

## Filaments in a laterally heterogeneous plume tail

C.G. FARNETANI<sup>1</sup> AND H. SAMUEL<sup>2</sup>

<sup>1</sup>Institut de Physique du Globe, Paris, France  
(cinzia@ipgp.jussieu.fr)

<sup>2</sup>Yale University, Dept. of Geology and Geophysics, New Haven, CT, USA (henri.samuel@yale.edu)

Unraveling mantle plume's structure and dynamics using petrological and geochemical observations of surface lavas is certainly a challenging task. For some hotspots (e.g., Hawaii) the question is not only to understand the origin of geochemical variability within each volcano, but to combine observations for different volcanoes and at different times to reconstruct the puzzle of the internal plume structure.

Numerical models of plume dynamics can be useful to constrain the temperature and velocity fields within the plume conduit. Moreover, the advection of passive tracers forward in time allows us to understand how deep mantle heterogeneities are deformed within rising mantle plumes. Our results show that plume tails are laterally heterogeneous, with a highly irregular zonation. Across the plume tail radial variations of the vertical velocity induce a shear stress that readily stretches heterogeneities into long and distinct filaments. Such filaments will be successively sampled by different volcanoes as the oceanic plate moves over the plume tail. Ideally, the isotopic fingerprint of a distinct filament could be detected in several volcanoes of different ages. Our results strongly indicate that filaments represent a fluid dynamically consistent framework to interpret space and time geochemical variability of hotspot lavas.

## An explanation of the longevity and composition of hotspot volcanism in terms of the dynamics of mantle plume formation

A. MARK JELLINEK<sup>1</sup> AND MICHAEL MANGA<sup>2</sup>

<sup>1</sup>Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, BC, Canada, V6T 1Z4

<sup>2</sup>Department of Earth and Planetary Science, University of California, Berkeley, CA, 94720

A physical link has been proposed between hotspots, regions with particularly persistent, localized, and high rates of volcanism, and underlying low viscosity deep mantle plumes constructed of large spherical heads and long-lived narrow trailing conduits. This plume model has provided a way to interpret observable phenomena including the volcanological, petrological and geochemical evolution of large igneous provinces, ocean island volcanoes, the relative motion of plates, continental breakup, global heat flow and the Earth's magnetic field within the broader framework of the thermal history of our planet. An essential test of the mantle plume hypothesis is to understand the longevity and composition of hotspot volcanism in terms of the mechanics governing the formation of mantle plumes at their core-mantle boundary. Using a combination of laboratory experiments, numerical simulations and scaling analyses we show that: 1) The high temperatures (and low viscosities) inferred for mantle plumes are likely a result of strong cooling of the mantle by large-scale stirring driven by plate tectonics; 2) The head-tail structure of such plumes is a necessary but insufficient condition for their longevity; 3) The longevity, spatial position and composition of mantle plumes are a consequence of interactions between plate tectonics, core cooling and a dense, low viscosity layer within D'', which is plausibly composed of a mixture of silicate partial melt and outer core material. Under certain conditions, analysis of entrainment from this dense layer leads to a prediction that the variation in <sup>3</sup>He/<sup>4</sup>He (or any tracer of the silicate component of the lower mantle plume source) will be proportional to plume buoyancy flux, which is broadly consistent with observations.

## Geochemistry and morphology of submarine terraces from the southwestern Galápagos platform

B. DIEFENBACH<sup>1</sup>, D. GEIST<sup>1</sup>, M. KURZ<sup>2</sup>, D. FORNARI<sup>3</sup>  
AND K. HARPP<sup>4</sup>

<sup>1</sup>University of Idaho, Department of Geological Sciences, Moscow, ID 83843, USA (dief5183@uidaho.edu, dgeist@uidaho.edu)

<sup>2</sup>Woods Hole Oceanographic Institution, Marine Chemistry and Geochemistry Dept., Woods Hole, MA 02543, USA (mkurz@whoi.edu)

<sup>3</sup>Woods Hole Oceanographic Institution, Geology and Geophysics Dept., Woods Hole, MA 02543, USA (dfornari@whoi.edu)

<sup>4</sup>Colgate University, Department of Geology, Hamilton, NY 13346, USA (kharpp@mail.colgate.edu)

The southwestern margin of the Galápagos Platform consists of large, stepped submarine terraces between depths of 800 and 3500 m. The terraces form the foundation for the southwestern part of the archipelago and provide indications of how the Galapagos platform has developed over time. The terraces are topped by plateaus and bound on their upper and lower sides by steep escarpments. Scarps average ~300 m in height, with an average slope of ~24°. Distal edges of the terraces extend tens of kilometers from current volcanic centers. Young submarine lava flow fields to the west of Fernandina and Isabela Islands have dimensions similar to the terraces, and it is possible that the terraces are constructed by eruptions similar to those that produced the large flow fields. The stepped morphology and sinuous continuity of the platform edges suggest that the terraces reflect episodic volcanic construction that builds the archipelagic platform.

A comparison of trace element contents and Sr, Nd, Pb, and He isotopic ratios of basalts dredged from the terraces indicate that most terraces are chemically similar to subaerial lavas erupted from Sierra Negra volcano on Isabela Island. A few of the basalts resemble subaerial Volcán Cerro Azul compositions, and one sample is comparable to Floreana Island lavas. Basalts from a ridge that extends south from Floreana Island have a strong Sierra Negra signature, which is interpreted as an older phase of volcanism and provides evidence for compositional evolution at Floreana.

These findings suggest that volcanism in the southern Galápagos consists of three phases; 1: construction of terraces by voluminous eruptions with a Sierra Negra-like composition; 2: eruptive activity focuses to form shield volcanoes; 3: a rejuvenation phase, producing Floreana and related submarine lavas.

## The depleted Galápagos mantle: Plume or upper mantle?

D. J. GEIST<sup>1</sup>, K.S. HARPP<sup>2</sup> AND M.D. KURZ<sup>3</sup>

<sup>1</sup>Dept. of Geological Sciences, University of Idaho, Moscow, ID, USA (dgeist@uidaho.edu)

<sup>2</sup>Dept. of Geology, Colgate University, Hamilton, NY, USA (kharpp@mail.colgate.edu)

<sup>3</sup> Dept. of Marine Chemistry and Geochemistry, WHOI, Woods Hole, MA, USA (mkurz@whoi.edu)

Recently, researchers have hypothesized that the depleted sources at the Iceland, Hawaii, and now Galápagos hotspots are intrinsic parts of the mantle plumes and not the ambient upper mantle. This hypothesis is evaluated by comparing the compositions of two of the most depleted volcanoes in the Galápagos (Wolf on Isabela island and Genovesa) to MORB from the Galápagos Spreading Center (GSC).

Wolf volcano lavas have similar Nd, Sr, Pb, and Hf isotopic ratios to GSC lavas erupted 250 km east and 400 km west of the area of maximum plume influence. <sup>208</sup>Pb/<sup>204</sup>Pb ratios of Wolf basalts are slightly lower (by 0.05 to 0.30) than those from the GSC with equivalent <sup>143</sup>Nd/<sup>144</sup>Nd and <sup>206</sup>Pb/<sup>204</sup>Pb. Highly incompatible trace element ratios (e.g. Ba/La and Ba/Nb) are also identical between the two suites. Genovesa has Sr, Nd, Pb, and Hf isotopic ratios that are indistinguishable from GSC MORB erupted 700 to 800 km away from the peak of plume influence. Helium isotopic ratios are higher at Wolf volcano than anywhere along the GSC (average of 9.0 Ra vs. 5.9 to 8.6 Ra). A submarine sample from Genovesa is also higher than any measured lava from the GSC. This pattern is consistent with extreme incompatibility and preferential extraction of helium near the plume center, which has been attributed to multistage melting during the ascent of the Galapagos plume (Kurz and Geist, 1999). Major element compositions of Wolf volcano and Genovesa lavas indicate melt extraction from greater depths than GSC magmas. Wolf magmas have higher La/Sm, Nb/Zr, and K/Ti than GSC rocks, indicating lower extents of melting at Wolf. Nb-Zr-Y relationships between the three suites are consistent with differences in the extent of partial melting from a similar source.

These observations are consistent with derivation of Wolf, Genovesa, and the GSC magmas from the ambient mantle that has been contaminated with plume material. The differences in depth of melt extraction and degree of melting are attributed to progressively thicker lithospheric lids with distance from the GSC.

## Temporal variations of a heterogeneous mantle plume source; Santiago, Cape Verde

A.K. BARKER<sup>1</sup>, P.M. HOLM<sup>1</sup>, D.W. PEATE<sup>2</sup>  
AND J.A. BAKER<sup>3</sup>

<sup>1</sup>Geological Institute (Danish Lithosphere Centre), University of Copenhagen, Øster Voldgade 10L, 1350 Copenhagen, Denmark (akb@geol.ku.dk)

<sup>2</sup>University of Iowa, Department of Geoscience, 121 Trowbridge Hall, Iowa City, IA 52242, USA

<sup>3</sup>School of Earth Sciences, Victoria University of Wellington, P.O. Box 600, Wellington, New Zealand

The Cape Verde Archipelago is known to display source heterogeneity on a 100-200 km scale, with different isotopic domains sampled in the northern islands (dominated by a HIMU signature), compared with the southern islands (a mixed EM-I, HIMU and DM character). A detailed investigation of one of the northern islands (Santo Antao) revealed small scale variations that show unique temporal variations between four components. Further investigation of small scale variations within the southern islands and a temporal comparison between the northern and southern islands is imperative to understand the dynamics of mantle flow and the lengthscales of compositional heterogeneities.

We have investigated several lava suites from one of the southern islands (Santiago) that erupted over the last 6 million years. We will present high precision Pb isotope data (using a <sup>207</sup>Pb-<sup>204</sup>Pb double spike) and Sr-Nd-Hf isotope data that highlight small scale temporal variations in source compositions.

The evolution of the different components through time on Santiago is best illustrated by variations in <sup>208</sup>Pb/<sup>204</sup>Pb. The submarine lavas of the earliest Flamengos Formation record the highest <sup>208</sup>Pb/<sup>204</sup>Pb. The intermediate volcanics erupted subaerially have lower <sup>208</sup>Pb/<sup>204</sup>Pb, forming an oblique trend to the submarine lavas. The youngest lavas also have low <sup>208</sup>Pb/<sup>204</sup>Pb and form a parallel trend to the submarine lavas extending to lower <sup>206</sup>Pb/<sup>204</sup>Pb. The submarine lavas have lower <sup>87</sup>Sr/<sup>86</sup>Sr than the intermediate volcanics. The young volcanics overlap the <sup>87</sup>Sr/<sup>86</sup>Sr of the submarine and intermediate lavas, extending to higher <sup>87</sup>Sr/<sup>86</sup>Sr.

Santiago shows contrasting positive  $\Delta 8/4$  relative to the negative  $\Delta 8/4$  of the northern islands confirming the presence of the north-south compositional divide for at least 6 million years. There are significant local variations produced by mixing of HIMU, DM, EM-I and a carbonatite related source.

## Isotopic and geochemical characteristics of the Réunion hotspot: Evidence from the lavas of Mauritius

S. NOHDA<sup>1</sup>, I. KANEOKA<sup>2</sup>, T. HANYU<sup>3</sup>

<sup>1</sup>Dept. Environ. Sci., Kumamoto Univ., Kumamoto 860-8555, Japan (snohda@sci.kumamoto-u.ac.jp)

<sup>2</sup>ERI, Univ. Tokuo, Tokyo, Japan (Ikaneoka@aol.com)

<sup>3</sup>IFREE, JAMSTEC Yokosuka, Japan (hanyut@jamstec.go.jp)

We report Sr, Nd, and Pb isotopic compositions for the lavas of Mauritius, the second youngest volcanic island in the Réunion hotspot. The lavas of the Older Series (7.8-5.5 Ma) have identical isotopic compositions with those of Réunion where the center of volcanic activity is currently located. The lavas of the Intermediate Series (3.5-1.9 Ma) and Younger Series (0.70-0.17 Ma) are shifted to the depleted isotopic signatures. The diagram of Zr/Nb vs. Ba/Y also revealed that the strong geochemical similarity between the Older Series lavas and those of Réunion and the involvement of a depleted MORB-source mantle component in the genesis of the Younger Series lavas. During the volcanic history of Mauritius, the magmas lost the principal isotopic and geochemical characteristics of the Réunion hotspot with time, and became gradually imprinted with the isotopic signature of a shallower source that produced the Central Indian Ridge basalts.

## Estimates of mantle temperatures based on olivine phenocrysts and olivine-melt equilibria

KEITH D. PUTIRKA

California State University, Fresno, Department of Earth and Environmental Sciences, 2576 E. San Ramon Ave., MS/ST25, Fresno, CA 93720, USA  
(kputirka@csufresno.edu)

The magnitude of the temperature differences between oceanic islands and mid-ocean ridges is crucial to the identification of thermal plumes. Green et al. (1999) have noted that maximum forsterite (Fo) contents of olivines from several MOR segments match or exceed maximum Fo values at Hawaii, and use estimated MgO contents to infer that mantle potential temperatures are nearly equal at Hawaii and MOR's. However, a re-consideration of olivine saturation temperatures, using the approach of Roeder and Emslie (1970) and Langmuir and Hanson (1981), indicates that very high Fo content crystals need not imply high mantle temperatures. A comparison of the highest Fo contents from the Hawaiian Islands and several mid-ocean ridge localities appears to require higher melting temperatures in the Hawaiian source region by approximately 250 K, when observed FeO contents (rather than calculated MgO contents) are used as model input. This analysis is in contrast to that of Green et al. (1999) in that by using FeO as input, greater amounts of MgO in primitive Hawaiian liquids (20 wt. %) are implied. In contrast, the methods of Green et al. (1999) underestimate FeO at Hawaii. The present calculations also utilize a higher value for the Fe-Mg exchange coefficient for ol-liq (0.35); this higher value is likely more appropriate for equilibration at the pressures appropriate to the base of the Hawaiian lithosphere (Herzberg and O'Hara, 1998). If melt fractions are similar at Hawaii (8-15%; Feigenson et al., 2003) and MOR's (6-18%; Kinzler & Grove, 1992), then decompression at Hawaii yields a smaller value for the difference in mantle potential temperatures: about 220 K, similar to estimates required by geodynamic models for mantle thermal upwellings. It thus seems unnecessary for mantle plume advocates to require that high Fo content olivines at mid-ocean ridges are disequilibrium xenocrysts, completely unrelated to melting or crystallization phenomena.

## Magmatic segmentation of the East Pacific Rise

D.R. TOOMEY AND E.E.E. HOOFT

Dept. of Geological Sciences, University of Oregon, Eugene, OR 97403, USA (drt@uoregon.edu, emilie@uoregon.edu)

Competing models for what controls the intensity of ridge crest processes are at odds on the scale of magmatic segmentation of the mantle and crust. One popular and long held view is the magma supply hypothesis, wherein mantle melt is centrally injected into a ridge segment bounded by long-lived tectonic discontinuities and ridge parallel flow of magma over distances of 10's of kilometers gives rise to along-axis variations in ridge crest processes. In this view, the scale of mantle melting at depths of 30 to 60 km is thought to govern the scale of magmatic segmentation of the mid-ocean ridge. Axial variations in volcanic, tectonic and hydrothermal activity are attributed to waxing and waning episodes of melting events. Where magma supply is high, greater amounts of volcanic and hydrothermal activity are predicted. Where the ridge is 'starved' of magma, tectonic activity predominates. Recent studies at the East Pacific Rise, however, bring up several challenges to the magma supply hypothesis and an alternative model which we refer to as magma plumbing. The two essential features of the magma plumbing hypothesis are the scale of along-axis segmentation of shallow mantle upwelling and the vertical (mis)alignment of the mantle and crustal magmatic systems. In this view, magma injection from the mantle to the crust occurs at more-or-less equally spaced intervals within a ridge segment bounded by tectonic discontinuities and the cross-axis offset between a center of mantle upwelling and an axial volcano regulates the intensity of ridge crest processes. When the mantle and crustal plumbing systems are aligned, the ridge crest is more volcanically and hydrothermally active. Conversely, when the mantle and crustal plumbing systems are misaligned by many kilometers, the intensity of extrusive volcanic and hydrothermal activity is less, while tectonic activity is increased. As a consequence, even at constant magma supply (or mantle temperature) the intensity of seafloor processes can be fundamentally different because of magma plumbing. We will show that the magma plumbing model can successfully predict along-axis variations in axial depth, major element basalt chemistry, crustal thickness variations and gravity anomalies. We will also discuss several implications, including the likelihood of active upwelling in the shallow mantle (<30 km depth), the effects of ridge migration on the secular evolution of ridge crest processes and the formation of replacive dunites along interfaces sub-parallel to the Moho.

## Boron isotope compositions of South Atlantic MORB and mantle sources

P.J. LE ROUX<sup>1</sup>, J.E. DIXON<sup>2</sup>, S.B. SHIREY<sup>3</sup>  
AND E.H. HAURI<sup>3</sup>

<sup>1</sup>Danish Lithosphere Centre, Copenhagen, Denmark  
(plr@dlc.ku.dk)

<sup>2</sup>RSMAS/MGG, University of Miami, Miami, Florida, USA  
(jdixon@rsmas.miami.edu)

<sup>3</sup>DTM, Carnegie Institution of Washington, Washington, DC,  
USA (shirey@dtm.ciw.edu, hauri@dtm.ciw.edu)

The B isotope composition of subducted materials such as altered oceanic crust ( $\delta^{11}\text{B} +3.7\%$ ) or marine sediments ( $\delta^{11}\text{B} -4\%$  to  $+16\%$ ) is typically significantly higher than the mantle ( $\delta^{11}\text{B} -10\pm 2\%$ ) making B isotopes potentially useful as a tracer of mantle recycling. New *in situ* B isotope compositions [1], plus volatile, halogen and light-element concentrations [2], are being obtained on South Atlantic MORBs that show effects in trace elements [3], water content [4] and radiogenic isotopes [5] of recycled plume or crustal components.

B isotope compositions of these MORB samples indicate local depleted MORB mantle (DMM)  $\delta^{11}\text{B}$  of  $-11.7\pm 1.0\%$  to  $-10.1\pm 0.9\%$ , while one sample affected by assimilation of high  $\text{H}_2\text{O}$ , altered crust [4], has  $\delta^{11}\text{B}$  of  $-3.8\pm 0.9\%$ . Samples affected by EM mantle components (Discovery and Shona Group II [4]) trend towards heavier  $\delta^{11}\text{B}$  (up to  $\sim 7\%\pm 1.0\%$ ) with increasing plume influence. Correlated increasing  $\delta^{11}\text{B}$ , Ba/Nb and decreasing  $\text{H}_2\text{O}/\text{Ce}$  in these samples indicate that although subducted lithosphere might be efficiently dehydrated [4], a heavy  $\delta^{11}\text{B}$  composition survives to raise  $\delta^{11}\text{B}$  in these EM-affected MORB mantle sources to  $\sim 7\%$  or higher. The  $\delta^{11}\text{B}$  of 2 samples affected by Shona Group I type components [4] (FOZO type mantle) is  $-7.8\pm 0.9\%$  and  $-7.5\pm 1.0\%$ , similar to EM-affected samples. This could reflect a fundamental difference between the MORB source and lower mantle in B composition.

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## Volatile (C, N, Ar) heterogeneity in MORB popping-rock vesicles: Mantle volatiles mixed with air

P. CARTIGNY, F. PINEAU AND M. JAVOY

Laboratoire de Géochimie des Isotopes Stables, Institut de  
Physique du Globe de Paris, France  
(cartigny@ipgp.jussieu.fr, fpi@ipgp.jussieu.fr,  
mja@ipgp.jussieu.fr)

In order to better characterise the so-called “air-like noble gases” measured among mid-ocean ridge basalt vesicles, we analysed C, N, Ar-contents, C- and N-isotopes of gas released during step crushing of two chunks of MORB popping rock dredged at 14°N on the Mid Atlantic ridge.

The results obtained through 13 crushing steps show large variations in  $\delta^{15}\text{N}$  from 0.0 to  $-5.1\%$ , the variations being correlated positively with  $\text{N}_2/\text{Ar}$  (from 83.3 to 41.6) and negatively with C/N-ratios (from 20 to 444) respectively. The variations are best explained by a binary mixing between an atmospheric [ $\delta^{15}\text{N} (\equiv 0\%)$ ,  $\text{N}_2/\text{Ar}$  (83.5) and C/N ( $\sim 0$ )] with one step being nearly atmospheric and a mantle component [ $\delta^{15}\text{N} \sim -5.1\%$ ,  $\text{N}_2/\text{Ar} \sim 45$  and C/N  $\sim 430$ ]. The mantle end-member is particularly well constrained by the intersection of the mantle-atmosphere mixing line with the late-stage degassing trend (increasing  $\delta^{15}\text{N}$ , decreasing  $\text{N}_2/\text{Ar}$ ) defined by three crushing steps. We stress that these specific values cannot reflect contamination by air-saturated water as the samples show associated increasing C/N.

We thus extend the observation of “air-like noble-gases” (i.e. as opposed to air-saturated sea-water, see Ballentine and Barford, 2000) to major volatiles (C, N). The origin of atmospheric-vesicles is unlikely to be related to “the subduction of air-like noble gases” (see Sarda, 2004). Indeed, a subducted component would rather show positive  $\delta^{15}\text{N}$  and  $\text{N}_2/\text{Ar}$  higher than air reflecting that in subduction zones, high amounts of nitrogen (with positive  $\delta^{15}\text{N}$ ) are present in metasediments. Moreover, following the model of Sarda (2004), air-like noble gas vesicles would form first. This is incompatible with the inferred amount of atmospheric nitrogen ( $0.20\text{-}0.22\ \mu\text{mol/g}$ ) and uncontaminated mantle-derived  $\text{CO}_2$  ( $\sim 69\ \mu\text{mol/g}$ ). From the data and the respective solubilities of N and C, we would indeed infer that the first vesicles to form would have been the  $\text{CO}_2$ -rich vesicles.

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## Upper mantle dynamics expressed in hotspot and mid-ocean ridge basalt chemistry

GARRETT ITO, TODD BIANCO, JOHN J. MAHONEY,  
JANET BECKER AND MICHAEL GARCIA

SOEST, Univ. of Hawaii, USA (gito@hawaii.edu)

The fact that the mantle is heterogeneous on scales much smaller than the size of upper mantle melting zones, and the likelihood that the different source components begin melting at different depths both allow for the possibility that 3D variations in upper mantle flow can contribute to geochemical variations in erupted magmas. One example is the spatial variations observed along hotspot-influenced ridges. If a ridge-centered hotspot is fed by a narrow, buoyant upwelling (e.g., mantle plume), then compared to the non-influenced portions of the mid-ocean ridge, the hotspot will tend to more heavily sample those materials that begin melting deepest. The main reason is that the flux of mantle through the deepest portion of the melting zone is predicted to be larger than the flux through the shallower portions. Such “plume flow” contrasts with normal mid-ocean ridge flow, which is likely to be more uniform at all depths of the melting zone. Assuming that the isotopic end-member DMM begins melting shallowest and the other end-members begin melting deeper, our models predict that a large percentage of the variation in Sr, Nd, and Pb associated with the Iceland-Mid-Atlantic Ridge system can be caused by the transition from plume-like flow beneath Iceland to normal mid-ocean ridge flow far from Iceland, even without any variation in the mantle source.

Another example pertains to the geochemical differences between Hawaiian shield and rejuvenated or secondary lavas. We propose that the secondary volcanism forms due to decompression caused by lithospheric upwarping at the flexural arch surrounding volcanic shields. Such an origin is supported by the observation that on- and off-shore secondary volcanism has most frequently occurred at distances from growing shields (200-400 km) that coincide with the likely locations of rising flexural arches. Models predict that mantle is drawn upward beneath the arch at a rate that is largest near the top of the melting zone and decreases with depth. Arch melting will thus tend to more heavily sample the shallower melting, DMM-like components in a heterogeneous Hawaiian hotspot mantle. In contrast, shield lavas are likely to form in the presence of rapid, deep mantle plume flow, as described above, which tends to sample EM or HIMU components. Calculations show how such processes can produce the differences in the average Sr and Nd compositions between the two volcanic stages.

## Spatial and temporal isotopic variability in ocean island volcanism: The noble gas story

MARK D. KURZ

Marine Chemistry and Geochemistry, Woods Hole  
Oceanographic Institution, Clark Laboratory, MS #25,  
Woods Hole, MA 02543, USA (mkurz@whoi.edu)

Extremely unradiogenic helium and neon isotopic signatures are preferentially found in the largest active ocean island hotspot provinces such as Hawaii, Iceland and Galapagos. Unradiogenic mantle noble gas isotopes have generally been interpreted as indicating deep, relatively undegassed mantle sources, but this has been challenged by researchers who do not believe relatively undegassed reservoirs can be accommodated within whole mantle convection models. The spatial and temporal variability within ocean island provinces and volcanoes provide important constraints on the dynamics of mantle upwelling and convection. The least radiogenic helium isotopes are found within the most active sectors of ocean island provinces (e.g., Loihi seamount, central Iceland, and Fernandina) supporting a global relationship between heat, melting, and unradiogenic noble gases. Correlations between helium and neon isotopes suggest that this relationship extends to neon. The best examples of temporal noble gas isotopic evolution are provided by Hawaiian lava flows where time scales and stratigraphy are relatively well constrained. The lowest  $^4\text{He}/^3\text{He}$  ratios are always found in the shield building tholeiites (e.g., for Haleakala, Mauna Loa, Hualalai, as well as newer data sets from Mauna Kea and Koolau volcanoes). Mauna Loa data indicates that the shield building stage of Hawaiian volcanoes is mostly characterized by unradiogenic helium, implying that this also represents the bulk of the upwelling/melting mantle. These considerations, and the correlations between helium and the other elements, show that large volumes of mantle with unradiogenic noble gases are required. This cannot be explained by dispersed upper mantle sources; the lower mantle, or at least mantle below the 670km discontinuity, is the most likely site for unradiogenic noble gases. Temporal isotopic evolution, as observed at Hawaii, has not been well documented elsewhere, but this may relate to the lack of appropriate sampling. This is important because temporal evolution can be obscured in global geochemical compilations and can complicate mixing relationships.

## Help yourself to some more mantle components! No, thanks, I'm fine.

F. ALBAREDE

Ecole Normale Supérieure, 69007 Lyon, France

Igneous geochemists hold an infinite supply of mantle components. Geochemical literature is rife with acronyms which initially helped capture a small set of geodynamic conditions that shaped mantle geochemistry. Unfortunately, adding more and more of these mantle components eventually confused this relatively simple picture: first, it has not always been clear whether these newcomers are actually demanded by existing data, and second, they added so many dimensions to the problem that they stopped providing a useful description of mantle composition and dynamics altogether. I here focus on the problem of eliminating spurious components and finding criteria for defining the minimum number of self-sufficient but exhaustive mantle components that will account for the geochemical variability of a given data set.

Mixing does not produce linear arrays in isotopic ratios diagrams unless the denominator isotopes are identical or in constant proportions. Such a linearity condition promotes Pb isotopic compositions as the prime criterion to assess a number of components with the full power of statistical tests. Mass conservation relationships in composite isotopic spaces such as Pb-Nd-Sr-Hf-He are curvilinear (hyperbolic). Simple simulations show that handling such relationships as linear relationship, e.g., using Principal Component Analysis, will spuriously redistribute variance among existing components and even create new ones. Propagating errors on PCA results helps identify this source of scatter, which is, however, further aggravated by elemental fractionation (e.g., Hf/Pb) during melting. I here give a few examples from the Mid-Atlantic MORB for which a careless PCA would produce 4-5 components whereas three geochemical components and precisely three are identified by Pb isotopes. In addition, among the competing components FOZO, PHEM, and C, only C passes the test of plotting on a PCA eigenvectors for Pb isotopes, while a participation of the HIMU component seems excluded by the data.

An additional test for the presence of live components is the consistence of the dominant wavelengths of isotopic anomalies over long distances along mid-ocean ridges. For instance, a harmonic analysis of the three Pb isotope components has been calculated for Atlantic MORB between 80°N and 60°S. The wavelengths of the relative abundances DM/C and EM/(DM+C) are very different, which requires that these components formed by distinct geodynamic processes.

## The Hikurangi oceanic plateau: Another large piece of the largest volcanic event on earth

K. HOERNLE<sup>1</sup>, F. HAUFF<sup>1</sup>, P. VAN DEN BOGAARD<sup>1</sup>,  
R. WERNER<sup>2</sup> AND N. MORTIMER<sup>3</sup>

<sup>1</sup>Leibniz Institute for Marine Sciences (IFM-GEOMAR), Wischhof Straße 1-3, 24148 Kiel, GER (khoernle@ifm-geomar.de; fhauff@ifm-geomar.de; pbogaard@ifm-geomar.de)

<sup>2</sup>Tethys Geoconsulting GmbH, Wischhofstrasse 1-3, 24148 Kiel, GER (rwerner@ifm-geomar.de)

<sup>3</sup>GNS, Private Bag 1930, Dunedin, New Zealand (N.Mortimer@gns.cri.nz)

New <sup>40</sup>Ar/<sup>39</sup>Ar age, geochemical and bathymetric data have been generated for the Hikurangi oceanic plateau (near New Zealand) with an area of  $\geq 800,000$  km<sup>2</sup>, if subducted portions are included. The data are consistent with the Hikurangi 1) having been part of the "Greater Ontong Java Event", during which 1% of the Earth's surface was covered with submarine volcanism, and 2) having been connected to the Manihiki Plateau, presently located more than 3000 km to the north. The Hikurangi plateau basement (93-118 m.y.) was derived from an enriched mantle (EM) source, similar in composition to the Ontong Java and Manihiki Plateaus (ca. 122 m.y.); whereas large alkalic guyots on the plateau (86-99 m.y.) were derived from a distinct high 238U/204Pb (HIMU) mantle source, similar to alkalic dikes (90 m.y.) on Ontong Java and possibly to seamounts (ca. 75-86 Ma) on Manihiki. Observations supporting the hypotheses that the Hikurangi and Manihiki Plateaus may have once formed a single plateau include bathymetric data indicating that the NW Hikurangi margin is a rifted margin and overlap in age range and Sr-Nd-Pb isotopic compositions of basement samples. Together a combined Hikurangi/Manihiki Plateau could have covered an area of  $\geq 1.3$  million km<sup>2</sup>, similar in size to the Ontong Java Plateau (1.5 million km<sup>2</sup>), the largest oceanic plateau on Earth. The compositional range of the Hikurangi Plateau is similar to the Cook Austral Islands, suggesting derivation from a common or at least similar source(s). We pose the question of whether a combined HikuMani Plateau might represent the initial event of the Cook Austral Island and seamount volcanism. Similarities in age and geochemistry of late-stage volcanism on the Hikurangi, Ontong Java and Manihiki Plateaus further suggest that all three plateaus may have had a similar long-term geochemical evolution lasting more than 30 m.y.

## The magmatic plumbing of volcanic plateaus: Petrogenetic and economic implications

NICHOLAS ARNDT

LGCA, Université Joseph Fourier, 38041 Grenoble, France  
(arndt@ujf-grenoble.fr)

Magmas in continental or oceanic plateaus result from the partial melting of an upwelling, sub-lithosphere source. The geometry of this source may be far more complicated than that of a classic cylindrical or mushroom shaped mantle plume, but a static source within or below the lithosphere cannot produce a sufficiently large volume of hot magma, erupted within a short period of time. Magmas of alkaline affinity interact little with the crust during their ascent because dissolved and subsequently exolved volatiles reduce the density of the magma and drive it to the surface without being trapped at density barriers at the base of or within the crust. Tholeiitic magmas, on the other hand, ascend through a complex series of lower to mid crustal magma chambers where they evolve and interact with the crust. Primary picritic magma fractionally crystallizes, assimilates its wall rocks and is homogenized to produce the uniform, evolved, siliceous flood basalts that make up to bulk of most volcanic plateaus. In the upper crust, particularly in the sediment piles that underlie most plateaus, the magma passes through a hugely complex network of sills, such as those beneath the Karoo or Siberian provinces. Further magma-crust interaction takes place in the sills. Very few magmas escape this interaction — the “continental” geochemical signature in most flood basalts results mainly from crustal interaction and is not inherited from a mantle source.

The assimilation of granitic or sedimentary rocks by magmas of the Siberian province led to the segregation of magmatic sulfides and the formation of the large and rich Ni-Cu-PGE deposits of Noril'sk-Talnakh region. The ore-forming process was triggered by the assimilation of evaporite at very shallow levels in the sediment pile. The dynamics of magma flow and the extent and mechanism of wall-rock assimilation was influenced by the structure and rheology of the sediments, particularly their degree of consolidation and lamination, features related to the depth below the surface at the time of intrusion.

## A HIMU source in metasomatised continental lithosphere

K.S. PANTER<sup>1</sup>, J. BLUSZTAJN<sup>2</sup>, S. HART<sup>2</sup>, C. FINN<sup>3</sup>  
AND P. KYLE<sup>4</sup>

<sup>1</sup>Dept. Geology, Bowling Green State University, Bowling Green, OH 43403, USA (kpanter@bgsu.edu)

<sup>2</sup>Dept. Geology & Geophysics, Woods Hole Oceanographic Institute, Woods Hole, MA 02543, USA

<sup>3</sup>U.S. Geological Survey, Denver Federal Center, MS 945, Denver, CO 80226, USA

<sup>4</sup>Dept. Earth & Environmental Science, New Mexico Tech, Socorro, NM 87801, USA

Late Cretaceous-Quaternary continental basalts from the Chatham and Antipodes Islands, New Zealand, are characterized by trace element and isotopic affinity with oceanic HIMU basalts. The alkaline basalts have trace element (Ce/Pb 28-36, Ba/Nb 4-7, La/Yb<sub>n</sub> 12-28) and isotopic (<sup>87</sup>Sr/<sup>86</sup>Sr 0.7029-0.7034, <sup>206</sup>Pb/<sup>204</sup>Pb 19.8-20.8) signatures that indicate low-degree melts (~3%) of garnet periodotite. Negative K-anomalies on spidergrams reflect residual amphibole ± phlogopite in the source. The inversion of trace elements reveal enriched mantle (1-4 x PM) and heterogeneity due to differences in the proportions of hydrous and anhydrous minerals.

Calculated melt segregation pressures of ~4.3 GPa (Chatham) and ~5.2 GPa (Antipodes) are equivalent to depths of ~130 km and ~160 km. Pressures calculated for individual episodes of volcanism on Chatham Island show that the depth of melting has varied little (±0.15 GPa) in ~80 Ma. Temperatures at the top of the asthenosphere are often defined to be ~1300°C, which for much of SW Pacific, would occur at shallow levels (~50-80 km). In this case, the continental geotherms would resemble the asthenosphere adiabat with major melting and generation of tholeiitic and not alkalic basalts. Lithospheric thickness estimates of 100-150 km based on geophysical data suggest that low velocity zones (<100-150 km) reflect melt/volatile sources with the lithosphere (Finn et al., in press). Melting within the lithosphere is also supported by the fact that Chatham Island has drifted ~3000 km (~65°S to 44°S) in ~85 Ma without significant change in depth or melt composition.

New Zealand was part of the eastern margin of Gondwana, juxtaposed to Australia, Tasmania and Antarctica in the Cretaceous. Cenozoic alkaline magmatism on each fragment has been linked to ancient metasomatised sources. The timing of metasomatism is constrained between 500 and 200 Ma, coincident with subduction and distribution of HIMU volcanism. We propose that subduction-related metasomatism modified the continental lithosphere and contributed to the HIMU signature (cf. Stein et al., 1997).

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## Geochemical and Sr, Nd, Pb, Hf isotope compositions of the Karoo large igneous province in Botswana-Zimbabwe

F. JOURDAN<sup>1,2</sup>, H. BERTRAND<sup>2</sup>, U. SCHÄRER<sup>1</sup>,  
J. Blichert-Toft<sup>2</sup>, G. FÉRAUD<sup>1</sup> AND A.B. KAMPUNZU<sup>3</sup>

<sup>1</sup>UMR-CNRS 6526 Géosciences Azur, O6108 Nice, France

<sup>2</sup>UMR-CNRS 5570, ENS & UCBL, 69364 Lyon, France

<sup>3</sup>University of Botswana, Gaborone, Botswana

The ~180 Ma Karoo continental flood basalt (K-CFB) province in southern Africa is one of the largest CFB on Earth (> 3 x 10<sup>6</sup> km<sup>2</sup>). It consists of tholeiitic lava flows, sills, and giant radiating dyke swarms related to the breakup of Gondwana. We report major and trace element and Sr-Nd-Pb-Hf isotope compositions for, respectively, 147 and 33 basaltic lava flows, sills, and dykes from Botswana, Zimbabwe, and northern South Africa, including both low- and high-Ti (< and >2 wt% TiO<sub>2</sub>) rocks. Both groups display LREE/HFSE enrichment (relatively to chondrite) with Nb depletion, but the latter has higher MREE/HREE ratios. Calculations suggest that the low-Ti basalts were generated by melting of a shallow spinel-bearing (2 % spinel) lherzolite, while the high-Ti magmas originated from a deeper garnet-bearing (2-7% garnet) lherzolite. In most isotope plots, the high-Ti lavas and picrites define a trend from BSE to compositions with strongly negative ε<sub>Nd</sub> and ε<sub>Hf</sub>, akin to those of some nephelinites and lamproites. The low-Ti rocks are shifted from BSE-like to more radiogenic Sr isotope compositions, indicative of some upper crustal contamination. The geochemical and isotopic signatures of the Bouvet, Shona, and Discovery hot spots are not evident in our data set and the role of a mantle plume head as direct contributor to K-CFB is speculative.

Alternatively, we suggest that K-CFB could have been produced by polybaric melting of a heterogeneous metasomatically enriched (partially veined) subcontinental lithospheric mantle (SCLM). Calculations show that mixing between a ~BSE-like component and strongly unradiogenic, with respect to Nd and Hf isotopes, nephelinite-like (vein-rich) material within the SCLM could account for the variations observed among most of the high-Ti group lavas. By contrast, the mantle source composition for the low-Ti lavas is more likely to be similar to a vein-free SCLM component. Our data do not exclude that a mantle plume may have contributed to the lithospheric melting. The spatial distribution of low-Ti and high-Ti magmas seems to match the craton-Limpopo belt positions, reinforcing the predominantly lithospheric control on K-CFB.

## Pb isotope heterogeneity between olivine-hosted melt inclusions, Eastern Snake River Plain, Idaho

LAUREN B. COOPER<sup>1,2</sup>, MARY R. REID<sup>3</sup>  
AND JULIA G. BRYCE<sup>4</sup>

<sup>1</sup>Dept. of Earth and Space Sciences, UCLA, Los Angeles, CA 90095, USA

<sup>2</sup>Dept. of Earth Sciences, Boston University, Boston, MA 02215, USA (lcooper@bu.edu)

<sup>3</sup>Dept. of Geology, Northern Arizona University, Flagstaff, AZ 96011, USA (mary.reid@nau.edu)

<sup>4</sup>Dept. of Earth Sciences, University of New Hampshire, Durham, NH 03824, USA (julie.bryce@unh.edu)

Isotopic compositions of intra-continental basalts could either under- or over-estimate the true heterogeneity of the subcontinental mantle, depending on the relative effects of blending isotopically distinct melt fractions and/or crustal contamination during ascent through the continental crust. We used a Cameca ims 1270 ion microprobe to obtain *in situ* Pb isotopic compositions of olivine-hosted MIs in basalts from the eastern Snake River Plain (ESRP), Idaho, to study early magma evolution in an intra-continental setting. Twenty-seven MIs from 21 olivine phenocrysts representative of 4 magnesian basalts (Mg#>59) were studied; the basalts are from diverse localities and span about half of the isotopic range observed for ESRP basalts. The ranges in Pb isotopic compositions obtained for the MIs are <sup>207</sup>Pb/<sup>206</sup>Pb = 0.831-0.892 and <sup>208</sup>Pb/<sup>206</sup>Pb = 2.058-2.17, larger than the ranges exhibited by the whole rocks (0.855-0.891, 2.107-2.201, respectively). Two samples yield isotopically homogenous MI populations. A third sample has a sole isotopically exotic MI. The same MI contains chemically distinct post-entrapment clinopyroxene (cpx) daughter crystals that require a distinct liquid line of descent. The MI population of the fourth sample is isotopically heterogeneous (<sup>207</sup>Pb/<sup>206</sup>Pb = 0.831-0.864 MSWD = 8.19, vs. 0.8491 for the groundmass). Geobarometry on cpx and glass within the same MIs yields pressures of no more than 0.5 GPa, significantly less than that obtained for cpx phenocryst crystallization (P>1.1 GPa) in another ESRP sample (Putirka et al., 2003). The somewhat greater variability in Pb isotopic compositions of these ESRP MIs than in their whole rock hosts (~factor of 2) contrasts with the 13 times greater variability of MIs than whole rocks for Cook and Society Island basalts (Saal et al., 1998). Either the ESRP source is relatively more homogeneous than that for these ocean islands or, more likely, homogenization occurs at levels at or deeper than the mid-crust prior to olivine growth and melt entrapment.

## Isotopic study of Mauna Loa's submarine Southwest Rift Mile High Section: Hawaiian mantle plume structure

DOMINIQUE WEIS<sup>1</sup>, J. MIKE RHODES<sup>2</sup>, MIKE O. GARCIA<sup>3</sup>  
AND THE SUBMARINE MAUNA LOA SCIENCE TEAM

<sup>1</sup>PCIGR, Dept. of Earth and Ocean Sciences, University of  
British Columbia, Vancouver, V6T 1Z4, Canada;  
(dweis@eos.ubc.ca)

<sup>2</sup>Dept. of Geosciences, University of Massachusetts, Amherst,  
MA 01003, USA

<sup>3</sup>Dept. of Geology-Geophysics, University of Hawaii,  
Honolulu, HI 96822, USA

A high-precision geochemical/isotopic study of a 1.6 km thick submarine stratigraphic section from the southwest rift zone of the Mauna Loa volcano has been undertaken to investigate the structure of the Hawaiian mantle plume. The Mile High section (MHS) may represent over 400 ka of eruptive activity, 50% of the volcano's total lifetime, and is comparable to the time period sampled by the Hawaiian Scientific Drilling Project (HSPD-2). Sr, Nd, Pb and Hf isotopes in the MHS range typically within literature data for the Mauna Loa volcano with  $^{87}\text{Sr}/^{86}\text{Sr}$  from 0.70368 to 0.70378 and  $^{206}\text{Pb}/^{204}\text{Pb}$  from 18.16 to 18.26 (i.e. somewhat more radiogenic than most of the Mauna Loa prehistoric lavas and clearly different from any basalt from the Mauna Kea trend, with distinctly higher  $^{208}\text{Pb}^*/^{206}\text{Pb}^*$ ). In the MHS, there is a distinct change in isotopic compositions, also recorded by major and trace element data, at a depth of 1353 m with an increase in Pb and Sr isotopic ratios that continues down to the bottom of the section at 2290 m. High-precision Pb isotopic systematics for Mauna Loa do not show binary trends as previously observed in the upper part of the HSDP-1 pilot hole [1]. This might indicate that the Mauna Loa plume source might be more thoroughly mixed than the Mauna Kea source. Most of the Mauna Loa isotopic compositions cluster at 18.15-18.20 for  $^{206}\text{Pb}/^{204}\text{Pb}$  and  $\sim 0.70370$  for  $^{87}\text{Sr}/^{86}\text{Sr}$ , which could be a ubiquitous component in the Hawaiian mantle plume. Nevertheless, a more radiogenic plume component with higher  $^{208}\text{Pb}/^{204}\text{Pb}$ ,  $^{208}\text{Pb}^*/^{206}\text{Pb}^*$  is clearly present in the lower part of the MHS and might be comparable to the Kilauea-like component observed in Mauna Kea lavas in HSDP-2 [2, 3]. This implies the persistence of specific chemical domains in the Hawaiian plume through time.

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## Assessing Kilauea volcano's historical parental magma compositional variations

MICHAEL O. GARCIA<sup>1</sup>, M. NORMAN<sup>2</sup>  
AND A. PIETRUSZKA<sup>3</sup>

<sup>1</sup>Dept. Geology-Geophysics, Univ. of Hawaii, Honolulu, HI,  
96822, USA (mogarcia@hawaii.edu)

<sup>2</sup>Res. School of Earth Sciences, Australian National Univ.,  
Canberra, Australia (Marc.Norman@anu.edu.au)

<sup>3</sup>Dept. of Geol. Sci., San Diego State Univ., CA, 92182, USA  
(apietruszk@geology.sdsu.edu)

Two hundred years of magmatic history are preserved by lavas and tephra from Kilauea's historical summit eruptions. New geochemical data are presented here for olivine-hosted, naturally quenched melt inclusions and host lavas. Whole-rock data show large and systematic compositional and isotopic variations during the last two centuries from 1820 to 1924, when the summit suddenly and violently collapsed. Thereafter, a reversed geochemical trend has continued for 80 years, including the ongoing, 22-year-old Puu 'O'o eruption [1, 2]. Melt inclusions in relatively primitive olivines (Fo 85-90 [3]) were examined from fire-fountain produced reticulite from the 1820 and 1959 eruptions and water-quenched lava from the Puu 'O'o eruption to determine the cause of these trends (e.g. magma mixing or systematic parental magma changes). These rapidly quenched samples show minimal post-entrapment re-equilibration with host olivine. The melt inclusions from a single lava trap a remarkable range in major and trace element compositions, much larger than recorded in the erupted lavas during the last 200 years, although inclusions within individual olivines show a limited range. There is no correlation of olivine composition with major element lava composition. Thus, the range of melt inclusion compositions is not related to equilibration with the host olivine, and in fact represents primary magmatic variation, especially for ratios such as Nb/Y. These results indicate that magma supplying Kilauea changes rapidly and that its source has small-scale mantle heterogeneities. These short-term magma compositional variations are buffered by the summit magma chamber but preserved in melt inclusions. The rapid and overall systematic nature of these temporal geochemical variations indicate that summit eruptions are fed from a single, relatively small reservoir that is being continuously fluxed with new, mantle-derived magma. The rate of compositional variation during the last two hundred years is correlated with magma-supply rate and the estimated degree of melting, which may be controlled by the scale of source heterogeneity within the Hawaiian plume.

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## Diversity and evolution of mantle sources of the Kilauea volcano, Hawaii

N. SHIMIZU<sup>1</sup>, K. KOBAYASHI<sup>2</sup>, E. NAKAMURA<sup>2</sup>  
AND M. KURZ<sup>1</sup>

<sup>1</sup>Woods Hole Oceanogr. Inst. (nshimizu@whoi.edu, mkurz@whoi.edu)

<sup>2</sup>ISEI, Okayama University, Japan  
(katsura@pheasant.misasa.okayama-u.ac.jp, eizonak@misasa.okayama-u.ac.jp)

Olivine-hosted melt inclusions from the 1960 picrite flow (MK91-8) of the Kilauea Volcano were analyzed for Pb isotopic compositions using the ISEI Cameca IMS 1270 with a multiple-collection system, using the techniques described by Kobayashi et al. (2004). Replicate analyses of a basalt glass standard with ~2ppm Pb yielded reproducibilities of 0.35% ( $2\sigma_m$ ) for both  $^{207}\text{Pb}/^{206}\text{Pb}$  and  $^{208}\text{Pb}/^{206}\text{Pb}$  ratios. In-run precisions for the melt inclusions with Pb at 0.3-0.5 ppm ranged from 0.65-0.95% ( $2\sigma$ ) for both isotopic ratios.

Salient features of the results are: (1) The ranges of Pb isotopic compositions ( $^{207}\text{Pb}/^{206}\text{Pb}$  from 0.795 to 0.847;  $^{208}\text{Pb}/^{206}\text{Pb}$  from 1.969 to 2.098) are greater than the three endmember compositions (Koolau, Loihi, Kea) proposed by Eiler et al. (1998), showing, in particular, that there is a radiogenic component ( $^{207}\text{Pb}/^{206}\text{Pb}=0.795$ ,  $^{208}\text{Pb}/^{206}\text{Pb}=1.969$ ), more radiogenic than any known Hawaiian lavas. (2) The radiogenic component, first observed in pre-shield stage (~270 ka) alkaline glasses from the Hilina Bench (Shimizu et al., 2001), shows that it has persisted throughout the evolution of the Kilauea magmatism. A similar composition was found in a melt inclusion from Mauna Loa (Kobayashi et al., 2004), indicating its ubiquitous, if not abundant, presence in the Hawaiian plume. (3) In the  $^{207}\text{Pb}/^{206}\text{Pb} - ^{208}\text{Pb}/^{206}\text{Pb}$  space, the present results show two distinct mixing arrays (EM2-EM1, and HIMU-DMM), and indicate that the EM2 component plays important roles in the Hawaiian plume and that diversity of mantle sources involved in the Kilauea magmatism is much broader than whole-rock/glass based data suggests. It is also suggested that the source diversity has persisted through the evolution of magma types from alkaline to tholeiitic over the past 270 ka.

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## Geochemical and isotopic characteristics of Cretaceous basalts in South China and constraint on Pacific plate subduction

W.F. CHEN, P.R. CHEN, X.S. XU AND M. ZHANG

State Key Laboratory of Mineral Deposit Research,  
Department of Earth Science, Nanjing University, Nanjing  
210093, China (cwf\_328@163.net)

Late Cretaceous Basalts (85~110Ma) distribute in the contemporaneous fault-bounded red basins and volcanic-sedimentary basins in South China (including Hunan, Jiangxi, Guangdong, Fujian, Zhejiang Provinces). They are divided into two groups delimited by Wuyi Shan Range, namely west area basalts (WABs) distributing over the west of Wuyi Shan Range and east area basalts (EABs) distributing over the east of Wuyi Shan Range respectively, and observed having distinct geochemical and isotopic characters.

WABs are characterized by low  $\text{K}_2\text{O}$  (0.44~3.17%), alkaline ( $\text{K}_2\text{O}+\text{Na}_2\text{O}=3.27\sim6.80\%$ ),  $\text{Al}_2\text{O}_3$  (13.08~16.75%), but high MgO (5.13~8.78%) and  $\text{TiO}_2$  (1.12~3.35%). WABs are similar to ocean-island basalts (OIB) or intraplate basalts on trace element compositions and isotopes: no negative Nb and Ta anomalies, low LILE/HFSE (e.g., Ba/Nb, Ba/Zr), relatively low  $\Sigma\text{REE}$  and  $\text{La}_N/\text{Yb}_N$ , high  $\epsilon_{\text{Nd}}(t)$  (-1.81~8.00).

In contrast, EABs display relatively high  $\text{K}_2\text{O}$  (0.55~4.86%), alkaline (2.95~7.55%) and  $\text{Al}_2\text{O}_3$  (15.80~21.10%), low MgO (2.63~6.28%) and  $\text{TiO}_2$  (1.19~1.86%), strong negative Nb and Ta anomalies, high LILE/HFSE, relatively high  $\Sigma\text{REE}$  and  $\text{La}_N/\text{Yb}_N$ , negative  $\epsilon_{\text{Nd}}(t)$  (-8.5~-1.22), similar to IAB (island arc basalts) or CAB (continental arc basalts).

Accordingly, geochemical and isotopic data suggest that two groups were derived from different mantle sources. WABs were probably generated under continental rifting tectonic environment related to asthenospheric materials upwelling, source of which was characterized by mixing between EM II and DM. EABs' source may be lithospheric mantle which had ever been undergone metasomatism by fluid/melt derived from subducted Pacific plate. This indicates that subduction of a paleo-Pacific plate (Kula) beneath the Asian continent had ever been occurred during late Mesozoic period, but the areas of influence by subduction on the continent was only limited the east areas of Wuyi Shan Range.

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## A new geochemical approach to model periodically replenished magma chambers: Application to the EPR axis at 17-19°S.

C. CORDIER, E. RANNOU AND M. CAROFF

Université de Bretagne Occidentale, Brest, France  
(carole.cordier@sdt.univ-brest.fr,  
Eric.Rannou@univ-brest.fr, Martial.Caroff@univ-brest.fr)

### A new theoretical approach

This model reproduces the geochemical evolution of steady-state magma chambers, continuously replenished and tapped. To traduce cyclic magma supplies, the injection is modelled through a sinusoidal function independent of the reservoir size, contrary to the expulsion and crystallization rates. The resolution of the model is based on the knowledge of several geological and geochemical parameters. In a first step, the range of REE contents in the lavas and the ratio between expulsion and crystallization rates are used to constrain the REE composition of the injected magma. By introducing the mean rate of injection and the range of the reservoir size variations, the period of the cycle and the crystallizing/expelling magma volumes can be calculated.

### Application to the EPR 17-19°S

Lagabrielle and Cormier (1999) have connected magma supply with ridge axial morphology of EPR. The spatial evolution of the morphology between segments traduces the time-related reservoir size and so the cyclic temporal variation of the magma budget. Geochemistry is also variable along axis: lavas sampled from incised domes displaying greater variability and higher REE contents. So, chemical data could be used to constrain the reservoir evolution. Among the results, three of them deserve a particular attention: the REE composition of replenishment liquid, corresponding to a N-MORB with MgO=9.4 wt%, the cycle period, equal to ca. 800 years, and the residence time, close to 300 years.

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## Near-solidus melt compositions from natural carbonated lherzolite

R. DASGUPTA, M.M. HIRSCHMANN AND A.C. WITHERS

Department of Geology & Geophysics, University of Minnesota, USA (dasg0007@umn.edu)

Carbonate melt is considered an important metasomatic agent and may be associated with very deep melting in the Earth's mantle, but constraints on mantle carbonatite formation, stability, and composition are incomplete. Near-solidus partial melting of carbonated peridotite generates carbonatitic melt above ~2 GPa, but detailed experiments on natural peridotite-CO<sub>2</sub> are absent above 3.5 GPa (e.g., [1]). Thus little is known about the location of the carbonated peridotite solidus or the compositions of near solidus melts produced from natural carbonated lherzolite during upwelling of oceanic upper mantle.

To determine the solidus of carbonated fertile peridotite and the composition of near-solidus carbonatitic liquid, iterative sandwich experiments were performed at 6.6 GPa and 1120-1325 °C in which a layer of carbonatite was equilibrated with fertile peridotite similar to KLB-1, prepared from a mixture of natural minerals. Near-solidus equilibrium between melt and 4-phase lherzolite was approached iteratively by adjusting the run temperature and the initial carbonatite composition. Added carbonatite compositions were successive approximations of the near-solidus ( $F=0$ ) equilibrium melt,  $C_L$ , derived from the relation  $C_L=C_0/D$ , where  $C_0$  is the elemental concentration in the peridotite layer and  $D$  is the peridotite/melt partition coefficient obtained from the previous experiment.

Results indicate that the solidus of carbonated natural peridotite at a depth of ca. 200 km is  $\geq 1100$  °C, which is 150-250° cooler than estimates derived from experiments in simple systems [2, 3]. Near solidus melts have  $\leq 9$  wt.% SiO<sub>2</sub>,  $\leq 2$  wt.% TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>, ~7 wt.% FeO, and ~4.5 wt.% Na<sub>2</sub>O. The molar Ca/(Ca+Mg) is 0.30-0.35, distinctly lower than 0.45-0.49 found for model CMAS-CO<sub>2</sub> peridotite [2] at similar depth.

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## Mixing two enriched and distinct mantle sources beneath Lucky Strike segment, 37° N on the Mid-Atlantic Ridge

P.L. FERREIRA<sup>1</sup>, B.J. MURTON<sup>2</sup> AND CLIVE BOULTER<sup>2</sup>

<sup>1</sup>INETI, Alfragide, Portugal (pedro.ferreira@ineta.pt)

<sup>2</sup>Southampton Oceanography Centre, Southampton, UK

New major and trace element, and Nd-Sr isotopic, data on samples from the Lucky Strike Segment are presented. All samples studied are enriched mid-ocean ridge basalts (E-MORB), but different degrees of enrichment are identified. Three distinct compositional groups can be established: - in Group 1, the lavas have the highest “more incompatible/less incompatible” (MI/LI) element ratios, <sup>87</sup>Sr/<sup>86</sup>Sr and the lowest <sup>143</sup>Nd/<sup>144</sup>Nd ratios. These lavas have a degree of enrichment between those of E-MORB and OIB and are spatially restricted to the central part of the axial volcano. Group 3 lavas have the smallest “MI/LI”, <sup>87</sup>Sr/<sup>86</sup>Sr and the highest <sup>143</sup>Nd/<sup>144</sup>Nd ratios. The lavas present REE and multi-element patterns typical of E-MORB and were collected throughout the Lucky Strike segment (from 37°12,0' to 37°27,3' in latitude). Group 2 lavas have chemical characteristics intermediate between those of groups 1 and 3 in terms of trace and isotope compositions, have the maximum dispersion in the different element or element ratios, and present an enrichment degree between those of group 1 and 3 lavas.

Relationships between various incompatible trace element ratios (e.g. La/Sm versus Nb/Zr), together with Sr and Nd isotopic ratios, or between both (e.g. La/Sm versus <sup>143</sup>Nd/<sup>144</sup>Nd) show clearly a continuous chemical trend, defined by group 2 basalts, progressively connecting the chemical characteristics shown by groups 1 and 3. The justification for that trend being the result of mixing processes was tested, and a good fit of the mixing lines to the data was obtained. Moreover, since the mixing processes between a depleted mantle source (N-MORB type), and a highly enriched source (Plume type) are frequently postulated to explain the origin of E-MORB type basalts (identical to those of group 3), calculation of the mixing lines were extended to a N-MORB end-member, and good fits were also obtained. These results show that mixing could be invoked to explain the chemical diversity among the Lucky Strike segment magmas, involving an N-MORB type source end-member and an enriched end-member similar to that assumed to generate the basalts from group 1. Hence, the existence of two distinct (both enriched) mantle sources beneath Lucky Strike segment could be postulated.

## Evaluating the relative roles of hydrothermal alteration at a single crystal scale: Sr isotope micro-sampling study of eruptive and intrusive magmatic rocks from Skye

L. FONT, D.G. PEARSON, J.P. DAVIDSON,  
C.G. MACPHERSON, G.M. NOWELL  
AND R.N. THOMPSON

Department of Earth Sciences, University of Durham, Durham DH1 3LE, UK. (laura.font@durham.ac.uk, d.g.pearson@durham.ac.uk, j.p.davidson@durham.ac.uk, c.g.macpherson@durham.ac.uk, g.m.nowell@durham.ac.uk, r.n.thompson@durham.ac.uk)

The Skye Tertiary igneous rocks (NW Scotland) are characterised by wide variations in wholerock Sr, Pb and Nd isotopic ratios. These are interpreted to result from magma mixing and contamination by upper and lower crust. In addition, both lavas and intrusives (particularly in the southern Skye) have low δ<sup>18</sup>O values due to extensive interaction with heated meteoritic ground waters. Since both Sr and Pb are mobile during hydrothermal alteration, at least some, whole rock Sr and Pb isotopic compositions are likely to have been significantly modified in some cases, complicating the quantification of crustal contamination processes. In this study we examine Sr, Pb and O isotopic ratios of the micro-drilled portions of feldspars and olivine phenocrysts, from lavas and dykes occurring at varying distances from the Skye centre of the hydrothermal circulation centre, as defined by oxygen isotopes. This will allow us to better constrain the origin of both, the phenocryst and wholerock isotopic variations. In particular, it is crucial to differentiate between variations caused by hydrothermal alteration and by magmatic processes. By evaluating alteration processes at a crystal scale we shall develop sample selection criteria for detailed isotopic studies of magma mixing and crustal contamination. This will improve understanding of the detailed mechanisms of magmatic evolution and crustal contamination in flood basalt regions.

## Small-scale heterogeneities in the enriched component of the Kerguelen mantle plume: Pb-Hf-Sr-Nd isotopic constraints from the Kerguelen Baie Charrier section

DIANE HANANO<sup>1</sup>, DOMINIQUE WEIS<sup>1</sup>,  
JAMES S. SCOATES<sup>1</sup> AND ANDRÉ GIRET<sup>2</sup>

<sup>1</sup>Department of Earth and Ocean Sciences, University of British Columbia, 6339 Stores Road, Vancouver, BC V6T-1Z4, Canada (diane23@telus.net)

<sup>2</sup>Laboratoire de Géologie, Université Jean Monnet, CNRS-UMR 6524, 42023 Saint Etienne, France

The Kerguelen Archipelago, located in the southern Indian Ocean, represents the emergent part of the Northern Kerguelen Plateau and is the world's third largest oceanic island with the longest history. The Baie Charrier basaltic section, on the northern Courbet Peninsula, is composed of mildly alkalic and olivine-phyric basalts, with MgO contents (3.1-16.7 wt.%) reaching much higher values than most of the archipelago flood basalts. The Baie Charrier basalts display a limited range of initial isotopic compositions at 24.5 Ma ( $^{176}\text{Hf}/^{177}\text{Hf} = 0.282813-0.282872$ ;  $^{87}\text{Sr}/^{86}\text{Sr} = 0.70482-0.70517$ ;  $^{143}\text{Nd}/^{144}\text{Nd} = 0.51257-0.51266$ ) except for Pb, where  $^{206}\text{Pb}/^{204}\text{Pb}$  ranges from 18.19-18.64. These compositions are consistent with that of the estimate for the enriched component of the Kerguelen mantle plume, which dominates the ~24.5 Ma 1000 m Mont Crozier basaltic section located 16 km to the southwest. The isotopic systematics of Baie Charrier and Mont Crozier basalts are very similar, suggesting that both sections are derived from the same enriched mantle source region. All of the alkalic basalts, including Baie Charrier, form linear arrays in Pb-Pb diagrams, in contrast to the older (29-26 Ma) tholeiitic-transitional basalts on the archipelago. In Pb-Pb and Pb-Sr diagrams, the trends for the alkalic basalts do not point towards the SEIR MORB field. This reflects the disappearance of the depleted component in these younger basalts (<25 Ma) as the archipelago evolved from a ridge-centered position at ~40 Ma to its current intraplate setting. The linear trends in Pb-Pb diagrams, revealed only by high-precision MC-ICP-MS analyses of the younger mildly alkalic basalts on the Kerguelen Archipelago, reflect the presence of small-scale heterogeneities within the enriched Kerguelen plume.

## Principal Component Analysis of Cenozoic Kerguelen plume basalts

FREDERICO HENRIQUES, DOMINIQUE WEIS  
AND JAMES SCOATES

Department of Earth and Ocean Sciences, University of British Columbia, 6339 Stores Road, Vancouver BC, V6T-1Z4, Canada (fhenriques@eos.ubc.ca)

We report the first results of Principal Component Analysis (PCA) of Pb, Sr and Nd isotopic compositions (TIMS and Nu Plasma MC-ICP-MS) from a set of 147 basalt samples from the Kerguelen Archipelago and Northern Kerguelen Plateau (NKP). These include 34 Ma ODP site 1140, Leg 183, on the NKP (n=20) and three distinct subaerial groups on the archipelago: (1) 29-28 Ma tholeiitic-transitional basalts (n=27), (2) 26-25 Ma transitional basalts (n=51), and (3) 25-24 Ma mildly alkalic basalts (n=49). With decreasing age, the 1<sup>st</sup> eigenvectors ( $v_1$ ) account for 91%, 63%, 56% and 66% of the variance of each group, while the 2<sup>nd</sup> eigenvector ( $v_2$ ) accounts for 6%, 32%, 33% and 20%. For all archipelago basalts,  $v_1$  and  $v_2$  show a variance of 67% and 26%, respectively. Using high-precision Pb isotopes only (n=110), the results are more skewed, with  $v_1$  explaining 87% of the variance and  $v_2$  8%. The temporal evolution of the studied basalts is associated with the northeast migration of the SEIR, increasing the distance between the depleted mantle source (ridge axis) and the Kerguelen plume. At 34 Ma this distance was 50 km, increasing to 250 km at 26 Ma, and finally to 400 km, at 24 Ma. Our study indicates that the Kerguelen plume is the dominant magma source throughout formation of the flood basalts. Pb-Pb isotope linear trends for the alkali basalts reflect the presence of heterogeneities among the plume source, which are represented by  $v_1$ .  $v_2$  accounts for the presence of a depleted mantle component, which decreases during formation of the flood basalts. New high-precision Pb and Hf isotopic compositions will constrain the 3<sup>rd</sup> eigenvector.

## Depleted rejuvenated-stage source component in Hawaiian shield-stage lavas

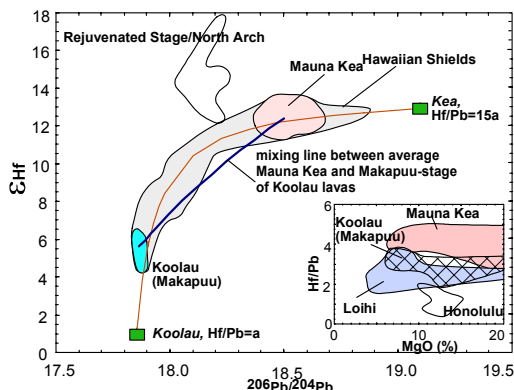
SHICHUN HUANG<sup>1</sup>, FREDERICK A. FREY<sup>1</sup>,  
JANNE BLICHERT-TOFT<sup>2</sup>, R.V. FODOR<sup>3</sup>  
AND GUANGPING XU<sup>1</sup>

<sup>1</sup>Department of Earth Atmospheric and Planetary Sciences,  
Massachusetts Institute of Technology

<sup>2</sup>Ecole Normale Supérieure de Lyon

<sup>3</sup>North Carolina State University

As a well-defined hotspot track the Hawaiian Ridge-Emperor Seamount Chain plays an important role in our understanding of mantle plumes. Geochemical studies on Hawaiian shield-stage lavas indicate considerable heterogeneity in radiogenic isotopic ratios, implying a heterogeneous Hawaiian plume. Specifically, among Hawaiian shield-stage lavas, lavas from the surface of Koolau (Makapuu-stage) have the highest  $^{87}\text{Sr}/^{86}\text{Sr}$ , La/Nb and  $\text{SiO}_2$  content, and the lowest  $^{143}\text{Nd}/^{144}\text{Nd}$ ,  $^{176}\text{Hf}/^{177}\text{Hf}$ ,  $^{206}\text{Pb}/^{204}\text{Pb}$ , Th/La and total iron content. Lavas from Loihi are characterized by the highest  $^3\text{He}/^4\text{He}$ . Lavas from Mauna Kea are characterized by the lowest  $^{87}\text{Sr}/^{86}\text{Sr}$  and highest  $^{143}\text{Nd}/^{144}\text{Nd}$ ,  $\epsilon_{\text{Hf}}$  and Pb isotopic ratios. Other Hawaiian shield-stage lavas can be explained by variable mixing proportions of these three components (Koolau, Mauna Kea and Loihi). Despite substantial isotopic variations in Hawaiian shield-stage lavas, they have similar trace element ratios such as Hf/Pb (see inset in figure). Consequently, we infer that mixing lines among different source components for Hawaiian shield lavas are near-linear. This inference contrasts with the hyperbolic trend of  $^{206}\text{Pb}/^{204}\text{Pb}$ - $\epsilon_{\text{Hf}}$  which requires a factor of 15 difference in Hf/Pb for two-component mixing (see figure). A possible explanation could be that an additional source component, similar to that manifested in Hawaiian rejuvenated-stage lavas, is also sampled by shield-stage lavas.



## Implications of mantle Fe/Mn for mantle plumes

M. HUMAYUN<sup>1</sup>, L. QIN<sup>1,2</sup> AND A.D. BRANDON<sup>3</sup>

<sup>1</sup>NHMFL & Dept. of Geological Sciences, Florida State  
University, Tallahassee, FL 32310, USA

<sup>2</sup>Dept. of Geophysical Sciences, University of Chicago,  
Chicago, IL 60637, USA

<sup>3</sup>NASA JSC, Mail Stop KR, Houston, TX 77058, USA

Abundances of Fe and Si control the density of the mantle, and thereby the compositionally driven aspects of mantle dynamics. Since elemental abundances in mantle-derived lavas are influenced by many factors, including source composition, degree of melting, etc., elemental ratios of lavas are better indicators of source composition. The Fe/Mn ratio is a planetary constant, published value =  $60 \pm 20$  ( $2\sigma$ ), in both mantle peridotites and in lavas. Compositional variations of  $X_{\text{Fe}} \sim 0.01$  (10% change in FeO or 1% change in Mg#) are important in thermochemical convection in the mantle, but have not been recognized in existing geochemical data, probably due to analytical noise ( $\sim \pm 30\%$ ). We have determined the Fe/Mn ratio with higher precision ( $\pm 0.5\%$ ) by magnetic sector ICP-MS. The procedure used at NHMFL determines the ratio  $^{54}\text{Fe}^+ / ^{55}\text{Mn}^+$ , and converts this to Fe/Mn ratio by comparison against gravimetrically prepared standards. We report new analyses of Kilbourne Hole mantle xenoliths spanning the MgO=38-49% range. We show that there is a systematic increase in the Fe/Mn ratio (61-74) with increasing MgO (melt depletion), which is more restricted than the  $60 \pm 20$  range in the literature. The Fe/Mn ratio in the primitive mantle (PM) is estimated to be  $(\text{Fe/Mn})_{\text{PM}} = 60.7 \pm 1.5$  ( $2\sigma$ ) at MgO=37.8%, an improvement in precision of an order of magnitude. This implies that the fractionation factor of Fe/Mn upon melting to form MORBs (Fe/Mn~57) is  $\sim 0.94$ . Since olivine modal abundance increases at higher MgO in peridotites, the fractionation factor of Fe/Mn increases such that melts derived from refractory peridotites should still have Fe/Mn~60. Thus, the Fe/Mn ratio of extracted melt is not sensitive to the fertility of the source. Then, the major factors controlling the Fe/Mn of primitive melts are source variations of Fe/Mg and the source olivine/orthopyroxene ratio. Since the olivine/opx ratio is dependent on Mg/Si of the mantle source, Fe/Mn is incidentally sensitive to both Fe and Si variations in the source. Increased Fe/Mn reflects both higher FeO or higher Si in the source. Hawaiian lavas exhibit a uniformly high Fe/Mn of 67, indicating that the source of Hawaii has  $\sim 15\%$  more FeO, or  $< 15\%$  olivine.

## Geodynamic and geochemical characteristics of Quaternary basaltic volcanism in the NW of Iran

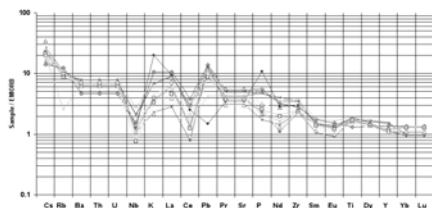
M. KHEIRKHAH<sup>1</sup> AND M.H. EMAMI<sup>2</sup>

<sup>1</sup>Islamic Azad University Research and Science Compass,  
Department of Geology, University of Tehran, Tehran,  
Iran (kheirkhah@gsi-iran.org)

<sup>2</sup>Research Institute of Geosciences, Geological Survey of Iran  
(emami@gsi-iran.org)

The volcanic rocks crop out in Ooromieh dokhtar zone (NW of Iran). The oldest units are Precambrian gneiss, amphibolite and micaschist. The volcanic rocks have basic composition and alkaline trend. These alkali olivin basalts show mainly hyaloporphyritic, intergranular, microlitic and hyalin textures. The xenocrysts of quartz in many alkali basalts show disequilibrium textures, possibly magma-mixing processes. These alkali basaltes show Hawaiian and Strombolian type eruption. Geochemical data suggest that the volcanites evolved by fractional crystallization and contamination with metamorphic and granitic rocks (AFC). According to geochemical and mineralogical composition, these basalts are relative comparable with Ararat lava flow in Turkey. Spider and REE diagrams show low degree of partial melting and crustal contamination (Fig. 1). Geodynamic research and tectonic setting show that these rocks are related to Quaternary extensional tectonic regime and have erupted along shear zone in pull-apart local basin.

Figure 1



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## Re-Os and PGE study of Philippine Sea Plate ocean island basalts: Constraining mantle sources

A. LUGUET<sup>1</sup>, C.G. MACPHERSON<sup>1</sup>, D.G. PEARSON<sup>1</sup>  
AND R. HICKEY-VARGAS<sup>2</sup>

<sup>1</sup>Department of Earth Sciences, University of Durham, UK  
(ambre.luguet@durham.ac.uk)

<sup>2</sup>Department of Geology, Florida international University,  
Miami, USA

Ocean island basalts erupted on the oldest part of the Philippine Sea Plate, have been interpreted as melting products of a mantle source containing a depleted MORB-source component and incompatible element enriched EMII-type material [1]. To provide further constraints on this model, we have analysed Os isotope ratios and platinum-group element concentrations in 3 alkali basalts and 2 olivine tholeiites from the Daito Ridge (DSDP Leg 58 Site 446).

Os abundances in the olivine tholeiites (22-60 ppt) are systematically higher than in the alkali basalts (7-12 ppt). Re contents vary between 729 ppt to 1114 ppt and are independent of sample petrology. Such high Re contents are typical of lavas that have minimal degassing during eruption [2]. The measured <sup>187</sup>Os/<sup>188</sup>Os ratios in all samples are highly radiogenic (0.2169-0.7402).

Calculated initial <sup>187</sup>Os/<sup>188</sup>Os ratios at the time of eruption (55 Ma, [3]) are slightly radiogenic (0.1348 to 0.1371) for the olivine tholeiites but significantly more radiogenic for the alkali basalts (0.2700 to 0.2958). These Os isotopic systematics require derivation of Os from 2 distinct reservoirs. The first possesses a composition very similar to the EMII material [4] while the second requires a relatively long-term Re/Os enrichment. Both reservoirs will be further characterized with platinum group element data.

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## Source characteristics of Jurassic ferropicrites from Dronning Maud Land, Antarctica

A. V. LUTTINEN<sup>1</sup> AND H. HUUMA<sup>2</sup>

<sup>1</sup>Department of Geology, P.O.Box 64, FI-00014 University of Helsinki, Finland (arto.luttinen@helsinki.fi)

<sup>2</sup>Geological Survey of Finland, P.O.Box 123, FI-21520 Espoo, Finland (hannu.huhma@gtk.fi)

Middle Jurassic basalts of Vestfjella, western Dronning Maud Land comprise an Antarctic extension of the Karoo large igneous province. In addition to intrusive equivalents of the lavas, crosscutting dolerite dikes include a group of picrites with unusually high total FeO (>14 wt.%) and low Al<sub>2</sub>O<sub>3</sub> (<10 wt.%) at given MgO (10–18 wt.%). The picrites are probably coeval, or nearly so, with the lavas, although precise age data are lacking. Mantle-normalised incompatible element fingerprints indicate two subgroups of such ferropicrites; these have similar high (Sm/Lu)<sub>N</sub> (~5), but quite different (La/Sm)<sub>N</sub> (1.6–1.7 and 1.1–1.4, respectively). The smooth fingerprint of the relatively more enriched ferropicrites (initial ε<sub>Nd</sub> +1 to +4) resembles that of average OIB, whereas the upward convex fingerprint of the relatively depleted ferropicrites (initial ε<sub>Nd</sub> +5 to +9) has marked positive LILE and V anomalies and resembles that of oceanic gabbros. We regard that the V anomaly, which is not typical of continental and oceanic basalts, reveals a “ghost clinopyroxene” fingerprint that can be ascribed to incorporation of clinopyroxene-rich recycled oceanic cumulate into the mantle source of these rocks. Positive LILE anomalies infer presence of cumulus plagioclase in the recycled component. Our results lend support to Gibson’s recent conclusion that, in contrast with previous models, the mantle source of ferropicrites was not exceptionally Fe-rich and that ferropicrite melts can be generated from eclogite-bearing mantle sources. The discovery of a strong cumulate fingerprint in ferropicrites implies that in some cases the eclogite component probably was recycled oceanic lower crust. A similar, albeit weaker, cumulate fingerprint has been reported in some Hawaiian basalts and we have identified it in other ferropicrites and Fe-rich primitive magma suites; Mesozoic and Precambrian ferropicrites and modern OIB have probably had rather similar sources, and ferropicrites can be regarded as the epitome of hotspot-related magmas derived from mixed eclogite-peridotite sources.

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## The Azores hotspot: A lower mantle origin for Terceira magmas as shown by Ne isotopic data

P. MADUREIRA<sup>1,2</sup>, M. MOREIRA<sup>1</sup> AND J. MATA<sup>3</sup>

<sup>1</sup>Institut de Physique du globe de Paris, Université paris VII, CNRS UMR 7579, 4 place Jussieu, 75005 Paris, France (moreira@ipgp.jussieu.fr)

<sup>2</sup>Centro de Geofísica de Évora/Departamento de Geociências da Universidade de Évora, Rua Romão Ramalho, 59, 7000-671 Évora, Portugal (pedro@uevora.pt)

<sup>3</sup>Centro e Departamento de Geologia da Faculdade de Ciências da Universidade de Lisboa, Campo Grande, C6-4º Piso, 1749-016 Lisboa, Portugal (jmata@fc.ul.pt)

The collection of helium isotopic data in the last twenty years has shown different signatures for MORB and OIB basalts and this has been used as the basis for the two-layer mantle model. However, for some OIB that appear in the vicinity of mid-ocean ridges, He isotopic ratios are similar to those typical of MORB, leading some authors to argue against the deep mantle plume hypothesis particularly in areas where geophysical evidence is lacking (Anderson, 2000).

For Terceira island (Azores), located close to the Mid-Atlantic Ridge, we analysed neon from olivine phenocrysts in order to better constrain the nature of the Azorian plume. Some of the analysed samples show higher <sup>20</sup>Ne/<sup>22</sup>Ne and <sup>21</sup>Ne/<sup>22</sup>Ne ratios than air suggesting the presence of a mantle component in the olivine melt inclusions. Moreover, in a three-Ne isotope diagram, the samples define a trend with a higher slope than the MORB line (Sarda *et al.*, 1988) arguing for a lower mantle origin. One basaltic sample coming from the 1998 submarine Serreta eruption is plotted along this line, suggesting that the influence of a deep plume is still active. In a plot of <sup>21</sup>Ne/<sup>22</sup>Ne<sub>corr</sub> vs. <sup>4</sup>He/<sup>3</sup>He, Terceira data is plotted in the same hyperbolic mixing line that encompasses Iceland, Shona and Discovery data (Moreira *et al.*, 1995, 2001; Sarda *et al.*, 2000). The data suggests the existence of plume-ridge interaction for these hotspots resulting on mixing between degassed MORB-type and deep plume-type magmas. In such an environment the data shows that neon is a better tracer of primordial material than helium.

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## Assessing shallow level interactions in OIB geochemical signature; Application to São Nicolau Island, Cape Verde

MARC-ALBAN MILLET, KARINE DAVID,  
CHANTAL BOSQ, PIERRE SCHIANO AND  
REGIS DOUCELANCE

Laboratoire Magmas et Volcans. Observatoire de Physique du  
Globe de Clermont-Ferrand. 5, rue Kessler, 63038  
Clermont-Ferrand, France.

Chemical and isotopic compositions of Ocean Island Basalts (OIB) related to plume melting in the Earth mantle can show large variations on a single island. These variations may reflect source evolution and/or interaction of plume-derived melts with their surrounding environment. Thus it is important to decipher the chemical fingerprint of each process to isolate the characteristics of the chemical signature of OIB related to the source composition and then to give insights into mantle chemical dynamics.

Several processes alternative to source variations are able to modify the plume-derived pristine chemical and isotopic composition of OIB. These include (i) post-eruption seawater interaction, which results in leaching of highly soluble elements relative to seawater (i.e. K, Rb, ...), precipitation of secondary phases and input in some elements. This interaction also leads to changes in the  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopic ratio of basalts due to mixing with radiogenic Sr ( $^{87}\text{Sr}/^{86}\text{Sr}$  of seawater  $\sim 0.7092$ ); (ii) assimilation – fractional crystallization (AFC) processes, which occur in magma chambers and combine the effects of mixing with a chemically and isotopically different reservoir and fractional crystallization; (iii) plume-lithosphere interaction which corresponds to pure mixing of plume-derived melts with a non-convective mantle reservoir; and (iv) fractionation effects of partial melting and fractional crystallization.

New measurements of São Nicolau Island basaltic samples, Cape Verde Archipelago, (major-, trace-elements, Sr and Nd isotopes) provide evidence for these different types of interactions. Using a combined multi-elemental and multi-isotopic approach as well as numerical modeling of basic processes, the ascending history of São Nicolau magmas can be re-built, leading to an estimate of the chemical and isotopic composition of the Cape Verde plume melts.

## Helium isotopic measurements from Raivavae and Rapa, Cook-Austral islands: New insights into the nature of the HIMU component

S. MUKHOPADHYAY<sup>1</sup> AND J. C. LASSITER<sup>2</sup>

<sup>1</sup>Department of Earth and Planetary Sciences, Harvard  
University, USA (sujoy@eps.harvard.edu)

<sup>2</sup>Geological Sciences Dept., Univ. Texas at Austin, USA  
(lassiter@mail.utexas.edu)

Helium is a unique tracer of the chemical evolution of the Earth's interior. The presence of low  $^3\text{He}/^4\text{He}$  ratios ( $< 7-9 R_A$ ) found in HIMU ocean islands (high  $\mu$ , where  $\mu$  is the U/Pb ratio) are attributed to recycled oceanic crust. However, recycled crustal material should be essentially devoid of  $^3\text{He}$  but have high concentrations of  $^4\text{He}$  produced from the decay of U and Th. It is, therefore, somewhat surprising that the average helium isotopic ratios at HIMU ocean islands are as high as 6-7  $R_A$ . Proposed explanations for the observed  $^3\text{He}/^4\text{He}$  ratios include 1) an open system behavior of He characterized by extremely high He diffusivity of  $10^{-4} \text{ cm}^2/\text{s}$  [1]; 2) mixing between a composite plume, composed of a high  $^3\text{He}/^4\text{He}$  component and a HIMU component, and depleted MORB mantle [2] and 3) derivation of He from recycled oceanic lithosphere [3].

To evaluate the above hypotheses and better constrain the origin of the  $^3\text{He}/^4\text{He}$  ratios in HIMU basalts we have started an investigation of helium isotopic ratios in a suite of geochemically well characterized samples (Sr, Nd, Hf, Pb, and Os; [4]) from Raivavae and Rapa, Cook-Austral Islands. Based on previous work [4], Raivavae lavas have a HIMU character while Rapa lavas have an enriched character. Our preliminary helium isotopic measurements indicate that Raivavae lavas have  $^3\text{He}/^4\text{He}$  ratios down to 6.3  $R_A$ , significantly more radiogenic than the MORB mantle. On the other hand, samples from Rapa, have  $^3\text{He}/^4\text{He}$  ratios up to 11.2  $R_A$ .

We observe good correlations between helium and other isotopic tracers (e.g., Os and Hf) which suggests that radiogenic helium at HIMU islands is carried by a mafic component. Further, combined He, Hf, Os data suggest that the EM- component sampled in Rapa lavas incorporates a FOZO/PHEM component, although in a volumetrically minor proportion. Hence, our new data argue against models that attribute the EM- component solely to recycled sediments or continental lithosphere.

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## The platinum group element and Re-Os isotopic composition of the Emperor Seamount Chain

JOHN T. SHAFER<sup>1</sup>, CLIVE R. NEAL<sup>2</sup>  
AND ALAN D. BRANDON<sup>3</sup>

<sup>1</sup>Department of Civil Engineering and Geological Sciences,  
University of Notre Dame, Notre Dame, IN 46556, USA  
(jshafer@nd.edu)

<sup>2</sup>Department of Civil Engineering and Geological Sciences,  
University of Notre Dame, Notre Dame, IN 46556, USA  
(Neal.1@nd.edu)

<sup>3</sup>NASA-JSC, 2101 NASA Road 1, Mail Code KR, Building  
31, Houston, TX 77058, USA  
(alan.d.brandon1@nasa.gov)

The Emperor Seamount Chain (ESC) preserves a record of Hawaiian hotspot volcanism from 85 to 42 Ma. Many studies have documented large variations in composition over this period, yet the platinum group element (PGE) and Re/Os isotopic characteristics of the ESC are largely unknown. Studies on picritic basalts from the Hawaiian Islands have shown variable PGE compositions and suprachondritic Re-Os isotopic compositions. How does the PGE and Re-Os characteristics of the ESC compare to the modern Hawaiian Islands? Do the PGE and Re-Os isotopic compositions vary over the length of the ESC?

Picritic and high-MgO basalts from the ESC were recovered during Ocean Drilling Program Leg 197 from Detroit and Nintoku Seamounts. These samples are well suited to study the PGE and Re-Os isotopic characteristics of the ESC. Major, trace, PGE, and Re-Os isotopic analyses will be conducted on each sample.

Preliminary data suggest that the PGE abundances of the ESC are variable, with approximately an order of magnitude greater concentrations than similar samples from Hawaii. Re-Os isotope data collection is in progress at the writing of this abstract, however, preliminary data suggests that the values are highly variable as well, with some samples having MORB-like initial  $^{187}\text{Os}/^{188}\text{Os}$  while others have suprachondritic initial  $^{187}\text{Os}/^{188}\text{Os}$ , similar to Hawaiian samples.

The Hawaiian hotspot has been active for >86 Ma but we know little about the evolution of the PGEs and associated isotopic systems throughout its history. Such information is necessary to fully evaluate models of the origin and evolution of the Hawaiian plume as recorded by the Hawaiian-Emperor Seamount Chain.

## Geochemistry of late Cretaceous lava flows from a Neo-Tethyan fossil oceanic island arc: The Raskoh arc, Balochistan, Pakistan

REHANUL HAQ SIDDIQUI<sup>1</sup>, MUHAMMAD ASIF KHAN<sup>2</sup>,  
MUHAMMAD QASIM JAN<sup>2</sup> AND NAGHMA HAIDER<sup>1</sup>

<sup>1</sup>Geoscience Laboratory, Geological Survey of Pakistan,  
Shahzad Town, Islamabad, Pakistan

<sup>2</sup>National Centre of Excellence in Geology, University of  
Peshawar, Pakistan

The Raskoh arc, which was previously known as Rasko Range, occurs in the western part of Pakistan, is about 250 km long, 40 km wide and trends in an ENE direction. The oldest rock unit in the Raskoh arc is Raskoh accretionary complex (Early to Late Jurassic), which is followed in age by Kuchakki Volcanic Group: the most wide spread unit of the Raskoh arc.

Geochemical studies based on major, trace and rare earth elements suggest that these are oceanic island arc tholeiites. The trace element patterns show enrichment in LILE and depletion in HFSE relative to N-MORB. Their primordial mantle-normalized trace element patterns show marked negative Nb anomalies with positive spikes on K, Ba and Sr which strongly confirm their island arc signatures, which are also supported by slightly depleted (in LREE) to flate chondrite normalized REE patterns. The trace elements ratios including Zr/Y (1.73-3.10), Ti/Zr (81.59-101.83), Ti/V (12.39-30.34), La/Yb<sub>N</sub> (0.74-2.69), Ta/Yb (0.02-0.05) and Th/Yb (0.11-0.75) of basaltic flows are more consistent with oceanic island arcs rather than analogues rocks of the continental margin arcs. On the basis of these studies it is concluded that Raskoh arc is an ancient oceanic island arc which was formed due to the intra-oceanic convergence in the Neo-Tethys during the Late Cretaceous rather than constructed on the southern continental margin of Afghan block, as previously claimed by several workers.

## **Petrography of basalt between Lat 4°06' – 3°50' N from Carlsberg Ridge, Indian Ocean**

P.V. SUNDER RAJU<sup>1</sup>, EVSSK BABU<sup>2</sup>  
AND ABHAY MUDHOLKAR<sup>3</sup>

<sup>1</sup>National Geophysical Research Institute, Hyd, India  
(pvsraju@ngri.res.in)

<sup>2</sup>National Geophysical Research Institute, Hyd, India  
(evvskbabu@yahoo.co.in)

<sup>3</sup>National Institute of Oceanography, Goa, India  
(abhay@darya.nio.org)

Pillow Basalt with Glass rims collected from ocean bottom is pristine sampling material to understand the mineralogical and geochemical characteristics of magma composition and its implication to Mid Oceanic Ridge (MOR) petrogenetic processes. Lithologies vary from pillow and vesicular basalts with glass rims thickness of ~3 to 5 mm. Alteration reduces the thickness of glass rims and leads to brown alteration product (Palagonite). The samples show a wide range of textures from aphyric to highly porphyritic basalts. The main phenocrysts mineral phases are plagioclase, olivine and clinopyroxene. Plagioclase is euhedral-subhedral and the most abundant mineral phase followed by olivine with trapped spinel with  $\pm$  clinopyroxene. Glomerophyric and hetrocumulate textures with olivine and plagioclase coexist as clusters with occasional melt inclusions. The matrix is glassy to microlithic, consisting of thin plagioclase needles forming intersertal textures.

## **Secular evolution of Cretaceous- Cenozoic lithosphere mantle beneath the Cathaysia block: Geochemical evidence for temporal variations in basaltic magmatism**

GUIQING XIE<sup>1,2,3</sup>, JINGWEN MAO<sup>2</sup>, RUIZHONG HU<sup>3</sup>,  
RUILING LI<sup>3</sup> AND JINJIAN CAO<sup>3</sup>

<sup>1</sup>Faulty of Earth Sciences, China University of Geosciences,  
Beijing, 100087, China (guiqingxie@sohu.com)

<sup>2</sup>Institute of Mineral Resources, Chinese Academy of  
Geological Sciences, Beijing, 100037, China

<sup>3</sup>Institute of Geochemistry, Chinese Academy of Sciences,  
Guiyang, 550002, China

### **Introduction**

Recent study indicates that ancient lithosphere mantle, has been removed and replaced by thinner material during Late Mesozoic to Cenozoic time. Nevertheless, the timing and mechanisms for this event still remain to be poorly understood, largely owing to the lack of knowledge about nature of mantle source during the Mesozoic-Cenozoic time in this region.

### **Discussion and conclusion**

Cretaceous basaltic rocks show enriched geochemical and isotopic compositions, whereas a number of late Cenozoic basalts which crop out in the Cathaysia block display geochemical characteristics with OIB. Paleocene basaltic rocks exhibit transitional features between Cretaceous and late Cenozoic basaltic magmatism in geochemical and isotopic compositions. The temporal shift from a lithospheric to asthenospheric magma source took place during the Paleocene which was probably related to lithospheric thinning/replacement in this region, which was probably related to lithosphere extension and asthenospheric upwelling, resulting from the retreating and steepening of the Pacific plate due to injection of asthenospheric material into the mantle wedge beneath the Cathaysian block.

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## Early J<sub>2</sub> basalts in SE China: The incipience of large-scale late Mesozoic magmatism

XIN XIE<sup>1</sup>, XISHENG XU<sup>1</sup>, HAIBO ZOU<sup>2</sup>,  
SHAORYONG JIANG<sup>1</sup>, MING ZHANG<sup>3</sup> AND JIANGSHENG QIU<sup>1</sup>

<sup>1</sup>State Key Laboratory of Mineral Deposit Research,  
Department of Earth Sciences, Nanjing University,  
Nanjing, 210093, China (xxie@eyou.com)

<sup>2</sup>Department of Earth and Space Sciences, University of  
California at Los Angeles, Los Angeles, CA90095-1567,  
USA.

<sup>3</sup>GEMOC ARC National Key Centre, Department of Earth and  
Planetary Sciences, Macquarie University, Sydney,  
N.S.W. 2109, Australia

Magmatism in SE China was dormant during 204~180 Ma, but was reactivated in 180~170 Ma (early J<sub>2</sub>), and then became more and more intensive towards the end of early Cretaceous. The small-scale early J<sub>2</sub> magmatism is the incipience to long term and large-scale magmatism in this region. A near east-west (EW) trend volcanic belt distributed across south Hunan, south Jiangxi and southwest Fujian was formed during early J<sub>2</sub> time. Along this belt from inland toward coast, the lithology of basalts changes from alkali into tholeiite, and the amount of erupted volcanic rocks and the proportions of rhyolites coexisting with the basalts increase. On the basis of geochemical characteristics of these basalts, we infer that the melting degree of source rocks and the extent of fractional crystallization and crustal contamination all increased whereas the depth of mantle source decreased from inland to coast, which led to the variations of geological characteristics of the volcanic belt. In early J<sub>2</sub>, the western spreading Pacific plate began to subduct underneath SE China continental block, reactivating near EW trend deep fault that was originally formed during Indosinian event. The stress of the western spreading Pacific plate and the extent of asthenosphere upwelling increased from inland to the coast, which is consistent with the generation and evolution of early J<sub>2</sub> basalts.

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## Petrogenetic similarities of East Molokai and younger Kea-trend Hawaiian volcanoes as they migrate away from the hotspot

GUANGPING XU<sup>1</sup>, FREDERICK A. FREY<sup>1</sup>,  
DAVID A. CLAGUE<sup>2</sup>, DOMINIQUE WEIS<sup>3</sup>  
AND MELVIN H. BEESON<sup>4</sup>

<sup>1</sup>Massachusetts Institute of Technology, Cambridge, MA  
02139, USA (gpxu@mit.edu, fafrey@mit.edu)

<sup>2</sup>Monterey Bay Aquarium Research Institute, CA 95039, USA  
(clague@mbari.org)

<sup>3</sup>University of British Columbia, Vancouver, BC, V6T-1Z4,  
Canada (dweis@eos.ubc.ca)

<sup>4</sup>U. S. Geological Survey, Menlo Park, CA 94025, USA

The Hawaiian plume is heterogeneous in radiogenic isotope ratios of Sr, Nd and Pb; there are systematic geochemical differences between the < 2 My shields that define the Kea and Loa trends. The overlap in Sr, Nd and Pb isotope ratios of recent Kilauea lavas and 550 Ka Mauna Kea lavas has been used to argue that Kea-trend shield volcanism samples a vertically continuous, geochemically distinct streak which persisted in the source for 550 Ka [1, 2]. As Kea volcanoes migrate away from the hotspot and evolve from the shield to postshield stage there are systematic changes in isotope ratios. We use lavas from East Molokai, the oldest Kea volcano, to address the question – are postshield lavas from Kea volcanoes similar in radiogenic isotopic ratios? We find that Sr, Nd and Pb isotopic ratios in late shield/postshield lavas from Mauna Kea (< 350 Ky) and East Molokai (~1.5 My) are similar [3] thereby showing that the isotopic differences between lavas erupted at the plume center and periphery remained the same during formation of Kea volcanoes. Therefore the spatial zonation of the plume persisted during growth of Kea volcanoes. Like rejuvenated-stage lavas erupted at other Hawaiian volcanoes, rejuvenated-stage East Molokai lavas have relatively low <sup>87</sup>Sr/<sup>86</sup>Sr and high <sup>143</sup>Nd/<sup>144</sup>Nd. Based on positive correlations of <sup>87</sup>Sr/<sup>86</sup>Sr versus <sup>206</sup>Pb/<sup>204</sup>Pb and negative correlations of these isotopic ratios with Nb/Zr, a smaller proportion of this depleted component also contributed to the late shield/postshield lavas erupted at East Molokai and other Kea volcanoes. This depleted component has Kea-trend Pb isotopic characteristics, relatively low <sup>208</sup>Pb/<sup>204</sup>Pb at a given <sup>206</sup>Pb/<sup>204</sup>Pb, and it is probably not related to oceanic lithosphere or the source of mid-ocean ridge basalt.

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## Cenozoic kamafugite in west Qinling, China: Age and geochemistry

ZHIDAN ZHAO<sup>1</sup>, HONGFEI ZHANG<sup>2</sup>, XUEHUI YU<sup>1</sup>,  
XUANXUE MO<sup>1</sup> AND DON J DEPAOLO<sup>3</sup>

<sup>1</sup>China University of Geosciences, Beijing 100083, China  
(zdzhao@cugb.edu.cn)

<sup>2</sup>China University of Geosciences, Wuhan 430074, China

<sup>3</sup>University of California, Berkeley, CA 94720, USA

The Lixian area in southern Gansu province (West Qinling in terms of tectonic unit), is the only locality in China where the special rock kamafugite was found. This place is situated in central China, just in the tectonic transition region between the main tectonic units of the Tibetan Plateau, North China craton and the Yangtze craton. So, the rock will provide very important clues for the Cenozoic continental geodynamics of China. The rocks have been studied in a series of papers of Prof. Xuehui Yu [for example, 1 and 2]. We present here new dating and element and isotope geochemistry results of the kamafugite collected in Lixian area. Ar-Ar dating of 4 phlogopite samples yields the age of 18-23 Ma. These rocks (SiO<sub>2</sub>=38-43 %, K<sub>2</sub>O=0.8-3.8 %, MgO=8.3-18 %, TiO<sub>2</sub>=2.7-4.4 %, CaO=9.5-13 %) are homogenous in trace element composition, with enriched LREE, Rb, Ba, Th, U, Nb, and Ta, and depleted Pb.  $\mathcal{E}_{Nd}$  range from 3.4 to 5.8, <sup>87</sup>Sr/<sup>86</sup>Sr range from 0.703 to 0.706. <sup>206</sup>Pb/<sup>204</sup>Pb range from 18.7 to 19.1, <sup>207</sup>Pb/<sup>204</sup>Pb vary from 15.5 to 15.6, <sup>208</sup>Pb/<sup>204</sup>Pb range from 39.1 to 39.4. A garnet-bearing mantle xenolith hosted in the rock show an extreme enriched Nd isotopes ( $\mathcal{E}_{Nd} = -20$ ). It is possible that the rocks originated from an enriched upper mantle.

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