is controversial: either a lava flow-unit or a pyroclastic flow (rheoignimbrite or ignimbrite) has been suggested. The chaotic aspect of the flow, highly fragmented crystals and flow-like texture of the glassy groundmass, suggest an ignimbrite flow; however, the massive and homogeneous aspect of this unit, and the lack of welded blocks, rather suggests a lava flow. Whatever the origin, observed flow banding structures indicates that the BTC emplaced at high temperature. We performed a geochronological (K-Ar; "Cassignol-Gillot" technique) and geochemical study to trace the magmatic evolution of Mt. Amiata, and discuss it in the context of the TMP. Preliminary K-Ar ages show that the BTC emplaced quickly, in less than 10,000 yrs, between 294ka±4ka and 283ka±5ka, covering more than 90km2 and reaching a volume of 18km2. After 15,000 yrs of apparent quiescence, DLC emplaced between 268±5ka and 200±11ka, differing from previous results that restrained this episode at 200±10ka. The final latitic unit erupted at 209 ka±4ka. The erupted products of Mt. Amiata define a shoshonitic sub-alkaline serie, the rocks of the BTC and DLC being trachydacites, while the final lava flows are trachyandesites (latites). They all display Nb-Ta negative anomalies reflecting metasomatic events affecting their sources and/or involvement of a crustal component. Their high Th/Ta (25-27) and La/Nb ratios (> 3) indicate an IAB-type orogenic affinity. Nb/Ta ratios (9-10) are similar to crustal values. Y/Nb ratios >1.2 reflect a source chemically similar to island arc or continental margin basalts. For all these ratios, the final latites display higher values. When plotted in Rb-Yb-Ta-Y-Nb geotectonic discriminating binary diagrams, Mt. Amiata products fall in the field of syn-collision setting, with the nearby Pliocene (5.4 to 2.3 Ma) rhyolites of Roccastrada and San Vincenzo

V32E MCC: 3008 Wednesday 1340h

Frontiers in High-Pressure Research: Earth's Deep Interior I *(joint with GP, MR, DI)*

Presiding: **P C Burnley,** Georgia State University**; S V Sinogeikin,** University of Illinois at Urbana

V32E-01 1340h INVITED

Seismic tomography and mineral physics

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Information from mineral physics is essential in interpretation of results of seismic tomography in order to interpret them in terms of dynamic processes rather than a snapshot of the state of the mantle. On occasion, seismic tomography can provide independent, *in situ*, measurement of certain quantities; this was the case with the early tomographic estimates of $d\ln v_S/d\ln v_P$ to be about 2.0, while the mineral-physics estimate was 1.3. In general, however, interpretation of velocity perturbations in terms of changes in temperature, density or composition requires input from mineral physics. Over the last 20 years there has been significant progress in seismic tomography. Examples are the discovery of the anisotropy of the inner core, the anti-correlation of the bulk-sound and shear velocities in the lower mantle, and the unique anisotropy of the Pacific plate. At this time, some of the most spectacular tomographic results remain an enigma. For example, are the Pacific and African low-velocity mega-plumes an expression of higher temperature, and therefore lighter material, or of different composition, thus perhaps being heavier. Of course, linear combinations of these two end-member interpretations are also possible. In addition to the symbiotic relationship between mineral physics and seismology, there is also an important role for geodynamics, which must show that a model can reproduce the observed results, as well as for geochemistry, which has to verify that all available information is consistent with the geochemical data.

V32E-02 1355h INVITED

Joint Modelling of Seismic, Geodynamic and Mineral Physics Data: Implications for the Origin of 3-D Density and Seismic Velocity Anomalies in the Mantle.

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Models of instantaneous (present-day) mantle dynamics provide strong constraints on the distribution and amplitude of 3-D density anomalies. In recent work [Forte, Mitrovica & Espesset, Phil. Trans., 2002], we developed models of 3-D mantle flow based on high-resolution tomographic models of global seismic shear velocity heterogeneity [e.g., Grand, Phil. Trans., 2002] which reconcile a wide variety of surface manifestations of mantle convection which include global gravity anomalies, plate tectonic motions, dynamic surface topography and the dynamic ellipticity of the core-mantle boundary. These diverse geodynamic observables provide direct constraints on the mantle density anomalies which are the driving force of the convective flow field. These density anomalies may be inferred by carrying out joint inversions of the geodynamic data sets, in which we assume a correlation between mantle density anomalies and the seismic velocity anomalies in a given tomography model. Neither the sign of the correlation (which may be positive or negative), nor the amplitude of the density anomalies is constrained to a-priori values in these inversions but are instead allowed to vary in order to provide optimal fits to the surface geodynamic data sets. The relationship between the geodynamically inferred density anomalies and seismic anomalies, when taken in conjunction with the separate mineral physical constraints on thermal and compositional derivatives [e.g., Karato, 1993; Wang & Weidner, 1996; Stacey, 1998], provide direct insights on the relative importance of thermal and chemical contributions to mantle heterogeneity [e.g., Forte & Mitrovica, Nature, 2001]. We will present the results of new density inversions employing mantle flow models based on the most recent mantle viscosity profiles derived by jointly inverting an updated and enlarged set of glacial isostatic adjustment data and mantle convection data sets [Mitrovica & Forte, 2003]. We have also devised a new and independent test of the origin of mantle heterogeneity by carrying out joint global inversions of seismic and geodynamic data [Grand & Forte, this meeting] assuming different scalings between density and seismic velocity which may be derived from mineral physics data. These hypothesis tests, as well as the direct inversions for mantle density, show a simple positive correlation between seismic shear velocity and density which is in accord with a dominant thermal origin for this heterogeneity.

V32E-03 1410h

Seismic mantle discontinuities and mineral physics

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Seismologists have been successful in measuring Clapeyron slopes for the transition zone discontinuities at 410 and 660 km depths; these are in approximate agreement with phase transitions in olivine. Clapeyron slopes are key to explaining the seismic discontinuities as either manifestations of phase transitions or of other mineral physical processes. Such observations place constraints on the thermal, compositional and physical state of the Earth's mantle and provide critical information able to distinguish between competing hypotheses concerning the upper mantle and transition zone reflectors. Here we extend the measurement of Clapeyron slopes to upper mantle discontinuities, in particular the Lehmann discontinuity at approximately 220 km depth, and seek to interpret the results in terms of mineral physics. We find that the Lehmann discontinuity is characterized by a regionally varying negative seismological Clapeyron slope. Reflections from greater depths (250-350 km) are required to possess a large negative seismological Clapeyron slope. In seeking mineralogical explanations of the Lehmann and X-discontinuities, we can reject hypotheses in disagreement with these observations. Of hypotheses proposed in the literature to account for the Lehmann discontinuity, only a transition in deformation mechanism from dislocation to diffusion creep has the required behavior. In the case of the X-discontinuity we are not aware of mechanisms having the observed characteristics. In addition, we show detailed seismic observations of the weak transition zone discontinuity at 520 km depth. In many regions we have confirmed the existence of a discontinuity at 520 km depth, but there are a number of regions in which we found two discontinuities at about 500 and 560 km depth, an effect which can be interpreted as 'splitting' of the discontinuity. These observations cannot be explained as the single effect of the olivine transition from the β-phase to the γ-phase, and the non-olivine transition from garnet to Ca-rich perovskite needs to be considered as well. Local variations in minor phases containing Fe, Ca and H_2O will probably also be needed to explain the regional variability in the seismic observations. This shows that mantle transition zone is less homogeneous than is generally assumed.

V32E-04 1425h

Generation of pressures exceeding 50 GPa in multianvil apparatus and some applications to lower mantle mineralogy

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We have been working to extend the pressure range available in Kawai-type multianvil apparatus using sintered diamond composites for the second stage anvils. Pressure was evaluated by unit-cell volume changes in some reference materials, based on in situ X-ray diffraction measurements using synchrotron radiation at SPring-8. Pressures to 55 GPa at room temperature has so far been produced in a cell assembly for anvils with TEL=1.5 mm, using the newly installed multi-anvil apparatus (SPEED-MkII) at BL04B1. Pressures greater than this may be available within the capacity of this apparatus by further modifications of the high-pressure cell. Phase transitions and P-V-T relations of some minerals relevant to the mantle and subducted crust lithologies, such as CaSiO3 perovakite, MgAl2O4 calcium ferrite, KAlSi3O8 hollandite, etc., have been successfully studied at pressures to 40 GPa, and temperatures to 2000K, equivalent to depths of 1200 km in the lower mantle, using the in situ X-ray diffraction measurements.

V32E-05 1440h

What do we Really Know About the Elastic Properties of Garnets at Upper Mantle Pressures?

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Garnets are a major constituent of the Earth's upper mantle. Detailed understanding of their elastic properties is essential for interpretation of seismic velocity profiles of the mantle. Garnets exhibit a wide compositional range and the elasticity of garnets have been studied far more extensively than any other mineral group. At ambient pressure, there is good agreement in both individual and aggregate elastic properties among various studies using different experimental techniques. At high pressures, however, there are drastic disagreements (up to 50% or more) in reported pressure derivatives of the bulk and shear modulus for a given composition. The magnitude of this effect completely precludes any assessment of high-pressure compositional effects using the current data set, and introduces considerable uncertainty in interpretation of features such as the transition zone seismic velocity gradient. To address these problems, we have carried out detailed single-crystal elasticity measurements on andradite ($Ca_3Fe_2Si_3O_{12}$), grossular ($Ca_3Al_2Si_3O_{12}$), and almandine-pyrope ($(Fe,Mg)_3Al_2Si_3O_{12}$) garnets to pressures in excess of 11 GPa by Brillouin spectroscopy. In these studies we have paid careful attention to sources of systematic error (e.g., vignetting), compositional heterogeneity, and have maintained strictly hydrostatic conditions in the diamond anvil cell. For the andradite-rich garnet (An98Gr2) we obtain K = 155 GPa, K' = 4.7, G = 90 GPa, and G' = 1.3. For the grossular-rich garnet (Gr87An9Py2Alm2), we obtain K = 165 GPa, K' = 3.8, G = 104 GPa, G' = 1.1. For the almandine-pyrope garnet (Alm72Py20Sp3Gr3An2), we obtain K = 175 GPa, K' = 4.7, G = 96 GPa, G' = 1.4. Compression curves derived from our results are generally consistent with static data under hydrostatic conditions, and the effects of non-hydrostaticity on previous static compression data can be identified. Our results allow us to assess the effects at high pressure of Fe-Al substitution on the octahedral site in andradite-grossular and in combination with earlier Brillouin scattering data for pyrope (Sinogeiken and Bass, 2000), the effect of

Fe-Mg substitution on the dodecahedral site in pyrope-almandine. This new data set allows us to place improved constraints on the effect of chemical variation on seismic wave velocities at upper mantle pressures.

V32E-06 1455h

Deep Recycling of Sedimentary Lithologies in Subduction Zones: Geochemical and Physical Constraints from Phase Equilibria and Synchrotron-Based Multi-Anvil Experiments at 15-25 GPa

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Ocean island basalts (OIBs) provide geochemical evidence for the presence of crustally-derived sedimentary material in the deep mantle plume source region for EM-type OIBs, and global seismic tomography provides us with dramatic images of subducted slabs, presumably carrying a sediment component, penetrating through the transition zone and into the lower mantle, in some cases to the core-mantle boundary. In an effort to better constrain the geochemical effects of deeply recycled sedimentary material in subduction zones, and their role in the petrogenesis of EM-type OIBs, we have undertaken a series of phase equilibria experiments in the multi-anvil apparatus at 10-25 GPa, using natural sediment lithologies as starting materials. The goal of these experiments is to identify the dominant phases in deeply subducted sediments, constrain their P-T stability limits, and to assess their role in crustal recycling and element redistribution in the deep mantle during subduction. The phase equilibria experiments were performed in a 2000-ton Kawai-type apparatus, using tungsten carbide cubes with 3 mm TEL and Cr-doped MgO and zirconia pressure media. A cylindrical lanthanum chromite heater was used, along with short (< 1 mm), thick-walled, pressure-welded gold capsules to minimize thermal gradients and to retain the small amounts of water (< 1 wt%) present in the starting material, and long rundurations (12-48 hours) in order to facilitate future analyses of the dominant phases for key trace elements using the ion microprobe. Our preliminary results at 10-25 GPa indicate that K-hollandite ($KalSi_3O_3$) and stishovite are the primary high-pressure phases in the sediment composition, with subordinate garnet and an as-yet-unidentified (possibly hydrous) Al-silicate phase present as well. These results suggest that K-hollandite is the primary repository for incompatible elements (e.g., La, Ce, Sr, Ba, Rb, etc., and the heat-producing elements K, U and Th) in sedimentary material recycled into the deep mantle via subduction. In-situ synchrotron-based multi-anvil experiments were performed on synthetic, pure K-hollandite at pressures up to 25 GPa to determine the equation of state parameters of this phase into the lower mantle. From these experiments, we derive the bulk modulus at room temperature for K-hollandite, $K_0 = 183(2)$ GPa, and coefficient of thermal expansion, $a_{20.5} = 2.18(3) \times 10^{-5} K^{-1}$. Although the overall buoyancy of deeply subducted metasedimentary lithologies will be determined by the modal proportions of high-pressure phases, the calculated density of K-hollandite under lower mantle conditions is less than that of Mg- or Ca-perovskite, and approximately equal to that of magnesiowustite.

V32E-07 1510h

Elasticity of $MgSiO_3$ Polycrystalline Perovskite by Brillouin Spectroscopy

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Magnesium silicate perovskite is the most abundant mineral phase in the lower mantle of the Earth. Even though it is probably the most studied high-pressure phase, its elastic properties at ambient conditions (bulk, and especially, shear modulus) remain uncertain. We have carried out a Brillouin spectroscopy study of $MgSiO_3$ perovskite to try to resolve discrepancies surrounding its elastic properties. The polycrystalline sample of perovskite was synthesized from pure $MgSiO_3$ glass starting material at SUNY, Stony Brook. The synthesis was performed at 25 GPa and 1873 K in USSA-2000 high-pressure apparatus, with an 8/3 cell assembly and rhenium heater. The perovskite structure was confirmed by X-ray and Raman spectroscopy. The Raman spectroscopy did not reveal any non-perovskite phases in the sample. The Brillouin measurements were performed on samples polished plane-parallel to 30 mkm. The measurements were performed in platelet symmetric scattering geometry, which yields compressional and shear velocities independently of the refractive index of the sample. Despite the polycrystalline nature of the sample, all spectra were of excellent quality, and the measured velocities showed very little variation from run to run. The measured aggregate velocities and elastic moduli differ significantly from those, calculated from single-crystal elastic constants measured earlier by Brillouin spectroscopy. The implications of new data to mantle mineralogy will be discussed.

V32E-08 1525h

Effect of Plasticity on Stress Heterogeneity at High Pressure

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It has become routine to measure the differential strain field in both diamond anvil and multi-anvil cells using synchrotron x-rays. In these experiments, the x-rays pass through the sample along a path perpendicular to the compressive axis of a cylindrical stress field. Then the diffracted x-rays sample the lattice spacings both parallel and perpendicular to the maximum stress. Detection can be by means of a 2-D system such as an imaging plate or a CCD detector with monochromatic x-rays, where the Debye rings are recorded as a function of the azimuthal angle. Then the lattice spacings parallel to the maximum stress axis can be compared with those parallel to minimum stress axis. White x-rays provide the same results with multiple solid state detectors, used in conjunction with a conical slit. These measurements have been possible with the use of x-ray transparent gaskets, usually Be for the diamond cell, and x-ray transparent anvils, such as cubic boron nitride, for the multi-anvil system. Each diffraction line will give rise to a measure of the stress field in the sample, giving stress measures for distinct populations of grains, namely those whose orientations meet the necessary diffraction conditions. If the sample has been compressed and strained elastically, then the Reuss - Voight bounds become the defining relationship among the stress - strain fields of the different populations of grains that are sampled by x-ray diffraction lines. Singh indicates the relationship between the strain field and the average stress field using the parameter, alpha = 1 to indicate a Reuss solid (uniform stress) and alpha = 0 indicating a Voight solid (uniform strain). A value between 0 and 1 indicates a mixed boundary condition solid. However, when the polycrystal is plastically deformed, several important changes occur. First, the x-ray diffraction is only sampling a portion of the total strain field. It does not reflect the plastic portion. Second, the stress in an individual grain is no longer controlled by the elastic properties, but rather by the plastic properties. The Schmidt factor, which represents the ratio of a stress on a dislocation to the stress on the grain, becomes the relevant measure of anisotropy and the stress fields in the different grain populations now evolve to maintain the necessary stress on the dislocations as to enable plastic deformation. The Taylor V Sachs bounds replace the Reuss - Voight bounds. In general, the stress field of the various populations of grains will change radically. Calculations, using a self-consistent polycrystalline model indicate that once plastic deformation has occurred in the sample, it will generally be no longer possible to use the Singh formalism to define the single-crystal elastic properties.

V32F MCC: 3006 Wednesday 1340h

Birth, Growth, and Death of Magmatic Arcs: Comparisons Among Arcs in Different Settings II

Presiding: **S B Mukasa,** University of Michigan; **C Kincaid,** University of Rhode Island

V32F-01 1340h

Spatial and Temporal Variability in the Circulation and Thermal Evolution of the Mantle in Subduction Zones: Insights From 3-D Laboratory Experiments.

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The subduction of oceanic lithosphere plays a key role in plate tectonics, the thermal evolution of the mantle and recycling processes between Earth's interior and surface. The majority of subduction models are two-dimensional (2-D), assuming limited variability in the direction parallel to the trench. Observationally based models increasingly appeal to three-dimensional (3-D) flow associated with trench migration and the sinking of oceanic plates with a translational component of motion (rollback). We report results from laboratory experiments that reveal fundamental differences in 3-D mantle circulation and temperature structure in response to subduction with and without a rollback component. In our experiments the upper mantle is simulated with glucose syrup and the subducting plate is represented with a Phenolic sheet that is forced to sink into the glucose along prescribed trajectories. An array of 40 thermisters embedded within the plate is used to monitor slab surface temperatures (SSTs). We vary the relative magnitude of downdip and translational components of slab motion and also consider cases where the plate steepens with time. Another parameter is the initial thickness of the thermal boundary layer (TBL) beneath the overriding plate. Without rollback motion, flow in the mantle wedge is sluggish, there is no mass flux around the plate, and plate edges heat up faster than plate centers. Rollback subduction drives flow around and beneath the sinking plate, velocities increase within the mantle wedge and are focussed towards the center of the plate and the surface of the plate heats more along the centerline. In addition to lateral variability in flow and mantle temperatures, results highlight temporal variability in SSTs and 3-D mantle flow trajectories associated with the initiation of subduction and variations between periods of predominantly downdip versus rollback sinking.

V32F-02 1355h

Melting due to Buoyant Migration of Water in the Hot Mantle Wedge Above a Subducting Plate

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Water-bearing magma generated at convergent plate boundaries is thought to be due to the release of water carried to depth by the subducting crust and mantle. The objective of our study is to create models of the buoyant upward migration of water-rich fluids from the slab, through the hot mantle wedge, and consequent mantle melting. Fluid in the models is assumed to migrate buoyantly along mineral grain edges with a prescribed melt fraction-grain size-permeability relationship (e.g. Wark et al., 2003). Pressure gradients in the solid mantle flow should be important to melt migration only if the mantle viscosity exceeds about 10^{18} Pa-s. The model results thus far neglect the effect of solid deformation on melt permeability, including the possible effects of the dependence of grain size on stress and the anisotropic permeability created by solid deformation (e.g. Kohlstedt and Zimmerman, 1996). The volume of melt generated by the interaction of water with the mantle is parameterized using results

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