

It is recognized that diffusion of siderophile elements in the metal phase could be an important rate-limiting factor in partitioning behavior. These preliminary results will lead to a more comprehensive understanding of siderophile diffusion in iron-rich metal and could help in placing important time constraints on element partitioning and possibly on models of core formation. It could also aid in understanding the siderophile element distribution observed in nature, in both terrestrial and extra-terrestrial materials.

## V52C-1302 1330h POSTER

### Re-Os and Pt-Os Isotopic Systematics of 3.81 Ga Metamorphosed Pillow Basalts and Layered Mafic/Ultramafic Units in the Isua Supracrustals Belt (W Greenland) and Adjoining Gneiss Areas.

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Re-Os isotopic data from basalts formed at different times in Earths evolution yield a fairly clear picture of how upper mantle magma sources have evolved through time. However, significant uncertainty remains with regard to mantle evolution in the Pt-Os system. Because of the different siderophile/chalcophile properties of daughter and parents, these two isotope systems provide sensitive information about mantle processes involving metal-silicate or sulfide-silicate reactions. The presence of coupled enrichments in <sup>186</sup>Os/<sup>188</sup>Os and <sup>187</sup>Os/<sup>188</sup>Os in some mantle-derived materials reflect long-term elevation of Pt/Os and Re/Os relative to the primitive upper mantle. In one scenario, such coupled enrichments are thought to derive from interaction between outer core and lower mantle material that subsequently is transported to the upper mantle by deep-rooted plume systems. Within the framework of this model, existing data from young (recent) as well as ancient (mid to late Archean) plume-derived magmas imply that crystallization of the inner core is likely to have happened fast and to have been completed already in the Hadean period. In order to precisely discern different core crystallization schemes, it is of vital importance to obtain coupled Os isotopic data on very early Archean mantle-derived rocks.

Re-Os isotope data of the least altered pillow basalts from the NE section of the Isua Supracrustals Belt (ISB; W Greenland) yield an average initial <sup>187</sup>Os/<sup>188</sup>Os ratio of  $0.1042 \pm 0.0008$  ( $2\sigma$ ;  $n=7$ ) at 3.81 Ga, which is the minimum extrusion age of these basalts. This corresponds to a  $\gamma$  Os[T=3.81 Ga] value of  $+3.4 \pm 0.8$ , which is broadly consistent with a value of  $+1.3 \pm 2.5$  for chromites from layered mafic/ultramafic units 20 km to the S of the ISB and from the ISB itself (Frei and Jensen, in press). These data suggest that parts of the early Archean mantle was characterized by a slightly suprachondritic <sup>187</sup>Os/<sup>188</sup>Os ratio. Two high-precision unspiked Os isotopic analyses of chromites of the units S of the ISB yielded suprachondritic <sup>186</sup>Os/<sup>188</sup>Os ratios of  $0.119838 \pm 0.00007$  ( $2\sigma_{pop}$ ) and  $0.119837 \pm 0.000008$  ( $2\sigma_{pop}$ ). In situ correction of these ratios with appropriately obtained Pt and Os concentrations from spiked aliquots lead to consistent slightly suprachondritic <sup>186</sup>Os/<sup>188</sup>Os ratios of  $0.119831 \pm 0.000008$  at 3.81 Ga, which at this stage cannot discriminate between a chondritic (or primitive upper) mantle evolution and inner core crystallization models that involve rapid, delayed, or constant growth schemes along with their possible effects on the PGE budget of the early Earths mantle.

Frei, R., and Kastbjerg Jensen, B., in press, *Chemical Geology*.

## V52D MCC: 106 Friday 1330h

### Evolution of the Igneous Rocks 2002 Edition II: Experimental Results at High Pressure, Petrogenesis, and the Physics of the Earth (joint with OS, P)

Presiding: M Ghiroso, University of Washington; G Bergantz, University of Washington

## V52D-01 1330h INVITED

### Mantle Melting Controls on Liquid Lines of Descent in Magmatic Systems

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Compositional variations in basaltic rock suites preserve information on the conditions of high-pressure mantle melting and low-pressure fractional crystallization (e.g. pressure, temperature and volatile content). The significance of compositional variations in igneous rock series was of considerable interest to N.L. Bowen, and the famous Bowen Fenner controversy was a protracted discussion that concerned the possibility of the existence of multiple liquid lines of descent (LLD) in magmatic systems. Miyashiro (1974) introduced the FeO\*/MgO vs. SiO<sub>2</sub> diagram and used it to demonstrate the existence of more than one LLD in arc and tholeiitic suites. In detail, Miyashiro recognized that there was not a single calc-alkaline or tholeiitic suite, but that a continuum existed from tholeiitic to calc-alkaline. Each arc has its own distinctive signature produced by an interplay of varying melting and crystallization conditions. Subsequent experimental work (Sisson and Grove, 1993) demonstrated that the different LLDs were caused by variable H<sub>2</sub>O contents (calc-alkaline = hydrous, tholeiitic = anhydrous). Sisson and Grove (1993) found that the calc-alkaline trends characteristic of a large volume of the Earths current output of arc magmatism represent fractional crystallization that occurs at high magmatic H<sub>2</sub>O contents (4 to 6 wt. %). These hydrous fractional crystallization trends are ones expected to result when the starting point for fractionation is an H<sub>2</sub>O -rich, high pressure mantle melt saturated with oliv + opx + cpx + spinel or oliv + opx + cpx + garnet. A rarer calc-alkaline differentiation trend exemplified by lavas from the Mt. Shasta region, USA, Adak, Aleutians and Setouchi Belt, Japan lie in a portion of the diagram that is not as commonly represented by modern arc environments. These important magmas, plot in the low FeO\*/MgO and high SiO<sub>2</sub> portion of the Miyashiro diagram. This unique compositional signature is imparted by unusually high degrees of melting (oliv + opx saturated) of shallow, hot mantle at the top of the mantle wedge, fluxed by an H<sub>2</sub>O -rich and trace element-rich fluid component released by dehydration of the subducting ocean lithosphere. The co-existence of tholeiitic and calc-alkaline trends in many arc volcanoes (e.g. Hakone region, Japan and the Nasu volcanic zone, northeast Japan) indicates variable inputs of H<sub>2</sub>O in the mantle melting process.

## V52D-02 1345h

### Partial Melting of a Heterogeneous Mantle - Progress and Prospects

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Whereas Bowen concentrated on the differentiation of basalt, much effort in petrology is now focussed on the origin of basalt. Simple models for basalt petrogenesis are well-developed, but one area of active research is the role of petrologic heterogeneity in the source. This remains a vexing problem in part because of poor constraints on the effect of lithologic heterogeneities on melting relations and the distribution and length scales

of heterogeneities, which likely have a critical effect on their role.

Pyroxenites are one (but not the only) likely type of heterogeneity in basalt source regions. Recent experimental studies have provided considerable constraints on the melting behavior of pyroxenites. Compositions similar to recycled oceanic crust melt at much lower temperatures than peridotite, resulting in contributions to basalt genesis much greater than their mantle abundance. Just 1-2% such materials in MORB source regions could account for 10-25% of the volume of crust created and could provide 10-60% of highly incompatible elements such as U. However, partial melts of recycled lithologies are far from equilibrium with peridotite, and so they probably have complex interactions with the predominant mantle lithology, possibly involving reaction, freezing, and remelting.

Oceanic island lavas with strong geochemical indications of recycled crust generally are strongly undersaturated, and this is not petrologically consistent with partial melting of quartz tholeiitic protoliths. Mg-rich garnet pyroxenites, perhaps derived from crust-peridotite hybridization, do produce strongly undersaturated liquids, though the temperatures required to form partial melts of these lithologies may be unreasonably high. Alternatively, carbonated pyroxenites and peridotites may be plausible sources of OIB magmas, but detailed partial melting studies needed to test these hypotheses are not yet available.

Field exposures and modelling of convective remelting of crust suggest that many pyroxenites in basalt source regions could have widths of less than a meter, and it is unclear how (if at all) melting and melt extraction from such bodies imparts petrologically and geochemically distinct signatures to aggregated basalts. Perhaps larger bodies play an important role. On the other hand, the preferential melting of small fertile domains likely has a profound influence on the physical properties of partially molten regions and on the melt extraction process, but this remains largely unexplored.

## V52D-03 1400h INVITED

### Evolution of MORB Generation Models

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Early debate on MORB petrogenesis focused on a low-pressure (<1.1 GPa, basaltic primary melts) vs. high-pressure (1.5-3.0 GPa, picritic primary melts) origin. This unresolved issue was later supplanted by the widely accepted model of Klein and Langmuir (1987) involving polybaric melting columns of varying length, with the initial pressure of melting ranging from 1.2 to 4.0 GPa (Langmuir *et al.*, 1992). The KL87 and other models (e.g. McKenzie and Bickle, 1988) rely on phase relations free of H<sub>2</sub>O and CO<sub>2</sub>. For H<sub>2</sub>O, this appears to be a good approximation at all pressures because of the low H<sub>2</sub>O concentration in the MORB source (~90-230 ppm) and the probability that these concentrations are less than the bulk solubility of H<sub>2</sub>O in nominally anhydrous mantle phases. At low pressures, CO<sub>2</sub> can also be neglected, to first order, because of its low solubility in melts. However, at P>~2.3 GPa, CO<sub>2</sub> dramatically modifies solidus phase relations and abruptly lowers solidus temperatures by >300°C (e.g. Falloon and Green, 1989; Dalton and Presnall, 1998). Presnall *et al.* (2002) addressed the issue of CO<sub>2</sub> by using phase relations in the CaO-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>-Na<sub>2</sub>O-FeO (CMASNF) system at 1-1.5 GPa (plagioclase/spinel lherzolite transition interval) to model the major-element characteristics of MORBs and phase relations in the CaO-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>-CO<sub>2</sub> system to produce very small amounts of carbonatitic melts at 2.3-7 GPa, which would mix with the more shallow melts and produce some of the trace element signatures. Asimow *et al.* (1995, 2001) showed the importance of near-isentropic melting and found that strong variations in isentropic melt productivity occur as a function of pressure. Although Asimow *et al.* found from MELTS calculations that melting is suppressed by isentropic decompression through the plagioclase/spinel lherzolite transition, Presnall *et al.* showed that the CMASNF experimental data require enhanced melting. KL87 explained the global inverse correlation of Fe(8) with Na(8) by large variations of potential temperature (1260-1530°C) in a relatively homogeneous peridotitic mantle, but Presnall *et al.* explained them by a much narrower range of potential temperatures (average ~1260°C) in a heterogeneous peridotitic mantle. Thus, the original disagreement over a low- vs. high-pressure origin for primitive MORBs has been transformed into a debate over the magnitude of potential temperature variations and the role of mantle heterogeneity. The outcome of this debate has important implications for temperature variations in the Earth's interior and for geodynamics.

## V52D-04 1415h INVITED

### A Skirmishing Against our Adversaries, the Rocks: The Significance of Multiple Saturation Points in the Context of Polybaric Near-fractional Melting

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In the preface to *The evolution of the igneous rocks*, Bowen justifies the use of "deduced diagrams" for problems where experimental information is unavailable or incomplete as the "necessary foundation for a more serious campaign of experimental attack, concentrated upon those points where progress is most likely to be made." The same philosophy underlies efforts to develop thermodynamically sound models of magmatic phenomena for interpolation and extrapolation among experimental data, and for testing of hypotheses too complex for direct experimental investigation. In particular, modern ideas of basalt petrogenesis, influenced by physical reasoning about the melting environment as well as a variety of geochemical arguments, postulate a process approximated by polybaric near-fractional melting along an adiabatic path that defies our ability to produce a meaningful primary basalt in a single experiment. The complexity of the model that now exists in the mind of the mantle petrologist has rendered moot the lengthy debate of the 1960's to 1980's about whether an experimental liquid can be found that is parental to primitive mid-ocean ridge basalt (MORB) glasses. But the observation remains that there exist liquids parental to primitive MORB with reasonable Mg/Fe ratios that are four-phase saturated or nearly so (either experimentally or in normative projections). If primitive MORB liquids are really mixtures of liquids last equilibrated with mantle assemblages over a considerable range of conditions, what is the significance of these observations?

With pMELTS, I can generate a set of saturation curves for each solid in the liquid of interest (metastable with respect to other solid phases); this type of diagram avoids the complexities of reaction relations and crystallization paths that occur in determining stable inverse-method phase diagrams. I show, using pMELTS for both the forward and inverse calculation for consistency, that aggregated liquids from polybaric adiabatic fractional melting processes may in fact approach four-phase saturation (olivine-orthopyroxene-clinopyroxene-spinel) to within 5 °C (and olivine-opx-cpx co-saturation to within 1 °C), which is finer than the resolution of any plausible experimental effort to determine the phase relations of a given liquid composition. Slight differences in the fractionation correction of a measured composition, such as one might make in testing the hypothesis that a given liquid is multiply saturated, easily bring the four saturation curves even closer to one another. These exercises show that, insofar as pMELTS provides an internally consistent representation of phase relations, near-multiple saturation points can occur in mixed liquids and may have no direct petrogenetic significance.

The model of perfect fractional melt transport is itself physically questionable, and a more reasonable view is that most of the liquid reaching the oceanic crust has migrated through high flux channels free of pyroxenes and hence only equilibrated with olivine and spinel beyond a certain point. In such a mode the coincidence of a primitive MORB with a multiply saturated liquid in projection from olivine might be taken to identify the location where melt was channeled, but MELTS calculations show that a model in which channels of all sizes and fluxes develop, and in which pyroxenes are exhausted over a range of pressures, can give the same result with a multiple saturation point of no particular significance.

## V52D-05 1430h

### Partial Melting of Ordinary Chondrite: Implications for Siderophile Behavior During Early Differentiation

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Core formation scenarios in growing planetesimals include a variety of possible physical mechanisms such as segregation in a solid or partially molten silicate body or whether or not the body was actively deforming. The resulting geochemical composition of the metal and silicate phases will also be a function of bulk composition, percent of metal melted and oxygen fugacity. To explore the relationship between physical core formation scenarios and geochemistry, deformation experiments have been conducted on a H6 ordinary chondrite at different stages of melting. Deformation experiments provide a dynamic component that allows liquid metal to segregate from solid silicate, or from matrices containing various amounts of silicate melt. Geochemical analyses of metal quench in several experimental charges and on metal grains in the Kernouve

H6 starting material have been performed by LA-ICP-MS (Humayun & Campbell, *EPSL*, 2002; Rushmer et al., *Geochim. Cosmochim. Acta*, Goldschmidt Conf. Abs., 2002). Below the silicate solidus (KM-10, 1.0 GPa, 925 °C,  $1 \times 10^{-5} \text{ s}^{-1}$ ), analyses of compatible (Re, Os) and incompatible (Pd, Au) siderophiles in residual, strained Fe-Ni metal and unmodified metal show little variation. These data suggest even though metamorphosed, siderophile abundances are not strongly modified by shearing. At higher temperatures, (KM-17, 1.2 GPa, 940 °C,  $10^{-6} \text{ s}^{-1}$ ) data from metal quench representing early formed liquid (S-rich and possibly O-rich) and of residual Fe-Ni metal have been plotted on a Fe, H-chondrite normalized plot with starting Kernouve metal and bulk H4-6 metal compositions. The quench metal resembles liquid, being depleted in compatible siderophiles, e.g., Re, Os, Ir, and enriched in Ni, Pd. Residual metal mirrors the quench metal and is enriched in compatible elements and depleted in the incompatible when compared with bulk H metal. Ga and Ge show slight fractionation. Ga, Ge, Co and Ir vs. Ni plots show quench metal compositions are similar to natural IIE iron meteorites, providing some support for the hypothesis that these irons come from an H-chondrite like precursor. Partitioning data collected from these charges also suggest deformation may play an important role in enhancing kinetics during partial melting.

## V52D-06 1445h

### The Minimum Potential Temperature of the Hawaiian Mantle is About 1420 °C

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Picritic glasses found in turbidite sands near the submarine part of Kilauea's East Rift Zone contain up to 15 wt.% MgO and are the most magnesian Hawaiian volcanic glasses reported to date (Clague et al., 1991, 1995). They have olivine phenocrysts as magnesian as Fo<sub>90</sub>, and when their compositions are plotted together on normative diagrams, they form a distinct olivine fractionation trend. Melt geothermometers indicate that the eruption temperatures of the picrite magmas were as high as about 1320 °C. On the assumption that these glasses represent primary melt compositions that coexisted with a hercynite phase assemblage, the CMASNF geothermometer (Gudfinnsson and Presnall, 2001) yields a maximum temperature of generation of about 1480 °C, which corresponds roughly to a pressure of 2.5 GPa. This assumes that the melts were essentially free of H<sub>2</sub>O and CO<sub>2</sub>. However, both of these volatile components have the potential to lower significantly the solidus temperatures of mantle peridotite and alter the chemistry of primary melts. The approximately 0.4 wt.% H<sub>2</sub>O measured in the Hawaiian picrite glasses is probably below the saturation limit for H<sub>2</sub>O, and can be assumed to be close to the original H<sub>2</sub>O content of the picrite melts. The measured amount of CO<sub>2</sub> in the glasses is low as most CO<sub>2</sub> was probably lost by degassing at the time of eruption. The CO<sub>2</sub> content of primary magmas at Kilauea has been determined as 0.7 wt.% (Gerlach and Graeber, 1985; Gerlach et al., 2001). Whereas the addition of CO<sub>2</sub> tends to shift melts derived from peridotite toward greater alkalinity, the addition of H<sub>2</sub>O tends to move liquids toward the quartz normative side of the basalt tetrahedron. Results of CO<sub>2</sub>- and H<sub>2</sub>O-bearing melting experiments indicate that with the low amounts of H<sub>2</sub>O and CO<sub>2</sub> expected in the primary melts of Kilauea their effect on the position of phase boundaries will be small. From phase relations involving melt in equilibrium with a garnet hercynite phase assemblage in the system CaO-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>-CO<sub>2</sub>, we estimate that the solidus temperature of mantle hercynite is lowered by about 10 °C for each 1 wt.% increase in the amount of CO<sub>2</sub> in the melt. The effect of H<sub>2</sub>O is to lower the solidus temperature about 40 °C for each 1 wt.% increase in this component. This yields a minimum potential temperature (T<sub>p</sub>) for Hawaii of about 1420 °C, which is consistent with data indicating at most only a very slight increase of heat flow at Hawaii relative to Pacific crust of the same age (Stein and Stein, 1993). This T<sub>p</sub> is 140-160 °C higher than petrological estimates of the average T<sub>p</sub> of the MORB source (McKenzie and Bickle, 1988; Presnall et al., 2002). Our data do not constrain the upper limit of T<sub>p</sub> at Hawaii.

## V52D-07 1520h

### Let's get physical: fluid-mechanically consistent models for melt and chemical transport (that seem to work)

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A fundamental goal of igneous petrology and geochemistry is to understand how to use observable chemical variability to make useful inferences about both properties and processes occurring in the Earth. The transport of melt from source to the surface should be crucial for controlling variability because it affects both the mixing of partial melts and the interactions between melts and their solid residues. To understand the relationship between observable chemistry and melt dynamics, however, requires a theory that explicitly includes the coupled fluid-solid mechanics of magma transport.

We review progress made over the past decade toward developing geochemical models that can explain a wide range of observations within a single, physically consistent theory. We emphasize recent models for reactive flow in *compactible* media that were developed to explain the organization of mantle plumbing systems and "replacive dunites" observed in ophiolites. These models show that reactive melt transport in a solubility gradient leads to networks of high porosity channels separated by low porosity compacted regions. These models have been extended to explore the response of stable and short-lived radiogenic trace elements (U-series) to channeled melt transport. We calculate synthetic data-sets that can be compared directly to observations and show they are consistent with distributions of melt compositions seen in melt-inclusion studies, suites of mid-ocean ridge basalts, and residual mantle peridotites dredged from the ridges and sampled in ophiolites.

Surprisingly, observations that have been difficult to understand such as the extreme variability of olivine hosted melt-inclusions at the hand-sample scale are reproduced by these models even from a homogeneous source. The key result is that slow, laminar flow in a channeled system can produce and *preserve* large chemical variability on the scale of the channels (~1-100m). These models not only provide an explanation for melt inclusion variability but are also consistent with the depletion of abyssal peridotites and correlations seen in U-series studies that have been difficult to explain with traditional chemical models. These models suggest that melt transport is not a homogenizing process but a source of variability that may be responsible for many of the observations in mantle derived rocks. We discuss future challenges for developing a fully physically consistent theory of open system igneous petrology.

## V52D-08 1535h

### Quantitative Modeling of Melt Infiltration in Porous Rock

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Ongoing studies in numerical models of crystallization and compaction behavior in layered intrusions by our group have led to a need to incorporate more realistic silicate crystallization behavior. A quantitative model for liquid-mineral equilibria with one-dimensional transport equations has been developed for modeling magmatic infiltration-reaction (IR) phenomenon. The liquid-mineral equilibria part of the IRIDIUM program is based on the MELTS software algorithm of Ghorso and coworkers and includes trace element modeling. The IRIDIUM program has both general and compaction-driven transport equations.

The program has been used to model compaction in the Holyoke flood basalt flow. For a crystal-liquid mush that is cooling from both the top and the bottom, the compaction is qualitatively different in the upper and lower parts of the flow. The solid fraction in the lower part increases because of concurrent compaction and solidification. In contrast, cooling from the upper boundary results in an increase in viscosity and a decrease in permeability toward the top. This causes the velocity of the solid matrix to increase downward and the upper part to undergo dilation of the solid matrix. The result is an S shaped profile for compatible elements, and an inverse profile for incompatible elements. The region of modeled maximum dilation matches the location of segregation sheets in the Holyoke flow. Discrepancy between observed deformation as calculated from textural deformation of plagioclase chain networks versus compositional profiles in both observed and model results suggest some crystal accumulation and/or compaction occurred prior to the formation of the plagioclase chains.

V52D-09 1550h INVITED

**Melt Distribution and Magma Plumbing Beneath Ridges**

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Efforts to image magmatic systems beneath oceanic ridges focus on several broad issues: The geometry of mantle flow and the distribution of melt in the mantle; the structure of crustal magma bodies; and the nature of the plumbing system that connects the mantle source region with sub-crustal and crustal reservoirs. To address these issues, a variety of geologic settings are studied that differ markedly from one another in terms of spreading rate, magma flux, and the near-axis thickness of the lithosphere. A review of the available results provides insight to the relations between geologic setting and the subsurface structure of magmatic systems.

Where the near-axis lithosphere is both thin and of uniform thickness along the ridge it is apparent that the organization of volcanic features is closely related to the deeper roots of magmatism. This is most evident at the fast-spreading East Pacific Rise, where we have been able to correlate variations in axial depth, seafloor subsidence rates, seamount distribution, morphologic segmentation of rise axis features and hydrothermal venting with the seismic signatures of melt retention at mantle depths. At this end-member of volcanic activity – located where the lithosphere is nearly absent – surface features inherit characteristics of scale from melt transport phenomena originating in the mantle. Seismic constraints on what governs this organization are thus far equivocal, providing a challenge for integrating geophysical results with other data and models.

In contrast, where the near-axis lithosphere is relatively thick and variable, such as the Mid-Atlantic Ridge, volcanic features are less directly related to melt transport processes originating in the mantle. At the regional scale the geometry of the plate boundary influences the thermal structure of the melting column, thus enhancing melt production beneath the relatively thin lithosphere at segment centers. At the local scale, tomographic images and the distribution of axial seismicity indicate that a melt supply originally focused toward a segment center may be redistributed along axis by lithospheric stresses. At the other end-member of ridge volcanic systems – located where the lithosphere is thick and variable – surface features inherit their characteristics from a combination of mantle and lithospheric processes.

The challenges to understanding further the seismic and physical structure of magmatic systems are several: We are just beginning to grapple with the competing effects of seismic anisotropy – induced by crystal texture or melt topology – and heterogeneity. As expected our estimates of physical properties (e.g., melt fraction) are dependent on our knowledge of seismic anisotropy and its causes. Regions of thick and variable crust pose persistent challenges to imaging, requiring the design of novel experiments or new methods capable of resolving lower crustal structure. Few seismic studies of magnetically active regions utilize waveform information, in part because of the degree and scale of heterogeneity and the resulting complexity of the wavefield. Lastly, and particularly promising, seismic data needs to be used more frequently to test directly the predictions of geodynamic models.

V52D-10 1605h INVITED

**Physical effects of mantle melting beneath western U.S.**

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From a geophysical point of view, the creation and segregation of mantle basaltic melt is important seismically and geodynamically.

Seismically, small amounts of partial melt reduces P and (especially) S velocities by great amounts (relative to common belief). Thus imaged velocity variations at depths of 100-200 km may be caused by small (<1%) melt fractions. Beneath the Yellowstone swell, we have seismic evidence for partial melt to about 200 km depth under the hotspot track, and basalt-depleted residuum under the swell away from the track. We also have seismic evidence for large volumes of basalt emplaced at the base of the crust and in the mid crust beneath the hotspot track. Beneath the southern Rocky Mountains we have seismic evidence for partial melt extending to about 200 km depth within what is thought to be Precambrian North America lithosphere modified during the Laramide orogeny.

Geodynamically, the residuum created by basalt removal can have important geodynamic effects. In particular, because the residuum is relatively buoyant and viscous, it has the long-term effect of making and stabilizing the lithosphere, causing uplift, and controlling asthenosphere flow (e.g., the location of upwelling and hence melting). All these effects are thought to be represented in Yellowstone swell structure and behavior.

V52D-11 1620h

**The (generally) Glassy Rocks Revisited: Deciphering The Scales of Open and In-situ Processes From Styles of Compositional Zoning in Volcanic Rocks**George W Bergantz<sup>1</sup> (bergantz@u.washington.edu)Olivier Bachmann<sup>1</sup> (bachmann@ess.washington.edu)<sup>1</sup>Dept. Earth Space Sciences, Box 351310 University of Washington, Seattle, WA 98195, United States

N.L. Bowen clearly understood the importance of 'glassy' rocks as those, "... of which we can say with complete confidence that they correspond in composition to a liquid." (Chap. VIII, The Evolution of Igneous Rocks). He also understood that the compositional clustering of broadly granitic compositions presents an inherent ambiguity as to whether one arrived there coming up or down in temperature (Hayden Medal address, 1953). Work since Bowen's life reveals that both in-situ and open system behavior are fundamental parts of the evolution of a magmatic system, but the processes by which magmas differentiate and interact, as well as the time scales involved, remain poorly known.

Erupted rocks show different styles of compositional zoning (see Hildreth, 1981 for a classification), which are thought to arise from (1) stratification in magma chambers due to in-situ differentiation, and/or (2) encounter of unrelated magma batches shortly prior to eruption. When combined with estimates of residence times, the style of compositional zoning emerges as a previously unused constraint to decipher magmatic processes in the upper crust. For example, a silicic cap generated in-situ can be an ephemeral feature that may only form during a period of significant rheological contrast between the forming cap and the dominant volume. Formation of a silicic cap may also require the absence of convection in the dominant volume, in order to prevent re-assimilation of the cap. Conversely, near-linear gradients in trace elements, isotopes and temperature observed in high-SiO<sub>2</sub> rhyolites do not preclude convection of the whole layer. These results suggest that the popular notion of sidewall convective fractionation leading to a cap over a dominant volume of low-crystallinity may need reevaluation. We will detail alternative hypotheses for the origins of a cap, and more generally in-situ stratification, that are in agreement with repose times, cooling rates and the compositions of co-eruptive sequences. Two of these are the 'rhyolite rain' and volatile over-pressure models. We will also illustrate the conditions by which open-system processes can lead to a persistent stratification, why the largest known pyroclastic deposits (Monotonous Intermediates) are characterized by an absence of gradients in the eruptive products, but a bewildering complexity in textures and crystal zoning, and why plutons often fail to display the extent of stratification seen in volcanic sequences.

Ref: Hildreth, W., (1981), Gradients in silicic magma chambers: Implications for lithospheric magmatism: Journal of Geophysical Research, v.86, p.10,153-10,192.

V52D-12 1635h

**The Glassy Rocks: Quantifying Petrogenesis Via Melt Physics**

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In "The Evolution of the Igneous Rocks", Norman Levi Bowen dedicated a small but succinct chapter to "The Glassy Rocks". His principle points involved the value of variation diagrams from glassy sample sets, their value as proof of liquid origin of igneous compositions, and the unavoidable loss of volatiles during their petrogenesis. In that chapter, and also quantified from his 1934 AGU abstract(!), it seems clear that Bowen was aware of the fundamental nature of igneous glasses as supercooled liquids and of the wide range of glassforming ability represented by the range of chemical composition of igneous rocks. With that insight the principles for the evaluation and quantification of the role of the glassy state in preserving evidence of petrogenetic and volcanic processes had a reasonable starting point for investigation. Nevertheless the significance of melt physics in particular for the quantification of the glassforming process in an igneous context was not vigorously pursued with any significant degree of success until some 50 years after the book. In the meantime, quantification of the glassy state had reached a stage where experimental and predictive methods for quantification of the final petrogenetic stages of vitrophyric rocks was overdue. Today we are in the favorable position that predictive models for many of the most relevant melt properties either exist, or will be within our grasp in the next decade. Similarly, quantification of the glassforming process is being pursued with considerable predictive success. The former allows petrogenetic models of all igneous rocks to

be accompanied by increasingly reliable melt physical constraints whereas the latter affords a quantification of the partitioning of liquid and solid values of thermodynamic properties for melts during the cooling of glassy rocks, as well as all other occurrences of glass in rocks (e.g. melt inclusions, glassy rinds, etc.) Further, such quantification has led to 1) a profound improvement in the interpretation of experimental petrology and geochemistry, and 2) the remarkable conclusion that the glass transition may lie at the heart of explosive volcanism. I speculate that the spirit of this utterly physico-chemical approach to the molten and glassy states in igneous petrogenesis would have greatly appealed to the father of the physico-chemical approach to petrology itself - Norman Levi Bowen.

V52D-13 1650h

**Volatile Constituents and Vapor Saturation: Integrating Petrologic and Remote Sensing Perspectives to Understand Magmatic Volatile Budgets**

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Over the past 25 years there has been a growing body of evidence based on petrologic, remote sensing, and volcanic gas data that andesitic, dacitic, and rhyolitic magmas in crustal reservoirs are saturated with a multicomponent C-O-H-S vapor phase before eruption. A key piece of evidence for magmatic vapor saturation is the excess S problem: the common observation that much more S is released by explosive eruptions than was originally dissolved in the erupted volume of silicate melt. If all of the excess S is derived from a magmatic vapor phase, then intermediate to silicic magmas must commonly contain several wt% exsolved vapor prior to eruption. The large amounts of volatiles implied by these estimates suggest that exsolved vapor accumulates in the apical regions of magma bodies during repose periods between eruptions. Isotopic studies of S and CO<sub>2</sub> in intermediate to silicic magmatic systems show that these volatiles are largely mantle-derived and are not dominantly related to crustal assimilation. The ultimate source of S and CO<sub>2</sub> in these systems must therefore be from mafic magma because it is well established that silicic magma reservoirs are created and sustained through long-term replenishment by mantle-derived basaltic magma during inter-eruption repose periods. Andesitic, dacitic, and rhyolitic magmas in crustal reservoirs are probably vapor saturated due to recharge and underplating by vapor-saturated basaltic magma. In this regard, vapor saturation in intermediate to silicic magmas can be viewed as a consequence of the relatively high CO<sub>2</sub> concentrations of basaltic magmas coupled with relatively low CO<sub>2</sub> solubility in silicate melts at crustal pressures. Understanding budgets of the major volatiles requires integrating remote sensing and volcanic gas data on fluxes of CO<sub>2</sub>, SO<sub>2</sub>, and H<sub>2</sub>S from volcanoes with petrologic data on temperature, pressure, oxygen fugacity, and dissolved volatiles in both differentiated magma stored in crustal reservoirs and mafic magma recharging these systems. Comparison of repose times, eruptive volumes, and basaltic magma supply rates for a spectrum of volcanic systems suggests that the flux of S, CO<sub>2</sub> and H<sub>2</sub>O from explosive eruptions is approximately balanced by the mantle-derived supply rate of these volatiles provided by mafic recharge into the crust. The importance of mafic recharge in supplying volatiles is exemplified by cinder cones surrounding Popocatepetel volcano in central Mexico. Olivine-hosted melt inclusions from these cones contain 1000-6000 ppm S, indicating that mafic magma recharging into the Popo system provides an abundant source of S that may explain the very large SO<sub>2</sub> emissions from the current eruption.

V61A MCC: Hall C Saturday 0830h

**Evolution of the Igneous Rocks 2002 Edition III Posters (joint with OS, P)****Presiding:** B R Edwards, Dickinson College; H Guetschow, University of Washington

V61A-1342 0830h POSTER

**A new approach to thermodynamic modelling of peridotite melting in synthetic and natural systems**Paula May Smith<sup>1</sup> (psmith@esc.cam.ac.uk)