topographic and crustal thickness anomalies without substantial thermal anomalies. Scattering of high frequency seismic waves is one way to test this hypothesis. The anisotropy and anelasticity of the asthenosphere is consistent with such a structure .The presence of CO_2 in the upper mantle, long advocated by Dean Presnall, explains the missing-CO_2 problem (and the helium paradoxes) and, together with trapped young slabs, may be responsible for the low seismic velocities, Q, and melting anomalies, at 'normal' mantle temperatures. Shallow recycling of crust- and slab-sized objects obviates the need for concentrated hot jets localized under 'hotspot' volcanoes and deep mantle reservoirs.

V42E-04 1430h

The Implications of Different Geotherms for the Generation of Carbonatites, Kimberlites and Melilitites

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Dalton and Presnall (1998) and Gudfinnsson and Presnall (2003) determined the melting relations of model garnet lherzolite in the system CaO-MgO-Al_2O_3-SiO_2-CO_2 (CMAS-CO_2) at 3-8 GPa, 1245-1800°C. These phase relations comprise a divariant surface in P-T space. The high-temperature side of the surface is bounded by the solidus curve for garnet lherzolite in the CO_2-free system. At several hundred degrees lower temperature, the surface is bounded by the solidus curve for CO_2-bearing compositions as a carbonate phase joins the phase assemblage. The garnet lherzolite phase assemblage coexists with CO_2-bearing melts along the divariant surface, and continuous gradations occur between carbonatitic, kimberlitic, and melilititic melts. The carbonatite melts are generated at the lowest temperatures, while kimberlites are generated at higher temperatures as the CO_2 content of the melts decreases and the SiO_2 content increases. At a pressure below 4 GPa, the kimberlites grade into melilitites, which contain less MgO and more Al_2O_3 than the kimberlites. Parameterization of the compositions of all the phases as a function of pressure and temperature and the use of published algebraic methods allows modeling of the melting of any selected CO_2-bearing garnet lherzolite composition within the CMAS-CO_2 system, including incipient melting near the carbonate-bearing solidus. We have modeled the melting of a relatively CO_2-rich garnet lherzolite composition containing 0.15 wt% CO_2. Because of the low melting degrees involved, the melting paths closely approach solid adiabats. A relatively cool adiabat with a potential temperature (T_P) of 1310°C and a slope of 15°C/GPa intersects the carbonate-bearing solidus at a pressure of about 7 GPa, and the melting path follows the solidus for a narrow pressure range until all the carbonate is exhausted after about 0.3-0.4% melting. Melting continues in the divariant field, and at a pressure of 3 GPa only about 0.5% melting has occurred, generating carbonatitic melts only. An adiabat with a T_P of 1510°C intersects the carbonate-bearing solidus at a pressure considerably higher than the range of our data, but at 7 GPa the melt composition is about to change from carbonatitic to kimberlitic as the extent of melting has reached about 0.6-0.7%. At lower pressures, the melt changes from kimberlite to melilitite composition. Thus, elevated geotherms are needed to generate kimberlite and melilitite magmas. This requirement is lessened, however, if considerable amounts of water are present. For example, Price *et al.* (2000) came to the conclusion that the Jericho Pipe kimberlite magmas contained about 6% H_2O, which will lower the equilibrium temperature 200-300°C. The other most important mantle component not present in the CMAS-CO_2 system, FeO, is likely to have only small effect on kimberlite generation, but its effect on the stability of carbonates, and hence the generation of carbonatites, could be important. As carbonatite melts could become interconnected at less than 0.1% melting (Minarik and Watson, 1995), they may be highly mobile in the upper mantle, and as they commonly carry large amounts of incompatible elements, they could have an important effect on the trace element signatures of basalt lavas (Presnall *et al.*, 2002).

V42E-05 1445h

Experimental constraints on the role of pyroxenite partial melting in formation of basaltic magmas

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Mafic lithologies (pyroxenites) are a minor but ubiquitous component in the Earth's mantle, and may play an important role in formation of basaltic magmas. The volumetrically dominant composition of pyroxenite in the mantle may originate from ancient subducted oceanic crust and be similar to MORB, but a wide range of pyroxenite composition may exist in basalt source regions, as indicated by the diversity of pyroxenites sampled from xenoliths and alpine-type peridotite massifs. A variety of magmas can be produced from such diverse pyroxenite compositions, and it is important to reveal systematic relationships between bulk compositions of pyroxenite and their partial melts for understanding the influence of pyroxenite on the chemistry and dynamics of basalt generation. We review experimental phase equilibria associated with partial melting of pyroxenites to examine the relationship between bulk composition and melting relations. An important aspect of pyroxenite phase equilibria is the existence of the garnet-pyroxene thermal divide, defined by enstatite - Ca-Tschermak pyroxene - diopside plane in CMAS projections. This divide appears at pressures above ~2 GPa at which garnet and pyroxenes are the principal residual phases in pyroxenite compositions. Pyroxenites on the silica-deficient (olivine-rich) side of the garnet-pyroxene divide produce low-silica liquids that also plot on the silica-deficient side of the divide, and silica-excess (quartz-rich) pyroxenites generate silica-rich melts that plot on the silica-excess side of the divide. Many of the silica-poor partial melts from silica-deficient pyroxenites have nepheline-normative compositions, and the silica-rich partial melts from silica-excess pyroxenites principally have hypersthene- or quartz-normative compositions. Silica-deficient pyroxenites are generally richer in olivine component, and thus their partial melts generally have higher MgO contents than those from silica-excess pyroxenites. Changes in phase volumes of residual minerals are another key factor controlling partial melt compositions. The phase volume of garnet expands relative to clinopyroxene with increasing pressure, producing liquids enriched in CaO and depleted in Al_2O_3 at higher pressures. As many silica-deficient pyroxenites lack olivine during partial melting, they produce high Ca/Al liquids with moderate MgO contents, which have strong similarities to nepheline-normative OIB lavas from many hotspots. Silica-excess pyroxenites also produce high Ca/Al melts with low MgO contents at high pressures, which have similarities to the silica-rich endmember of Hawaiian tholeiites.

V42E-06 1500h

Stability of Carbonated Eclogite in the Upper Mantle: Experimental Solidus from 2 to 9 GPa

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Carbonates are pervasive alteration products of the oceanic crust and likely survive subduction-related dehydration and/or melting. Thus, significant quantities of carbonated refractory eclogite are probably delivered to the deeper mantle. The melting behavior of such recycled carbonate influences the fate of recycled carbon, determines the possible sources and depths of carbonated metasomatic melts in the mantle, and delimits the conditions under which carbonated eclogite may act as a source of carbonatite and other types of magmatic CO_2. We present partial melting experiments of carbonated eclogite that constrain the solidus and near solidus phase relations from 2 to 9 GPa. To simulate the near-isochemical nature of ocean floor carbonation, the starting material was prepared by adding 5 wt.% CO_2 in the form of a mixture of Fe-Mg-Ca-Na-K carbonates to a bimineralic eclogite from Salt Lake crater, Oahu, Hawaii. The starting composition is a reasonable approximation of carbonated oceanic crust from which siliceous hydrous fluid has been extracted by subduction. We find that melt-present versus melt-absent conditions can be distinguished based on textural criteria. Garnet and cpx appear in all the experiments. Between 2 and 3 GPa, the subsolidus assemblage also includes calcite-dolomite$_{ss}$ + ilmenite, whereas above the solidus (950-975 °C at 2 GPa and 1050-1075 °C at 3 GPa) calcio-dolomitic liquid appears. From 3 to 4.5 GPa, dolomite$_{ss}$ becomes stable at the solidus and the near solidus melt becomes increasingly dolomitic. Appearance of dolomite above 3 GPa is accompanied by a negative Clapeyron slope of the solidus, with the cusp located between 995 and 1025 °C at *ca.* 4 GPa. Above 4-4.5 GPa, the solidus again rises with increasing pressure to *ca.* 1245 °C at 9 GPa and magnesite becomes the subsolidus carbonate. Dolomitic melt coexists with magnesite + garnet + cpx + rutile between 5 and 9 GPa. If extrapolated to higher pressures, the carbonated eclogite solidus intersects the oceanic geotherm deeper than 400 km. Thus, eclogite cannot host carbonates in the asthenosphere. Carbonated eclogite bodies entering the convecting upper mantle would release carbonate melt in the mantle transition zone. Upon release, this small volume, highly reactive melt could be an effective agent of deep mantle metasomatism. Comparison of our eclogite-CO_2 solidus with that of peridotite-CO_2 shows a shallower solidus-geotherm intersection for the latter. This implies that carbonated peridotite is a more likely proximal source of magmatic carbon in oceanic provinces. However, carbonated eclogite is a potential source of continental carbonatites, as its solidus crosses the continental shield geotherm at *ca.* 4 GPa.

V42E-07 1515h

Chemical Order in Silicate Melts: Implications for Microscopic Origins of Mantle Melting Behavior

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Configurational thermodynamic properties of silicate melts (e.g. activity coefficient of silica) at high pressure govern composition of melts in equilibrium with mantle mineral assemblages. These properties are controlled by the distribution of framework units (e.g. $^{[4]}$Si, $^{[5,6]}$Si, $^{[4]}$Al), and the disorder among network-modifying cations (e.g. Ca^{2+}, Mg^{2+}, Na^{+}) in the melts (Lee, Fei, Cody, & Mysen, Geophys. Res. Lett., 2003, 30, 1845; Lee and Stebbins, Geochim. Cosmochim. Acta., 2003, 67, 1699). Spectroscopic data obtained in the diamond anvil cell (DAC) together with quantum chemical simulations, allow us to measure details of distributions of framework units and network modifying cations with varying pressure, temperature and compositions. Here we report structural details of model basaltic melts (sodium silicate and aluminosilicates with varying degree of polymerization) mainly using solid state NMR, vibrational spectroscopy and synchrotron X-ray with DAC. These results highlight the tendency for chemical ordering resulted from cation mixing in silicate melts and glasses at ambient as well as high pressure (6-10 GPa). The chemical ordering among framework units leads to the formation of $^{[5,6]}$Si-O-$^{[4]}$Si in silicates and $^{[5,6]}$Al-O-$^{[4]}$Si in aluminosilicates, contributing to the total negative deviation of silica activity from ideal solution in silicate melts at high pressure. Network-modifying cations also prefer to form dissimilar pairs (e.g. Ca-Na and Mg-Ba). These results indicate that there will be a further reduction in the activity coefficient of silica in multi-component melts. We also present modeling results of configurational enthalpy and entropy of multi-component silicate melts derived from the spectroscopic analysis and calculated the effect of degree of chemical order in melt properties. Increasing chemical ordering among framework units leads to a decrease in configurational entropy and enthalpy of melts, and also contributes to the decrease of silica activity coefficient in melts. Structural ordering in the melts, together with extensive mixing among framework units, strongly affect the composition of the partial melts. The alkali or silica content in equilibrium with mantle peridotite can increase as a results of these structural effects, thus manifesting the strong links between melt structures, properties and magmatic processes.

V42F MCC: 3006 Thursday 1340h

Modeling Metamorphism II *(joint with T)*

Presiding: **M. Brown,** University of Maryland**; B. Dutrow,** Louisiana State University

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V42F-01 1345h INVITED

Heat production distributions and the geochemical self-organization of the crust

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The distribution of the heat producing elements within the lithosphere provides an important control on continental thermal regimes and the mechanical strength

of the lithosphere. Moreover, the strong temperature-dependence of lithospheric rheology suggests the possibility of an important feedback between tectonic processes, such as metamorphism, deformation and magmatism, and the distribution of heat producing elements. Simple models for lithospheric rheology are used to illustrate how such feedback might serve as an important control on both the characteristic abundance of, and spatial variation in, the heat production elements in the crust. These models also imply that the organization of heat producing elements is essential for the long-term tectonic stabilisation of the continental crust. This is particularly relevant to evolution of cratons in early Earth history, wherein lies the most dramatic evidence for the role played by tectonic processes in achieving a stable ordering of the heat producing elements, consistent with the crust as a self-organizing geochemical system.

V42F-02 1405h

Modeling Peak T and Retrograde Evolution of Ultra-hot Granulites From Brazil

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Granulite-facies rocks record extreme thermal perturbation of Earth's lithosphere. Characterizing these rocks yields information critical to our understanding of the P-T-X environment of formation and modification of continental crust. Ultrahigh-temperature (UHT) metamorphism was introduced for rocks that record extreme thermal conditions. Mineral associations characteristic of UHT conditions include Spr-Qtz and Sp-Qtz, and rare Opx-Sil-Qtz, which requires XMg >0.60-0.65, corresponding to minimum P and T of 8 kbar and 850°C. The migmatitic aspect of metapelites and metagreywackes suggests they were once melt-bearing, but survival of peak assemblages and depleted compositions suggest melt loss. Unless most melt is extracted, significant retrogression will occur during cooling as melt-consuming reactions are crossed. Where UHT assemblages are preserved, they occur within larger areas of common granulite. The restricted occurrence of UHT assemblages raises questions about the metamorphic processes involved. Did the extreme P-T conditions occur regionally? If so, did protolith composition restrict the record of these conditions or was retention of melt responsible for widespread retrogression? Given the clockwise P-T path inferred for many granulite terranes, how was the extreme thermal perturbation required by UHT assemblages achieved? We address these questions with new petrologic data from the Anápolis-Itauçu Complex (AIC) of central Brazil, within the Neoproterozoic Brasília Belt. The Brasília Belt, including the Goiás arc, lies between the Sao Francisco and Amazon Cratons. Within the internal zone, the AIC comprises orthogranulite (metagabbro, charnockitic/enderbitic gneiss) and paragranulite (Grt-Sil/Opx-Sil gneiss, calc-silicate rock); magmatism and metamorphism occurred in the interval 650-630 Ma. Spr-Qtz occurs in Grt-Opx-Sil-Qtz assemblages at localities 20 km apart, recording extreme T. At Fazenda Califórnia, N of Goiânia, the post-peak evolution is constrained to begin at 10 kbar by down T stability of Grt-Opx-Sil-Qtz and absence of Crd. To the N near Damolândia, the post-peak evolution is constrained by a succession of melt-present reactions, inferred from coronae/symplectites between Grt, Opx and Sil, crossed at P <9 kbar. We report new data from samples from Fazenda Califórnia. Equant Opx (up to 10 mm; with exsolved Rt and Sil, and rare Spr and Bt inclusions) and sporadic elongate Grt (up to 15 mm; with Spr inclusions) occur as porphyroclasts in a mylonitic fabric defined by variable, but smaller (commonly 3 mm) elongate Opx and laths of Sil set in a matrix of mm-size Qtz (with rare Spr inclusions) showing marked SPO and patchy CPO. Spr and Qtz are common as inclusions in Sil. In one sample, Crd occurs sporadically (together with Pl) separating Opx from Sil (rarely from Spr). These features are consistent with the peak assemblage Grt-Spr-Opx-Qtz-L, followed by reaction during cooling to produce Sil and, rarely, Crd; this implies that retrograde evolution was near the P-T stability of the Crd-producing reaction, with Crd controlled XMg. Al2O3 in equant Opx reaches 12.5-12.9 wt % in cores [y(Opx) of 0.30], to suggest maximum T of 1175-1150°C. Rims are zoned to <8.0 wt % Al2O3 [y(Opx) of 0.19]. Elongate Opx have lower Al2O3 in cores than porphyroclasts but similar rim compositions. Rim compositions indicate cooling to <975-950°C. We speculate that closure of an ocean basin inboard of the Goiás arc coeval with continuing subduction outboard enabled synchronous magmatism and crustal thickening to achieve UHT conditions.

V42F-03 1420h

Modeling Metamorphism Using Pseudosections

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To maximize our potential to recover full information from mineral assemblages and microstructures in metamorphic rocks we must be able to model in a reliable manner mineral equilibria in a majority of systems of geological interest. As experimental and thermodynamic data for a wider range of compositional end-members have become available, and models for activity-composition relations have improved, so chemical systems for which was are able to produce equilibrium phase diagrams have become increasingly more complex and now more closely approximate natural rocks. Pseudosections are equilibrium phase diagrams constructed for fixed bulk compositions or bulk compositional ranges against varying intensive parameters (P, T, X, aH2O, etc.) using internally consistent sets of thermodynamic data (e.g. Holland and Powell, 1998, JMG). Pseudosections allow precise quantitative predictions to be made on multivariant stability fields of paragenetic associations; however, we must ask how close are these predictions to real values for intensive parameters of interest. Previous studies of subsolidus to suprasolidus metapelitic rocks from southern Brittany have used reaction microstructures and conventional thermobarometry to suggest the Variscan lower crust followed a clockwise P-T evolution (Jones and Brown, 1990, JMG; Brown and Dallmeyer, 1996, JMG). We construct pseudosections for the MnNCKFMASH system and use average P-T calculations to investigate in more detail metamorphic evolution of these rocks. For migmatites, phase relations predicted based on the superimposition of the P-T path inferred from microstructural relations among mineral phases onto pseudosections calculated for an average metapelite composition, contoured for proportions of L and Grt, are broadly consistent with those inferred from petrography. The sequential occurrence of Ky, Ky + St and Sil suggests prograde evolution to P > 8 kbar at 625°C decreasing to P around 6 kbar at 650°C, and followed by increasing P and T to the metamorphic peak. A major melting step occurred at 750°C and 9 kbar by incongruent breakdown of Ms. At the metamorphic peak of 8 kbar and 800°C, 25 mol % L and >20 mol % Grt are predicted from volatile phase-absent melting that also consumed Bt. Retrograde evolution began with decompression and cooling, allowing crystallization of melt and replacement of Grt by Bt + Sil; this was followed by near-isothermal decompression from around 6 kbar to 4 kbar. The decompression segment was associated with widespread development of Crd, which commonly occurs as large peritectic porphyroblasts with leucosome in interboudin partitions indicating a second episode of melt generation. Crd growth that accompanied decompression melting is only predicted in melt-depleted low-Mn rocks. Preserved bell-shaped spessartine profiles in Grt suggest that Mn was effectively removed from the reacting rock volume. Microstructural relations in upper amphibolite facies metapelites from the unit structurally overlying the migmatites suggest retrograde development of St, And and white mica in these rocks. Based on a pseudosection contoured for the quantity of H2O required to saturate the assemblage at P-T, we suggest that an influx of an H2O-rich volatile phase is required, which we infer to have been derived from crystallising melt in underlying migmatites and granites. The correspondence of the predictions from the pseudosections with classical thermobarometric estimates that account for all dilutents within participating phases is encouraging, suggesting that quantitative inferences are valid using either method. When used in conjunction with geochronology, accurate constraints may be placed on the P-T-t evolution of rocks and sophisticated tectonothermal models advanced.

V42F-04 1435h

Subduction-stage P-T path of eclogite from the Sambagawa belt: Prophetic record for oceanic-ridge subduction

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The Sambagawa belt in SW Japan is a subduction-type high-P/T metamorphic belt. Subduction-stage P-T paths of its constituent rocks are important because they directly constrain physical conditions of the EarthOs interior at the time exhumation of high-P/T metamorphic rocks became feasible. Although a few examples of subduction-stage P-T paths for the Sambagawa rocks have been recognized, these are limited to relatively low-pressure regions (10 kbar). To augment these data the subduction-stage P-T path of the Kotsu glaucophane (Gln) eclogite is derived. The tectonic significance of the derived and previously determined P-T paths is further examined using a new thermal model. By using compositions of matrix minerals and rims of porphyroblastic garnet (Grt), the peak-T conditions of the Kotsu Gln eclogite have been estimated as 20 kbar/ 600°C. However, the dP/dT of the P-T path leading to the peak-T conditions is unknown. Petrological studies focusing on inclusion minerals in Grt show: (1) albite is absent as inclusions within Grt; (2) acmite (Acm) component of cpx decreased during growth of Grt; (3) Tschermakite (Ts) component of amphibole decreased and Gln component increased during growth of Grt; and (4) Grt-Cpx thermometry shows a temperature increase during growth of Grt. Along with mineral textures observed in the matrix, the Gln-formation reaction can be determined as: 4Acm + 2Ts + 2quartz + H2O (R) 2Gln + 2epidote + hematite. P-T curve of this reaction always has a large positive dP/dT (>7.1 kbar/100 ?C) with the Gln stability field on the high-P/T side. To cross this reaction curve into the Gln stability field during a rise in temperature, the Kotsu eclogite must trace a very steep subduction-type P-T path. Compilation of previously obtained subduction-stage P-T paths for the Sambagawa rocks along with the P-T path of the Kotsu Gln eclogite shows that the series of subduction-stage P-T paths are not distributed on a straight line starting from the origin, but in a curve with dP/dT increasing with metamorphic pressure. In previous thermal models curved P-T paths of the same kind were predicted for subduction of a very young slab (< 5 Ma) suggesting that the curved P-T paths will be formed just before oceanic-ridge subduction. A new model incorporating progressive approach of an oceanic ridge to a subduction zone shows that the series of the Sambagawa subduction P-T paths well fit the results for a setting where a ridge is close to being subducted at a slow rate relative to the subduction rate. The subduction P-T paths from the Sambagawa belt can, therefore, be regarded as a prophetic record of the subsequent ridge subduction. This suggests that exhumation of high-P/T metamorphic rocks in oceanic subduction zones may be associated with the slow approach and subsequent subduction of oceanic ridges.

V42F-05 1450h

Formation And Exhumation Of High Pressure Metamorphic Rocks From Oman: New Constraints From U-Pb Dating Of Zircon And Rutile

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Basement and continental shelf units structurally underlying the Semail ophiolite in Saih Hatat, NE Oman were metamorphosed under high pressure, low temperature (high P/T) conditions, and occur in two plates. The lower plate consists of eclogite facies rocks that grade westward into garnet blueschists and crossite epidote schists. The upper plate consists of thrust sheets of lower grade metasedimentary and metavolcanic rocks formed under pumpellyite - actinolite to lawsonite albite facies conditions. The eclogite facies rocks had a clockwise P-T path, with peak conditions of 12 < P < 15 kbar, and T of 550 to 580°C, a stage of near isothermal decompression from >12 kbar to $\sim$ 4 kbar, and a stage of near isobaric cooling followed by cooling and decompression. High P/T rocks from the upper plate are also characterized by clockwise P-T paths with a segment of near isothermal decompression, and reached peak conditions that ranged from $\sim$ 310°C, P < 6 kbar to 380 to 430°C, 6.5 to 9 kbar, depending on location in the thrust pile. A distinct pressure gap of > 3 kbar results from the juxtaposition of the lower and upper plates. U-Pb dating of zircon and rutile grains from two lower plate blueschists yield ages ranging from Proterozoic to Late Cretaceous: data cluster near a Late Creatceous age on the younger end of the array and spread to Mesoproterozoic values at the older end. A weighted mean of the ^{238}U/^{206}Pb ages from the youngest and most concordant fractions (one zircon and 2 rutile crystals) yields 80.1 $\pm$ 5 Ma. These results are consistent with Rb/Sr isochron ages of 78 $\pm$ 2 Ma obtained using phengite, clinopyroxene, and epidote from seven eclogite facies samples, and suggest that high P/T metamorphism in Saih Hatat was

almost coeval with the emplacement of the Semail ophiolite. We conclude that the lower plate blueschists and eclogites formed by intracontinental thrusting and subduction of the thinned leading edge of the Oman continental margin in an east dipping subduction zone. The upper plate rocks which were part of the hanging wall of this subduction zone, were metamorphosed by tectonic loading by the ophiolite. Entrance of thicker portions of the positively buoyant continental crust into this subduction zone choked it, and caused the ductile thinning of mantle lithosphere in its hanging wall. This initiated the rapid exhumation of the blueschists and eclogites from > 40 km to 14 km ~ 78 Ma, and led to their juxtaposition by the lower grade upper plate rocks. Erosion and crustal extension led to the final exhumation of all high P/T rocks in Saih Hatat.

V42F-06 1505h INVITED

Formation and Segregation of Melts in the Continental Crust: Time Scales From Trace Element Modeling of Rocks From the Sikkim Himalaya, India

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It is difficult to quantify the distribution of trace elements during crustal melting because equilibrium partitioning of these elements is often not attained. But modeling the distribution is crucial for understanding intracrustal differentiation (into upper, middle, and lower crust) as well as the nature and timescale of melt formation and segregation in the crust. To address this problem, we have developed a numerical model to simulate the evolution of trace elements in a system undergoing melting. The model accounts for equilibrium partitioning as well as kinetic processes such as dissolution, crystal growth, and diffusion along arbitrary temperature - time paths. In this project we have field tested the model on rocks from the classic inverted metamorphic sequence in the Sikkim Himalaya. The geological and petrological history of the area has been well constrained in a parallel project. Our study material consists of a sequence of prograde metamorphic rocks with rather similar bulk compositions that have been subjected to progressively increasing pressures and temperatures to ultimately undergo melting by well defined mica dehydration reactions. Using measured protolith and reactant mineral compositions, inferred balanced reactions, petrologically constrained peak temperatures, and known partition and diffusion coefficients in our model we reproduce observed mineral and melt compositions for any one element (e.g. Sr) by varying the thermal history. Once a good fit was observed, the same thermal history was then used to predict other trace element distributions (e.g. Rb, Ba) with a high degree of success. In our simulations so far we have ignored minor phases (e.g. apatite) and back reactions during cooling. Consequently, fits for elements that are known to reside primarily in minor phases (e.g. La) are poor, indicating that our model does indeed capture the essence of processes taking place in nature. Protolith bulk composition, stoichiometry of melting reaction, and partition and diffusion coefficients are found to be the key parameters controlling the distribution of trace elements. Our results so far indicate that the time scales of melting and melt segregation in such a continental collisional setting where dehydration melting reactions are taking place are on the order of 100,000 years.

V42F-07 1525h

Modeling Lithospheric Isostatic and Thermal Evolution: Application to the Proterozoic Orogen of the Southwestern United States

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The integration of high-resolution cooling histories with exhumation constraints and thermobarometric, heat production and heat flow data can be used to understand long-term lithospheric thermal and isostatic evolution. Cratonic lithosphere retains a record of the net temperature dependent lithospheric density change, as net lithospheric heating causes density decrease, uplift and erosion, while net cooling causes density increase, subsidence and sedimentation. We use this to construct isostatically consistent primary lithospheric geotherms, and use a finite-difference model to compute the time-dependent change of the geotherms following assembly to steady-state. The Proterozoic orogen of the southwestern U.S., characterized by disparate crustal domains with distinct cooling records, levels of exposure, and peak metamorphic conditions, is an ideal location to evaluate the controls on lithospheric thermal and isostatic evolution. In West-central AZ, apparent protracted cooling (1°C/m.y.) in 3-4 kbar exposed rocks of the Hualapai block contrasts with rapid cooling (25-100°C/m.y.) in 1-2 kbar exposed rocks of the Ash Creek block. Our thermal analysis indicates that observed differences in radiogenic heat production (3.1-5.2 microW/m^3 for Hualapai vs. 0.7-1.4 microW/m^3 for Ash Creek), but similar initial lithospheric mantle temperatures (900-1000°C), can explain the distinct thermal and isostatic records of the two blocks. Thus, heat production variation not only significantly influences crustal cooling histories, as has been previously documented, but also can induce diverse isostatic responses during geotherm evolution. The approach applied in this study can place important constraints on feasible, isostatically consistent models for cratonic lithosphere, and provides a framework with which better understand its assembly, stabilization and preservation.

V42G MCC: 3006 Thursday 1600h

Modeling Metamorphism III *(joint with T)*

Presiding: **M Brown,** University of Maryland**; B Dutrow,** Louisiana State University

V42G-01 1600h INVITED

Cenozoic and Mesozoic metamorphism in the Longmenshan orogen: Implications for geodynamic models of eastern Tibet

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The Tibetan Plateau is characterized by both its great height (much of it above 5,000 m) and flatness. It has been proposed that the flat topography is due to ductile flow of highly mobile lower crustal rocks. This idea has lead to a radical new idea in continental tectonics that horizontal outflow of mobile lower-crustal rock from topographic highs is one of the principal mechanisms by which plateaus grow laterally. It has been proposed that the large-scale topography of the whole of the SE Asian continent has been strongly influenced by this process. The best case for such a mechanism is made in the eastern border of Tibet in the Longmenshan orogen. The Longmenshan region lies on the western fringe of the S-China craton and has been involved in two stages of orogenesis: one event at 200 Ma associated with the collision between the N- and S-China cratons and a second, the Cenozoic Himalayan orogeny related to the collision between India and Asia. However, a number of studies have emphasized that the upper crustal deformation in the Longmenshan is almost entirely Mesozoic and, therefore, unrelated to the India-Asia collision, which began around 54 Ma. This discrepancy can be explained if the crustal thickening in the Longmenshan was caused by solid-state inflow of mobile lower-crustal metamorphic rocks from a topographic high. New zircon U-Pb and mica $^{40}Ar/^{39}Ar$ dating combined with structural studies confirm that most of the upper crustal deformation in the eastern margin of Tibet is Mesozoic. The deepest exposed parts of the orogen have undergone Barrovian facies metamorphism with estimated peak conditions around 8 kbar and 725°C (Huang et al, 2003) and associated deformation generally thought to have occurred around 200 Ma. However, new apatite U-Pb and monazite electron microprobe dating in the sillimanite zone give ages around 65 Ma. Metamorphic minerals occur both surrounding and as inclusions of the dated monazite suggesting 65 Ma is the age of metamorphism. The main phase of syn-metamorphic deformation is overprinted by a phase of folding associated with N-S fold axes and steep axial planes with geometries that indicate an E-W shortening of 10 - 50%. The evidence for originally thick crust existing around the time of the India-Asia collision and the presence of moderate amounts of Cenozoic E-W shortening can account for most if not all of the present thickness of the continental crust in the Longmenshan area. These results do not, therefore, support models of crustal thickening in the region caused by solid-state lateral flow of mid-crustal metamorphic rocks. Reference: Huang, M.-H., Buick, I. S. & Hou, W. 2003. Tectonometamorphic evolution of the Eastern Tibet plateau: evidence from the central Sogpan-Garze orogenic belt, western China. Journal of Petrology, 44 255-278

V42G-02 1620h

Deformation Structures and Geochronology of the Deformation-Metamorphism Event of the South Sulu High-Pressure Metamorphic belt

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The present structure of the Sulu HP-UHP belt in east China is a product of subduction and exhumation, resulting in a foliation parallel to the trend of the HP-UHP metamorphic belt, SE-ESE dips of 20-30æ, with NW-SE stretching lineation. The Sulu HP-UHP belt has two parts: a southern stacked set of HP tectonic slices overlain by a northern stacked set of UHP slices. Previous studies indicate that the northern UHP slices is the product of Indosinian continental deep subduction and exhumation. SHRIMP ages indicate UHP metamorphism at 220-245 Ma and exhumation at 202-220 Ma. The HP belt is further subdivided into high-pressure (HP) and low-temperature (LT) slices in the southeast and the HP and medium-temperature (MT) slices in the northwest. The HP/LT slices have P-T estimates of 0.70-0.85 GPa and 300-360°, and contain characteristic minerals such as winchite, barroisite, phengite and aragonite. These rocks are strongly sheared and individual tectonic slabs are separated by mylonitize zones. During exhumation, HP-LT rocks underwent continuous retrograde metamorphism from blueschist through laucophane-greenschist to greenschist facies. Retrographic metamorphic minerals are developed on regional strong penetrative shearing foliations and have inferred P-T conditions at 350-410 $^{\circ}$ and 0.2-0.4 GPa. The HP-MT belt is composed of kyanite-topaz quartzite (500 to 600 $^{\circ}$) kyanite-bearing albite-quartz schist, marble, phosphatic marble and phosphorite. The HP-MT rocks experienced retrograde metamorphism from epidote-amphibolite to greenschist facies (350 to 410° and 0.2 to 0.4 GPa). The LPO of quartz from mylonitized gneiss and schist constrains LPO models of the prism {1010} <a> and base {0001}<a>, which reflects the MT (450-650 $^{\circ}$) and LT ($<$ 400 $^{\circ}$)shear strain conditions. Shear strain and LPO of quartz indicate that shearing vector was from ESE to WNW. Three biotite samples yielded a weighted mean (WM) age of 232.5 $\pm$ 2.4 Ma and an isochron age of 232.9 $\pm$ 2.5 Ma, a plateau age of 253.9 $\pm$ 2.6 Ma and an isochron age of 254.0 $\pm$ 2.7 Ma and a plateau age of 243.9 $\pm$ 2.6 Ma and an isochron age 244.2$\pm$2.6 Ma. Two muscovite samples have a WM age of 214.2 $\pm$ 2.3 Ma and an isochron age of 213.8 $\pm$ 2.7 Ma and a WM age of 218.7 $\pm$ 2.3 Ma and an isochron age of 218.8 $\pm$ 2.4 Ma. Two K-feldspar samples yield WM ages of 173.1 $\pm$ 2.0 and 180.5 $\pm$ 2.0 Ma and an isochron age of 180.5 $\pm$ 2.2 Ma, and one hornblende has a WM age of 208.5 $\pm$ 2.2 Ma and an isochron age of 207.5 $\pm$ 2.6 Ma. All are the products of ductile

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