V42H MCC: 3008 Thursday 1600h

Melting of the Mantle and Formation of Basalt Magmas: Experiments, Field Studies, and Models III *(joint with OS)*

Presiding: **G Sen,** Florida International University**; M Walter,** Institute for Study of the Earth's Interior, Okayama University

V42H-01 1600h INVITED

The Morphology and Composition of Groundmass Spinel in Kimberlite

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Chromite and chromian spinel are a common, but very minor (<1%), early phase found in the groundmass of both basalt and kimberlite. The spinel is often zoned from a chromite core to a magnetite rim depending on the original melt composition, cooling rate and the nucleation of surrounding minerals. The primary silicate minerals in many kimberlites are often destroyed by late-stage alteration leaving spinel as one of the few minerals that retains morphological and chemical evidence of the progression from an early magmatic stage to a late-stage subsolidus alteration. The composition of basaltic and kimberlitic spinel can be compared by plotting FE2#(Fe2/(Fe2+Mg)) versus FE3#(Fe3/(Fe3+Al+Cr)). The primary chromite in both basalt and kimberlite usually have FE3# <0.15 and FE2# = 0.2-0.6 whereas the late stage magnetite for both rock types is high in FE3# and FE2#. Most spinel in basalts show a consistent trend of increasing FE2# with increasing FE3# whereas kimberlitic spinel can show a variety of different trends of increasing FE3# at a constant, or even decreasing, FE2#. Evidence will be presented that suggests that trends of FE3# vs. FE2# of spinel in various kimberlites may reflect variations in cooling rate of the kimberlite. It is useful to consider the morphology and compositional variation of spinel in kimberlite in terms of four stages: 1) High Cr2O3, TiO2<1 wt.%, FE2# < 0.5, FE3# <0.1. 2) High Cr2O3, TiO2 1-3 wt.%, FE2# <0.5, FE3# <0.1. 3) Cr2O3 1-50wt.%, TiO2 3-20 wt.%, FE2# 0.4-0.9, FE3# 0.1-0.9. 4) Cr2O3 <1 wt.%, TiO2 <2 wt.%, FE2# >0.8, FE3#>0.9 . The chromite of stage 1 reflects the bulk melt composition well before intrusion of the kimberlite whereas stage 2 is thought to reflect the relatively rapid and local change in melt composition during intrusion . Stage 3 reflects a very large change in composition due to very local crystallization of the groundmass minerals and diffusion-controlled crystallization that gives rise to atoll spinels. Stage 4 reflects late subsolidus crystallization of magnetite from alteration and oxidation of silicates. The compositional boundary between stages is arbitrary and rarely are all four stages found in the same kimberlite. The varied morphology of spinel and the zoning of spinel in kimberlites reflect not only changes in the bulk melt compostion but on the relative cooling rates of kimberlites. The complex growth forms of chromite found in some MORB glasses and atoll chromites found in some kimberlites reflects relatively rapid growth rates from a melt. Thus the composition and morphology of spinel may be useful in estimating relative cooling rates and may even help us to better understand the survivability of diamonds during the cooling of kimberlites.

V42H-02 1615h

Field Studies of Mantle Melting at Ultra-slow Spreading Ridges

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Field studies of ultraslow spreading ridges put new constraints on the generation of abyssal basalts and the nature of the mantle. At the transition from slow to ultra-slow spreading there is a sharp discontinuity with an abrupt transition from continuous to discontinuous volcanism along the ridge. On the ultra-slow side of the discontinuities, the ridges consist of linked amagmatic and magmatic accretionary segments, and transform faults disappear despite often extreme oblique spreading. The amagmatic accretionary segments expose abundant mantle peridotites and exhibit sparse volcanism. There is no correlation between the volume of magmatism and further decreases in spreading rate across the discontinuities, with magmatism often locally increasing again with decreasing spreading rate. Magmas dredged across these discontinuities share similar major element characteristics, with an increase in Na_8 and decrease in Fe_8. Trace element compositions across these discontinuities, however, show different patterns of variation, though generally the basalts are trace element and isotopically enriched compared to typical MORB. One interpretation of this pattern is that there is bimodal melting behavior: suggesting a multi-component mantle source with an early melting vein or vein-like components. This is consistent with the hypothesis that the composition of a heterogeneous mantle many thousands of kilometers apart can be significantly different. While all the discontinuities lie at an effective spreading rate corrected for ridge geometry near 12 mm/yr full-rate, at the Gakkel Ridge the discontinuity matches a prominent bathymetric discontinuity associated with early rifting and the Morrice Jessup Rise and Jermak Plateau. The discontinuity at 16°E on the SWIR, on the other hand, is migrating rapidly eastward along the ridge - suggesting that it is a plate driven discontinuity. In the third case, the discontinuity appears at the Melville F.Z. These contrasting observations indicate that while the discontinuities in mantle melting behavior may be a primary function of spreading rate, mantle composition and major physiographic discontinuities also play a major role in fixing their position.

V42H-03 1630h

Geochemical Systematics of Hotspots and Mid-Ocean Ridges Arising from Melting of a Non-Layered Heterogeneous Mantle

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Many fundamental geochemical differences between ocean island basalts (OIBs) and mid-ocean ridge basalts (MORBs) are often explained by a chemically layered mantle, with lower mantle material delivered to the surface by mantle plumes forming ocean islands, and a compositionally distinct upper mantle feeding mid-ocean ridges. A dilemma arises from geophysical evidence for whole mantle convection, which is predicted to efficiently stir the mantle and prevent any long-lasting, global chemical layering. We present models of decompression melting in which mantle heterogeneities are present as veins or small blobs, equally numerous in plume mantle as they are in the ambient mantle. Three different components are considered. Enriched mantle (EM) is highly concentrated in the most incompatible trace elements, has isotopic characteristics reflecting long-term enrichment, and begins melting deepest. Pyroxenite (PX) is relatively depleted in the most incompatible trace elements, has Pb isotope compositions reflecting a high U/Pb ratio, and begins melting at intermediate depths. Depleted mantle (DM), the most abundant (90%) component, is depleted in the most incompatible elements, has corresponding isotope signatures, and begins melting shallowest. Models predict the deeper melting, EM and PX components to be preferentially extracted at intraplate settings where thick lithosphere limits melting to large depths and low extents. In contrast, DM is more heavily sampled at mid-ocean ridges where thinner lithosphere allows for shallower and more extensive melting. Besides lithospheric thickness, differences in mantle flow also contribute to compositional contrasts between OIBs and MORBs. Plume-driven upwelling is most rapid at depth, decreases to the base of the lithosphere, and therefore enhances the extraction of EM and PX. In contrast, seafloor spreading at mid-ocean ridges allows for more uniform upwelling with depth and more even sampling of all mantle components, including DM. Models predict general systematics consistent with observations: incompatible trace-element and Sr, Nd, and Pb isotope ratios with large variability, extending to more enriched compositions at hotspots, and a smaller range of variability, with more DM-like compositions at mid-ocean ridges. Models can also explain the apparent mixing arrays defined by OIB and MORB isotope compositions. Considering melting of heterogeneous sources is thus crucial to any inferences of the bulk composition of the source material. In fact, many major geochemical systematics of MORB and OIB may arise from melting of a ubiquitously heterogeneous mantle without large-scale chemical layering.

V42H-04 1645h

Volatile-Rich Mineral Phases in the Hawaiian Lithosphere: Phlogopites and Carbonates in 0-age Garnet Pyroxenite Xenoliths From Salt Lake Crater, (Oahu, Hawaii).

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We present the first detailed Hf, Nd, Sr isotope and trace and major element investigation on clinopyroxene (cpx), garnet, phlogopite and carbonate mineral separates from garnet pyroxenite xenoliths from the Salt Lake crater, Oahu, Hawaii. These xenoliths are brought to the surface by the post-erosional lavas that mark the last stage of the evolution of a Hawaiian volcano. Previous studies have suggested that these pyroxenites are either high pressure cumulates associated with the Honolulu volcanics (HV) post erosional lavas, or MORB-related cumulates at a 80-100 Ma paleo ridge. In both Nd-Hf and Nd-Sr isotope spaces all cpx and garnet data are within the range of the HV and other Hawaiian post-erosional lavas. The Lu-Hf and Sm-Nd isotope systematics of the cpx - garnet pairs give essentially 0 ages, providing the first direct evidence that these garnet pyroxenites are indeed 0-age high pressure cumulates from melts isotopically similar to the HVs. Some 0-age pyroxenites also contain veins with volatile-rich mineral assemblages (phlogopite, carbonates and associated glass pockets), that have infiltrated and reacted with the cpx-garnet matrix. These phlogopites have identical $^{143}Nd/^{144}Nd$ ratios as the cpx (0.51303) but significantly more radiogenic $^{87}Sr/^{86}Sr$ (0.7032 - 0.7033 in cpx, 0.70365 - 0.70385 in phlogopites, carbonates and glass). These minerals have higher $^{87}Sr/^{86}Sr$ (for a given $^{143}Nd/^{144}Nd$) than MORBs or HVs and fall at the extension of the horizontal displacement of the post shield and post erosional Hawaiian lavas from the Pacific MORB field in Nd-Sr isotope space. Isotopically then, these volatile phases are more similar to the post-erosional lavas than the shield (Koolau) tholeites, providing new evidence for the involvement of volatiles in the generation of the post-erosional volcanism. The association of these volatile-rich phases with garnet pyroxenites and their absence in the more shallow, spinel peridotites points to a deep (i.e. non-lithospheric) origin for these volatiles. We speculate that these volatile-rich melts originate from the cooler periphery of the radially layered Hawaiian plume, either as direct plume melts, or melts from the upwelling asthenosphere that is passively coupled with the rising plume. These volatiles can act as a fluxing agent causing or enhancing melting in the source of the post-erosional lavas, and contribute to their relatively radiogenic Sr isotope compositions.

V42H-05 1700h INVITED

A Physical Description of the Lithosphere and Seismic Low-Velocity Zone beneath Oahu: Perspectives from Hawaiian Mantle Xenoliths

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Mantle xenoliths provide a random sampling of a significant portion of the uppermost mantle beneath Oahu, including all of the lithosphere and the lithosphere-asthenosphere transition (LAT). We combine all the petrological, geochemical, and isotopic information on these xenoliths and evaluate existing models of the lithosphere and LAT beneath Oahu. The xenoliths are principally of two kinds - spinel peridotites and garenet clinopyroxenites; and they occur within the post-erosional Honolulu Volcanics (HV). Plagioclase peridotites are rare, and plagioclases in them are exotic, having crystallized from Koolau-like (enriched) magma. Trace element and Nd-Hf isotope ratios indicate recent metasomatic enrichment of the depleted peridotitic lithosphere by HV-like fluids. The pyroxenite suite xenoliths are dominantly composed of clinopyroxene and garnet with variable proportions of olivine, minor spinel and orthopyroxene, and rare phlogopite, carbonate, amphibole, and melt pockets. Phase equilibrium considerations indicate that these

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rocks form accumulates at the LAT and along the walls of fracture-conduits within the deep lithosphere. Nd-Sr isotope data on whole rocks and garnet and cpx separates show them to be depleted as well, partially overlapping with the host HV lavas and lithospheric spinel peridotite xenoliths. We view the Oahu lithosphere (below the crustal part) as follows: 20-30 km - depleted harzburgite with veins of plagioclase; 30 - 90 km - spinel peridotite layer (we model the vertical modal variation), 90 -130 km - cumulate garnet clinopyroxenites and "piclogites" with small amounts of (5 percent) intergranular H2O+CO2-rich fluids that may be of kimberlitic-carbonatite affinity. Our inferred compsition of the lithosphere and LAT are generally similar to geophysical models but predict a 200-250oC lower temperature within the LVZ beneath Oahu than the latter. In our model, Hawaiian plume-derived shield-stage magmas have little interaction with the lithosphere, suggesting that these magmas are efficiently transported via dikes. During the post-erosional stage, limited interactions occur between the lithosphere and fluids that escaped from the main HV conduits. We estimate that the post-erosional HV magmas were generated from a minimum depth of about 100-130 km, and that Koolau shield magmas were produced from even deeper levels based on the rarity/absence of cumulate/residue type xenoliths with such compositional affinity.

V42H-06 1715h INVITED

Origin and Evolution of Mantle Lithosphere

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Mantle lithosphere beneath oceanic and continental crust is characterized by mineralogic and chemical variability resulting from extraction of partial melt. Normative mineral and major element composition trends from oceanic and off-craton subcontinental lithosphere intersect at an Mg# of about 89.3, indicating a common fertile lherzolite protolith. A model fertile upper mantle composition is calculated from these trends and has non-chondritic refractory lithophile major element ratios. Phase relations for melting of fertile peridotite are used to deduce melt extraction trends as a function of pressure and temperature. These trends are compared to compositional trends exhibited by mantle lithosphere to constrain the conditions of formation. Reconstructed abyssal peridotite compositional trends are best modelled by moderate degrees (5 to 25%) of combined batch and near-fractional melt extraction at an average pressure of about 1 GPa. Off-craton subcontinental mantle lithosphere, generally Proterozoic in age, is modelled by similar extents of melting but at a higher average pressure of about 2 GPa. Low SiO_2 Archean cratonic lithosphere has compositional features indicating high-degree melt extraction (40 to 50%) at average pressures of 4 to 5 GPa. High-SiO_2 cratonic lithosphere is modeled by melt extraction followed by addition of opx in a secondary process. Based on the assumption of nominally anhydrous melt extraction, estimates for average mantle potential temperature at the time of lithosphere formation indicate secular cooling of the mantle by about 350 $\pm$ 50 $^{\circ}$C since the Archean. This amount of cooling is greater than predicted in models that assume whole-mantle convection, and could indicate transient periods of layered convection and mantle overturn during the first several billion years of Earth history.

V42H-07 1730h

The Relationship Between Partial Melt Composition and Trace Element Partitioning Along the Peridotite Solidus

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Peridotite partial melting occurs primarily within the upper 80 to 90 km of the Earth's mantle, where the fractionation of incompatible trace elements is controlled largely by their relative compatibilities in high-Ca clinopyroxene (Cpx). A significant number of Cpx-melt partition coefficients (D_i) have, therefore, been determined experimentally for geochemically important trace elements over a broad range in pressure, temperature, and bulk composition. These experiments have produced Cpx exceeding the compositional range produced in peridotite partial melting experiments. Collectively, the results from these studies demonstrate that composition-related variations in Cpx structure produce significant changes in D_i by varying the misfit between the lattice site and the substituent cation, or by facilitating the charge balance required for heterovalent substitution. Gaetani and Watson [1,2] determined that the influence of melt structure on trace element partitioning increases with decreasing extent of partial melting at 1.5 GPa due to increasing polymerization of the melt. Systematic changes in the major element composition of peridotite partial melt generated near the peridotite solidus causes this effect to be very significant at 1.0 to 1.5 GPa, but relatively unimportant at higher pressures. This reconciles the large D_i values determined by Blundy et al. [3] with the lower compatibility measured by Salters and Longhi [4]. The compositions of low-degree partial melts of mantle peridotite change dramatically over the pressure range of 1.0 to 2.5 GPa. With increasing pressure, the concentrations of SiO_2, Al_2O_3 and Na_2O in the melt decrease as FeO, MgO and CaO increase. This leads to a systematic decrease in melt polymerization as reflected in the ratio of non-bridging oxygens to tetrahedrally coordinated cations (NBO/T). As the value of NBO/T for low-degree melts increases from a value of $\sim$0.15 at 1.0 GPa to $\sim$0.95 at 2.5 GPa, the compatibility of the rare earth elements in Cpx monotonically decreases. For NBO/T values of $\sim$0.49 or less, melt structure plays a significant role in determining compatibility. In less polymerized melts, trace element compatibility is determined almost solely by the composition of the Cpx. Given these systematics and the range of pressures at which mantle peridotite is thought to cross its solidus beneath oceanic spreading centers, the large partition coefficients determined by Blundy et al. [3] are likely to be relatively unimportant for modeling trace element fractionations during partial melting. References: [1] Gaetani and Watson, 2000, EOS, 81:1383; [2] Gaetani and Watson, 2001, Eleventh Annual V.M. Goldschmidt Conf, Abst 3292. [3] Blundy, Robinson and Wood, 1998, EPSL 160:493-504; [4] Salters and Longhi, 1999, EPSL 166:15-30.

V42H-08 1745h INVITED

Magma Genesis in the Hawaiian Hot Spot: From melting experiments on basalt/peridotite hybrid source

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Melting mantle peridotite is one of the central themes in experimental petrology. Melting studies in CMAS, NCMAS and natural peridotites have extensively documented the magma genesis process at Mid Oceanic Ridges (e.g., Presnall et al., 1979). Magma genesis in OIBs and LIPs, on the other hand, has been poorly constrained by experiments. Evidences from isotope geochemistry indicate that the source materials for basalt magmas in these provinces are not peridotite alone. Based on a geological and geochemical reconstruction of 3 Ma old Koolau volcano, I proposed that the size of eclogite blocks in the Hawaiian plume would exceed 1000km3 (Takahashi and Nakajima, 2002) and therefore the melting interaction of eclogite blocks and the surrounding peridotite would play essential roles in magma genesis in the Hawaiian hot spot. Melting experiments on basalt/peridotite composite starting materials were carried out at 2.5 to 3.0 GPa at temperatures from the peridotite dry solidus to that of basalt for 20 to 100 hours. Three layered starting materials consisting of 1 basalt to 2 peridotite (in volume) were placed in graphite/Pt double capsules. Peridotite KLB-1 (Fo89.6) and two basalt-starting materials (CLG-46 and CRB72-31) were used as starting materials. In temperatures ca.50-100 degrees below the peridotite solidus, silica-rich partial melts are produced in the basalt zone and the boundaries between the basalt and peridotite are coated with a 10 to 50 micron thick opx reaction band. The chemical reactions between the basalt and peridotite domains are controlled by solid diffusions across the opx reaction band and are very slow. In temperatures within 50 degrees of the peridotite dry solidus, a time dependent reaction process takes place. The basalt/peridotite boundary gradually partial melts as the chemical reaction lowers the peridotite solidus locally. At 2.8 GPa and 1450-1470C after 50-100 hours, resultant melt in the basalt layer becomes saturated with oliv + opx + cpx + gar and has 13-15 wt% MgO. Compared with partial melt of KLB-1 at 1500-1525C (Hirose and Kushiro, 1993), the basalt/peridotite hybrid melts are much lower in Al2O3 and CaO but are distinctly higher in K2O and TiO2. Compared with partial melt of KLB-1+50%MORB at 1500-1525C (Kogiso et al., 1998), melt in this study are much higher in SiO2 but lower in Al2O3. Among the three sets of experiments at 2.8-3.0GPa, compositions of the basalt/peridotite hybrid melts are most similar to the primitive Hawaiian tholeiite. Various hypotheses have been proposed to explain the chemical character of the Hawaiian magma (e.g., involvement of a metasomatic component at the base of the Pacific plate, melting of a fertile lower mantle component, melting at much higher pressure, etc). Based on the above experiments, I propose that Hawaiian tholeiite magmas are produced in basalt-peridotite reaction domains in the plume. The systematic change in the SiO2 content of Hawaiian tholeiites (from lower to higher, Loihi, Kilauea and Mauna Loa) could be explained by lowering melting temperatures in magma feeding zones from Loihi to Mauna Loa. This model predicts that the PMT for the Hawaiian plume could be roughly 100C lower than the previous model (PMT=1558C, Watson & McKenzie, 1991) and the involvement of eclogite component in magma genesis in the Hawaiian tholeiite would be 30 to 100%, which is much higher than the previous estimate (0-10%, Hauri, 1996).

V51A MCC: 3006 Friday 0800h

Light Element Geochemistry: Insights Into High-Temperature Processes I

Presiding: **B McDonough,** University of Maryland**; P J le Roux,** Carnegie Institution of Washington

V51A-01 0800h

Li isotope composition of the upper mantle

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Subduction returns altered oceanic crust to the mantle as an integral part of plate tectonics. Yet evidence for recycled material in the mantle remains scarce. Li isotope ratio measurements have the potential to be a highly effective tracer of recycled material. Recent development of measurement procedures on our Finnigan Neptune plasma ionisation mass spectrometer allows us to measure small samples (1ng Li) with a reproducibility (2 sigma standard deviation) of $\pm 0.2^{o}/_{oo}$. This considerably improves our ability to detect small variations in the Li isotope ratios and thus our sensitivity in identifying recycled contributions in mantle derived material. We have used our new technique to analyse the Li isotope ratios of a suite of MORB. The current Li isotope database for MORB is small, but nevertheless ranges from 1.5 to $6.5^{o}/_{oo}$ in samples from normal ridge depth. We wanted to assess the variability of MORB Li isotope ratios at high precision (± 0.2 rather than $\pm 1^{o}/_{oo}$) in a suite of spatially closely related lavas. Thus we analysed samples from two small study areas around 10°30'N and 11°30'N East Pacific Rise (EPR) which comprise a range of compositions from normal (e.g. ϵ(Nd) $\sim$ 10) to enriched (e.g. ϵ(Nd) $\sim$ 8). Our δ^7Li results vary from 3.1-$5.2^{o}/_{oo}$ and correlate with other geochemical indices-positively with $^{87}Sr/^{86}Sr$ and La/Sm and negatively with $^{143}Nd/^{144}Nd$. These correlations suggest shallow contamination is an unlikely cause of Li isotope variations. Thus the sources of these lavas appear to be variability enriched with recycled material with a heavy Li isotope signature. Recent work has suggested that after subduction zone processing the slab is isotopically light and thus is not a likely candidate as this recycled component. We suggest instead that the fluid-fluxed mantle wedge is mixed back into the upper mantle and forms the enriched component in the sources of these MORB and probably other mantle derived magmas.

V51A-02 0815h

Lithium isotopic composition of the lower continental crust: A xenolith perspective

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