday 0830h**

**Heavy Element Stable Isotope Fractionations I (joint with B, OS, P)**

**Presiding: M Rehkamper, ETH Zurich; A D Anbar, University of Rochester**

**V21A-0958 0830h POSTER**

**High-Temperature Fractionation of Fe Isotopes**

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Fe isotope fractionations of as much as 3 permil have been reported for the 57Fe/54Fe ratio in low-temperature environments. For high-metamorphic and magmatic temperatures, Polyakov and Mineev (2000, *Geochim Cosmochim Acta* 64, 849) used Mossbauer spectroscopic data to predict that a range of ca. 1 permil might be resolvable between different Fe-bearing phases. According to Polyakov, heavy Fe isotopes are enriched in minerals that tend to concentrate ferric iron relative to those that incorporate mainly ferrous iron. Further, the degree of these fractionations is predicted to be inversely correlated with temperature. We analysed, using a Nu-Instruments MC-ICP-MS, Fe isotopes in minerals from greenschist and upper amphibolite facies conditions. Differences were found in Delta57Fe between Fe3+ containing magnetite and Fe2+ based sheet silicates (Biotite, Chlorite) of as much as 1.2 permil. Contrary to the predictions of Polyakov, however, these are entirely uncorrelated with temperature. Furthermore, in a well-studied Alpine migmatite setting, Fe in magnetites is always lighter than in minerals containing ferrous iron. Differences in Delta57Fe of magnetites of as much as 0.8 permil are found between residue, leucosome, and protolith. These are correlated with the Fe2+/Fe3+ ratio of the bulk rock. Similar relationships are found in an alkaline intra-continental volcanic suite. Delta57Fe (relative to IRM14) is almost zero in bulk rocks of a highly reducing carbonatite melt, and increases to 1 permil to the most oxidising phonolitic melt. These preliminary data indicate that, contrary to predictions, Fe isotopes are a potential proxy for oxidation state rather than a geothermometer.

**V21A-0959 0830h POSTER**

**Iron Isotopes in Meteorites**

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The recent identification of naturally occurring isotopic mass fractionation of the transition metals on the Earth has prompted a search for similar variability in meteorites. Studies of Cu, Zn, and Fe, for example, have revealed per-mil level and larger mass fractionations between different bulk meteorites. Such variations can result from temperature-sensitive isotope exchange reactions and kinetic processes, and therefore may reflect conditions in the solar nebula and on meteorite parent bodies.

Recent advances in ICP-MS have permitted isotope studies of transition metals and other elements with similarly small isotopic mass dispersions. Among the transition metals, Fe is perhaps the most difficult to analyze by ICP-MS because plasma sources are copious producers of argide molecules that interfere with the measurement of iron isotopes. However, the stable isotope behavior of Fe is of special interest because it is a non-refractory major element in meteorites, present in a variety of mineral associations and redox states.

Considerable effort has gone into overcoming the inherent analytical difficulties of measuring Fe using ICP-MS. We recently reported on a technique that achieves argide reduction by operating the plasma source in so-called 'cold' mode. In this presentation, we report results from this ongoing work.

To date, analyses of nine different meteorites, and eight individual Tieschitz (H3) chondrules have been completed, along with a number of measurements of the Hawaiian basalt sample Kil1919. All of the bulk meteorite compositions, which include both chondrites and irons, have identical 56Fe/54Fe to within ~ 0.14 per mil (2 sigma), and are indistinguishable from the composition of the terrestrial basalt. The Tieschitz chondrules, on the other hand, tend to have isotopically light compositions. This could reflect formation from fractionated starting material. Alternatively, Fe condensation, under non-equilibrium conditions can enrich light isotopes. Future work will focus on determining the extent of Fe mass fractionation in chondrules from Tieschitz as well as other chondrites. This growing database will help us to understand the conditions in which chondrules formed, potentially placing stringent constraints on theories of their formation.

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**High Precision Iron Isotope Compositions in Components From the Allende CV3 Meteorite by MC-ICP-MS**

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Four chondrules and one matrix sample of Allende were examined for Fe-isotope fractionation, using multi-collector inductively coupled plasma mass spectrometry (MC-ICPMS). Iron is the most volatile major constituent of chondrules and a recent study [1] suggested that solar system Fe was initially isotopically homogeneous. Thus, any isotopic variation is likely due to mass fractionation during nebular processing.

The chondrule samples were split. One portion was subject to a standard acid dissolution whilst the other was polished, enabling textural and compositional characterisation. Fe, Cu and Zn are separated from the remaining matrix elements [2], removing potential interfering ions from the solution. 100 % elemental recovery (within error) is achieved, ensuring that chromatographic fractionation does not occur [2]. Hydrogen is bled into the collision cell, minimising Ar polyatomic species interferences. Typical precisions of 0.1‰ (2σ) for 54Fe/56Fe ratios are achieved for 75 replicates. Instrumental mass bias is assessed using (1) sample-standard bracketing and (2) doping with Cu.

A variation of 0.8‰/amu is observed, which is approximately 18 times the analytical uncertainty at the 2σ level. Our high precision data show that: (1) Allende chondrules and matrix exhibit clear isotopic variation in iron. (2) δ54Fe values appear to be correlated to the bulk FeO content, with the more iron rich samples enriched in the lighter 54Fe isotope. (3) δ54Fe values appear to be unrelated to texture, and consequently to the temperature of chondrule formation.

Bulk Fe-content may be a proxy for the amount of volatilisation experienced, and volatilisation of Fe in chondrule precursor material has resulted in a residue of the heavier Fe isotopes. Chondrules are known to have often experienced several heating events, and their texture primarily reflects the nature of the last event. Thus, the lack of correlation between the δ54Fe value and chondrule texture suggests that Fe-isotope composition was derived from chondrule precursor material.

[1] Zhu et al. (2001) *Nature* 412, p.311 [2] Mullane et al. (2001) *LPS XXXII*, No.1545.

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**Widespread Evaporation/Condensation Related Cadmium Isotope Fractionation in Chondritic Meteorites**

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