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Fe-Mg Interdiffusion Experiments in Olivine

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We are conducting a series of experiments on Fe-Mg interdiffusion in olivine from 600-800°C using Rutherford backscattering (RBS) to measure concentration profiles produced by diffusion. Two mm thick slices of pure synthetic forsterite are cut parallel to (001) from a Union-Carbide boule and polished on one side. After annealing at 800°C to remove possible damage from the polishing, samples are packed in powder of an Fe-bearing olivine (San Carlos, NM olivine or synthetic fayalite) and sealed in an evacuated silica tube along with a solid buffer assemblage (NNO or QFM). The samples are held at temperature, quenched, and the forsterite crystal is separated from the powder and cleaned, revealing a still-polished surface. Compositional depth profiles are obtained by Rutherford backscattering from the polished surface with a 2 or 3 MeV 4He⁺ beam. The profiles are consistent with a strong compositional dependence of the Fe-Mg interdiffusion coefficient. As observed by others at higher temperatures, Fe-rich compositions have diffusivities that are approximately 2 orders of magnitude higher than Mg-rich compositions. Variability of duplicate experiments led us to investigate the rate equilibration of the NNO assemblage at these modest temperatures because of the dependence of Fe-Mg interdiffusion on oxygen fugacity. NNO reaction rates are rapid on the diffusion time scale. Unlike many previous diffusion experiments of the same design with other systems, our data do not appear to be consistent with rapid diffusion in the powder relative to diffusion in the single crystal, changing the boundary conditions from “surface composition constant” to those of a semi-infinite system (with a highly composition-dependent diffusivity). This is perhaps a consequence of the relatively rapid rate of Fe-Mg interdiffusion in olivine single crystals compared with diffusivities in previous systems investigated. Additional experimental designs are being explored to obviate these difficulties and make use of the sensitivity of RBS to measure short (< 200 nm) compositional profiles to complete the olivine Fe-Mg interdiffusion data set for lower temperatures.

Linking Stream Geomorphology, Watershed Condition, and Aquatic Ecosystem Health

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Watershed management and protection and the restoration of aquatic ecosystem health have been identified as priorities by the Environmental Protection Agency and the National Research Council. This presentation explores how aquatic ecosystem health is affected by local-scale and watershed-scale variables. Twenty-five stream reaches in northwestern Vermont were surveyed during 2003 and 2004 at multiple spatial scales. Local-scale data included quantitative and qualitative geomorphic and habitat surveys. Watershed-scale data included landuse characterization and modeled annual average flow and sediment loading. Aquatic ecosystem health was measured by assessing the diversity and condition of multiple taxa (fish, macroinvertebrates, and birds). The results indicate that while both local-scale and watershed-scale variables impact stream biota to some extent, their relative influence depends upon the individual ecology of each taxa. In order to address these issues, comprehensive watershed management and restoration/protection plans should include assessment at multiple scales from a geomorphological, watershed, and ecological perspective.

Paleogeography of Avalonia: New Fossil Discoveries and their Tectonic Implications

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Perhaps the greatest geological jigsaw puzzle is the continuing attempt to reconstruct the Proterozoic supercontinent Rodinia. The existence of this supercontinent now seems well established, but its exact configuration is still subject to debate.

Most researchers agree that North America holds a central position in Rodinia. In the early phases of research, the primary uncertainty revolved around the identity of the continent or continents to the west of North America (present day coordinates). This problem seems to have been at least partly solved, as several hypotheses (some with amusing acronyms) suggest that Australia and part of Antarctica were to the west or southwest of North America, juxtaposed against the North American continent in the vicinity of Caborca, Mexico. These connections were made based on the presence of similarities among the billion-year-old Grenvillian basement rocks in Australia, Antarctica and North America, respectively. The ensuing rift between Australia-Antarctica and North America formed the Pacific Ocean.

Research now focuses on the identity of the continents that rifted away from the east coast (again, present day coordinates) of North America. An extensive belt of Grenvillian basement runs from Caborca to Nova Scotia. The identity of continents that rifted away from this belt as Rodinia split apart is currently under scrutiny. Some models place Amazonia (i.e., northern South America) against North America in the vicinity of New Orleans, others place it closer to Cape Cod. Either way, a big gap like a missing tooth or two is left along the Grenvillian margin of present-day eastern North America.

This gap could be filled by various African cratons (such as the Congo and Kalahari), but some researchers suggest that the Kalahari and West African cratons were never part of Rodinia. We must now turn to paleobiogeography to help fill the gap.

Avalonia is a loose association of terranes extending from Florida to the Canadian maritime, forming a belt of allochthonous rock just to the east of (and paralleling) the Grenville belt. New fossil finds in Avalonia of trilobites and Ediacarans suggest dynamic changes in Avalonia's paleobiogeographic affinities with other continents, in particular North America and parts of Africa. Analysis of these changes will help to determine the identity of the continental blocks that separated from the east coast of North America during the Rodinia breakup.

Active microbial methane production and organic matter degradation in a Devonian black shale

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Microbial methane in organic-carbon rich fractured black shales and coal beds accounts for a significant and growing percentage of global natural gas production. These distinctive reserves are unusual, in that they are located at relatively shallow depths and are associated with active groundwater flow regimes. In many shale gas and coal-bed reserves, indications of very low organic matter thermal maturity cause a solely thermogenic origin for the gas to be questioned. Instead, geochemical and isotopic indicators reveal that much of the gas is microbial in origin, possibly generated in the recent geologic past or even continuing on to the present day. Microbial methanogenesis and other associated metabolic processes impart distinct chemical and isotopic signatures on subsurface dissolved gases and formation waters. In this study, major cation and anion analyses are shown to be consistent with prior results demonstrating recharge of dilute meteoric waters and mixing within saline formation waters in Devonian black shales along the northern margin of the Michigan Basin (USA). Formation water chemistry is coupled with stable carbon isotopic analyses of dissolved inorganic carbon and C1-C3 hydrocarbons and with deuterium isotopic analyses of methane and co-produced waters to demonstrate that a considerable flux of microbial methane generation has occurred in the deep subsurface of this sedimentary basin. Organic matter degradation and methanogenesis in this environment operate in the absence of terminal electron acceptors such as sulfate that could support anaerobic heterotrophy. Instead, a model of subsurface microbial methanogenesis is presented in which anaerobic biodegradation of shale hydrocarbons yields acetate and H₂, which in turn serve with dissolved CO₂ as the principal substrates of methanogenesis. This model is supported by Archaeal and Bacterial community analyses of shale formation waters based on 16S rRNA sequences and by culture-dependent enrichments selective for particular metabolic roles, consistent with observations of other methanogenic hydrocarbon-contaminated groundwater aquifers.

Geochemical Arguments Favoring an Hawaiian Plume

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Most of the earth's active volcanoes occur at plate boundaries and are related either to plate separation or to subduction. Those that occur in an intra-plate environment, or are characterized by high magma production rates (including Large Igneous Provinces, LIP's), have been widely attributed to deep, hot mantle plumes that may initiate at the core-mantle boundary. Recently, this, perhaps too widely accepted, view has been vigorously and vociferously challenged. Opponents of the plume hypothesis argue that these intra-plate volcanoes may still be explained by plate tectonic processes, involving crack propagation, weaknesses in the lithosphere, and the availability of shallow, but very fertile/fusible (eclogite plus peridotite) mantle source material.

Hawaii volcanoes are regarded as the archetypal expression of a mantle plume, and only the most stalwart opponent is likely to challenge this position. Geodynamic models suggest that the Hawaiian plume is zoned in both temperature and composition. Consequently, the magmatic evolution of Hawaiian volcanoes, and their inter-volcano compositional differences, are widely interpreted in terms of melting within such a zoned plume. The Hawaii Scientific Drilling Project (HSDP) provides an excellent record of about 400 ka (180 - 600 ka) of Mauna Kea's magmatic history. Our studies of samples from Mauna Loa volcano, including historical lavas (0.2 ka), ¹⁴C-dated prehistoric lavas (0.2 - 36 ka), lavas recovered by the Hawaii Scientific Drilling Project (10 - 100 ka) and lavas from Mauna Loa's submarine southwest rift zone (<100 - ~400 ka), provide a similar 400 ka magmatic record for Mauna Loa. Both records provide an ideal opportunity for testing and/or modifying the plume model. This is because, due to the motion of the Pacific plate (9 - 13 cm/yr), both volcanoes will have transited about 40 km to the NE across the plume during the last 400 ka. This means that if the plume model is tenable, both volcanoes should record differences in the compositions of their lavas, reflecting changes in both source components and melting processes as the volcanoes traverse the plume.

A critical parameter of plume models is that the plumes are hotter (100 -300 °C) than the ambient mantle, and are therefore thermally zoned with a hotter core and cooler margins. The volcanic growth stages of Hawaiian volcanoes (introduced by Stearns almost 60 years ago) provides compelling evidence for a thermally zoned plume (and therefore for a higher temperature). Additionally, melting experiments on peridotites indicate that changes in the extent of melting, or in the depth of melt segregation, will result in differences in SiO₂, MgO and FeO in the parental magmas. Given a thermally-zoned plume, one should expect to see differences in these variables over time as the volcano transits the plume. This is the case for Mauna Kea. The normalized SiO₂ content of the lavas decreases over time, along with eruption rates, as the volcano approaches the post-shield stage. Paradoxically, there are no such temporal changes of composition in Mauna Loa lavas. All Mauna Loa lavas follow well-defined olivine-control trends that are indistinguishable from modern historical lavas. The implications are that melting and melt segregation processes have remained remarkably

constant over a broad region of the plume without signs of any thermal gradient. How hot is the plume relative to ambient mantle? Calculations using an olivine - melt geothermometer indicates that Mauna Loa parental magmas are about 150 °C hotter than parental MORB magmas, consistent with the expected differences of between 100 and 300 °C.

Pb and Sr isotopic data, in combination with X/Nb ratios, for Mauna Loa lavas, clearly indicate that lavas older than 100 ka are distinct from younger lavas (<36 ka). The younger lavas are more variable, and tend to have higher Sr and lower Pb isotopic ratios than the older lavas. The older lavas have Pb and Sr isotopic ratios that approach those of Kilauea, Loihi and Mauna Kea volcanoes. In contrast, Mauna Kea lavas older than 320 ka are isotopically similar to modern Kilauea lavas. These data can be reconciled with a concentrically zoned plume model, resulting from entrainment, in which the so-called “Kea” components are peripheral to axial “Loa” components. New, high precision, Pb - Pb isotopic data tell a somewhat different story. The Pb isotopic data require bilateral asymmetry in the plume with long-lived vertical heterogeneities.

These inferences are consistent with (but derived independently!) recent plume models where entrainment is minimal and heterogeneities at the core - mantle boundary are stretched into long vertical streaks within the plume (Farnetani and Samuel, 2004).