

V22B MC: Hall D Tuesday 1330h**Geochemical and Isotopic Tracers of Earth Processes (a session in honor of Gil Hanson) (joint with H, T, GC, MR)**

Presiding: J F Luhr, Smithsonian Inst;
B D Marshall, United States
 Geological Survey; **R N Taylor**,
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V22B-1019 1330h POSTER

Dating low-grade metamorphic events: A case study from the Vesser Zone and the Schwarzburg Anticline (NW Saxothuringian-Zone; Mid-European Variscides)

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The Lower Paleozoic units of the Vesser Zone and the Schwarzburg Anticline are located at the southern border of the Mid German Crystalline Rise. To clarify the evolution of these units we performed K/Ar age determinations, illite crystallinity and illite polytype determinations on fine mineral fractions (2-1, <2, <1, <0.2; all size fractions in microns). To characterise the source area detrital muscovites were analysed using the K/Ar method. As all investigated samples had been heated over 350°C during Variscan metamorphism, all ages of the fine mineral fractions have to be interpreted as being cooling ages, except retrograde hydrothermal alterations, instead of reflecting the formation time of the authigenic illites. K/Ar ages of detrital white micas from the Vesser Zone (539 Ma) and the Schwarzburg Anticline (584 Ma) indicate a Cadomian tectonostratigraphic unit as source area. The detrital micas also clearly different Si contents compared to the more phengitic metamorphic micas.

Regional cooling and retrograde events have been recognized with K/Ar ages of fine mineral fractions.

Vesser Zone: Only two fine mineral fractions seem not to be affected by retrograde illite forming events and therefore reflect a minimum cooling age of 301 Ma for the late Variscan HT-metamorphic event. The big differences between K/Ar ages of different fractions from the same sample, indicate multiple retrograde alterations. The oldest alteration is correlated to Permian volcanism (280 Ma). The highly sensitive <0.2 fractions show Triassic and even younger stages of alterations. The analysed illite crystallinities and illite polytype determinations document comparable mixing phenomena as the K/Ar ages, with at least two different geological events.

Schwarzburg Anticline: Two <2 fractions show cooling ages of 309 Ma and 303 Ma for the late Variscan HT-metamorphic event. In contrary to the Vesser Zone no signs of intensive retrograde overprints could be observed in the samples of the Schwarzburg Anticline.

V22B-1020 1330h POSTER

Ultramafic Lamprophyres of the Ferrar Large Igneous Province: Evidence for a HIMU Mantle Component

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Ultramafic lamprophyre dikes from the Ferrar Province (Pensacola Mountains) of Antarctica preserve trace element and isotope signatures, which reflect the palaeo composition of the Bouvet mantle plume. We report Sr, Nd, Pb, and Os isotope ratios for three ultramafic lamprophyre dikes emplaced at 183.2 ± 2.2 Ma, coincident with the main Karoo - Ferrar magmatic event. The ultramafic lamprophyres are classified as oenite and are characterized by high Ti, Cr, Ni, Nb/La, La_N/Yb_N, and Mg#, and are the most primitive rocks of the Ferrar Province. The dikes have initial (at 183 Ma) ⁸⁷Sr/⁸⁶Sr ratios of 0.7044 to 0.7055, Nd of 4.6 to 4.8, ²⁰⁸Pb/²⁰⁴Pb of 39.6 to 40.3, and ¹⁸⁷Os/¹⁸⁸Os of 0.120 to 0.146 and contrast markedly with even the most primitive rocks of the Ferrar and Karoo provinces. The trace element and isotope

characteristics have affinities to ocean island basalt and the highly radiogenic character of ²⁰⁸Pb/²⁰⁴Pb and ²⁰⁶Pb/²⁰⁴Pb bear closest resemblance to Bouvet, which has previously been postulated as the plume responsible for the Ferrar Province. The ultramafic lamprophyres are believed to be the result of melting of peridotite enriched by metasomatic vein material associated with the upwelling Bouvet mantle plume and represent one of three mantle end members in the Karoo - Ferrar province.

V22B-1021 1330h POSTER

Low Nb/Ta in the Archean Mantle: Ancient Missing Niobium in the Silicate Earth

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Recent investigations of oceanic basalts (MORB, OIB) and samples of the continental crust show that the continental crust and the sources of MORB and OIB all have Nb/Ta ratios that are significantly lower than the CI-chondritic value of 17.4. The missing, complementary high-Nb/Ta reservoir has been suggested to exist in the form of Nb-rich, high-Nb/Ta refractory eclogites deep in the mantle (McDonough, 1991; Rudnick et al., 2000). Alternatively, Wade and Wood (2001) recently showed that at high pressure Nb may fractionate into the core, and thus no hidden reservoir would be required within the silicate portion of the Earth. To get further insight of the missing Nb in the silicate portion of the Earth and to test the two hypotheses, we used spark source and ICP mass spectrometry to investigate the geochemically very similar element pairs Nb-Ta and Zr-Hf in komatiitic basalts from 6 Archean greenstone belts. Samples include 3.8 Ga old rocks from Isua (Greenland), 3.4 Ga old rocks from the Onverwacht Group (South Africa) and the Pilbara Craton (Australia), and 2.7 Ga old rocks from the Abitibi (Canada) and the Norseman-Wiluna belts (Australia). Our results show that the mean Zr/Hf ratio of 37 for the Archean samples is identical within error limits with the values found in modern oceanic basalts and in chondritic meteorites. This means that Zr and Hf have not been fractionated in the Earth's mantle since at least 3.8 Ga and that the primitive mantle has a chondritic Zr/Hf ratio. In contrast, Nb and Ta behave differently. The mean Nb/Ta ratios are about 13 for the 3.8 Ga old samples from Isua, and 14 for the 3.4 Ga and 2.7 Ga old samples. These ratios are similar to those of MORB (15), OIB (about 15) (Jochum et al., 1997), and upper crustal material (13; Barth et al., 2000), but are significantly lower than the CI chondritic Nb/Ta of 17.4. This implies that there was no significant fractionation of Nb and Ta in the major reservoirs since 3.8 Ga, not even during formation of the continental crust. Fractionation of Nb-Ta from the CI value had to occur very early in the Earth's history. This provides general support for the hypothesis of Wade and Wood (2001), suggesting that during core formation Nb entered the core as a weakly siderophile element. The core now contains a significant fraction of the Earth's Nb. Thus, Nb is slightly depleted in the silicate Earth and the primitive mantle has a Nb/Ta of about 15, about 15 % lower than the CI chondritic ratio. From these data we estimate a Nb concentration for the core of about 0.2 ppm. Another possible explanation is that the Earth was built from a material with a lower-than-CI chondritic Nb/Ta ratio. A hypothetical, hidden eclogitic Nb-rich reservoir would have to have remained isolated in the mantle for more than 3.8 Ga, a hypothesis which seems to be less plausible, because such a reservoir would be continuously produced by subduction and growth of the continental crust.

WF McDonough, Philos. Trans. R. Soc. London 335, 407 (1991); RL Rudnick et al., Science 287, 278 (2000); J Wade and BJ Wood, Nature 409, 75 (2001); KP Jochum et al., EOS 78, F805 (1997); Barth et al., Chem. Geol. 165, 197 (2000)

V22B-1022 1330h POSTER

Isotopic and Nb Correlations in Hawaiian Lavas: Evidence for a Ubiquitous Refractory Plume Component?

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Tholeiitic lavas from the shield building stage of Hawaiian volcanoes display strong correlations for the isotopic ratios of Sr, Nd, Pb, Hf and Os. This covariance is widely interpreted in terms of melting of mixtures of two end-member mantle plume components. One component, with high ⁸⁷Sr/⁸⁶Sr and low ²⁰⁶Pb/²⁰⁴Pb and ¹⁴³Nd/¹⁴⁴Nd is best characterized by lavas from Koolau volcano, whereas the other component, with low ⁸⁷Sr/⁸⁶Sr and high ²⁰⁶Pb/²⁰⁴Pb and ¹⁴³Nd/¹⁴⁴Nd, is represented by lavas from Kilauea volcano. A third component is required to account for high ³He/⁴He and variations in Pb isotopes in Loihi lavas. Nb abundances, relative to other incompatible elements, are higher in lavas dominated by the Kilauea component than in lavas dominated by the Koolau component. Consequently, trace element ratios involving Nb (e.g. Zr/Nb, Nb/Y, K/Nb), correlate strongly with the various isotopic ratios. Zr/Nb, for example, is positively correlated with ⁸⁷Sr/⁸⁶Sr and negatively correlated with ²⁰⁶Pb/²⁰⁴Pb and ¹⁴³Nd/¹⁴⁴Nd.

In contrast with these inter-volcano correlations, some individual volcanoes display well-defined trends in isotopic - Nb trace ratios that are tangential, or even in an opposing sense, to the overall, inter-volcano trends. This is best seen in Nb/Y because this ratio is influenced by both the source components and by melting processes. The trends for individual volcanoes, from along both the "Kea" and "Loa" trends, tend to converge at low Nb/Y to similar values of Sr, Pb and Nd isotopic ratios. We interpret this convergence as evidence of a refractory component within the plume that is progressively incorporated into the magma with increasing melt extraction. The individual volcano trends indicate variable contributions from this refractory component with contributions from relatively uniform mixed components along the inter-volcano Nb/Y - isotopic array. Because the proposed refractory component is found in lavas from volcanoes along both the "Kea" and "Loa" trends, we suggest that it is a ubiquitous component, intrinsic to the Hawaiian plume. Isotopically, this refractory component plots along the array for Hawaiian tholeiites, between modern Mauna Loa and Kilauea lavas. It does not correspond to any previously proposed plume component such as lithospheric mantle, EM1, DMM, FOZO, or a depleted component recently inferred for the Icelandic plume.

V22B-1023 1330h POSTER

Contamination of OIB-Type Magmas by High-T Altered MORB Crust Documented in the Composition of Seamount Volcanics of the Central Atlantic Ocean

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A roughly 3000 km long belt of volcanic edifices comprising numerous islands and seamounts characterizes the eastern Central Atlantic along the West African continental margin. The Saharan Seamounts, located southwest of the Canary Islands and northeast of the Cape Verde Islands, are part of this volcanic belt. The seamount group includes four major (Tropic, Endeavour, Paps, and Hierro Seamount) and a number of smaller volcanoes, apparently arbitrarily positioned in the 4000 m deep oceanic basin and ca. 80-200 km apart.

We present geochemical and isotopic data of volcanic rocks dredged from the seamounts during RV Meteor cruise M 43/1. Alkali basalts and trachytes predominate in the rock compositions whereas intermediate rocks are less abundant. Trace element patterns of the basalts are similar to those of Santa Helena basalts suggesting derivation from a mantle plume with HIMU signature. The basalts are even more enriched in incompatible elements such as LILE, HFSE and LREE than typical HIMU basalts (e.g., Ba/Yb = 266-332, Zr/Y = 14.7-15.4). This could indicate lower degrees of melting or a more enriched mantle source for the Saharan Seamounts. Nd- and Pb isotopes characterize the mantle source of the Saharan Seamount rocks as a clearly HIMU-component dominated mantle plume (initial ¹⁴³Nd/¹⁴⁴Nd = 0.51274-0.51278, ²⁰⁶Pb/²⁰⁴Pb = 19.8-20.5). However, Sr isotopes, measured on mineral separates in order to avoid secondary alteration effects, are unusually unradiogenic (initial ⁸⁷Sr/⁸⁶Sr = 0.7027-0.7028) and oxygen isotopes are distinctly low ($\delta^{18}O_{P_x}$ = 4.5-4.9).

We interpret the Sr- and oxygen isotopic signature of the Saharan Seamount rocks as a result of contamination of the mantle-derived magmas with high-temperature altered, lower oceanic crust. Partial melting of the oceanic crust during the ascent of the mantle-derived magmas also explains the large amount of highly evolved volcanics. Our study gives evidence that volcanics of ocean islands and seamounts, which were formerly thought to mirror directly the composition of the parent mantle material, may be severely altered in their geochemistry as a consequence of interaction with the pre-existing crust onto which they were erupted.

V22B-1024 1330h POSTER

Lead Isotope Measurement by Lead Double Spike and Thallium Spike Using MC-ICP-MS and TIMS - a Comparison Using Basaltic Samples

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Multi-collector ICP-MS has provided a new level of precision to lead isotope analysis using Thallium addition as an internal mass bias monitor. Further enhancement of precision has been achieved by the application of double lead spike to measurement procedures. In this study, we directly compare results using thallium addition and the new SBL74 double lead spike on both TIMS and MC-ICP-MS (Micromass IsoProbe). The comparisons are performed using standard Pb solutions and basaltic matrix-bearing solutions.

Analyses of standards measured over 8 analytical sessions using the thallium spike method are reproducible to within 100 ppm for ²⁰⁶Pb/²⁰⁴Pb, 130 ppm for ²⁰⁷Pb/²⁰⁴Pb and 220 ppm (2sd) for ²⁰⁸Pb/²⁰⁴Pb. If the ratios for individual analytical sessions are normalised to the SRM981 $\text{dayaverage}/\text{SRM981true}$ the increasing error with greater mass difference of the ratio is eliminated and all ratios are less than 85 ppm. This implies that variability between the Tl and Pb mass bias factors on a day-to-day basis is the cause of increasing imprecision with mass difference.

Double spike MC-ICP-MS is found to produce similar levels of precision to the Tl method for standards. However, the decreasing precision with increasing mass difference is greatly reduced, indicating that the correlation is due to Tl and Pb differences. With basaltic matrix samples with a single anion exchange separation, the effects of Tl-Pb differential mass bias are slightly exaggerated. We present the results from mixtures of SRM981 with Pb-free Fe measured using MC-ICP-MS using Tl and double spike mass bias correction, to replicate the basaltic matrix analyses.

URL: <http://www.soc.soton.ac.uk/isotope>

V22B-1025 1330h POSTER

Helium Isotopic Signatures of Icelandic Alkaline Lavas

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Iceland is widely accepted to be underlain by a plume of actively upwelling mantle. The nature of the individual mantle components within the plume however remains enigmatic. The most compelling evidence for involvement of relatively undegassed, 'undepleted' mantle material are the high ³He/⁴He lavas (>20 RRA) that mainly extrude in the neovolcanic rift zone above the plume stem. It has been proposed that the high ³He/⁴He mantle component is equivalent to the FOZO component on the basis of the Sr, Nd and Pb-isotopic signature of the most extreme high ³He/⁴He sample (Selardalur, 37 RRA). The mildly alkaline centre Snaefell, which is situated close to the plume axis in SE Iceland, has Sr, Nd and Pb-isotopic ratios similar to the high ³He/⁴He sample from Selardalur, which may indicate that Snaefell is mainly sourced by FOZO. Incompatible trace element-rich, high ⁸⁷Sr/⁸⁶Sr, ²⁰⁶Pb/²⁰⁴Pb and low ¹⁴³Nd/¹⁴⁴Nd alkaline basalts from the other off-rift zones have also been attributed to an 'undepleted' plume component, which could be FOZO. However, ³He/⁴He measurements of these alkaline lavas are sparse and are typically comparable to MORB values (Snaefellsnes & Vestmannaeyjar, 6.9-15.1 RRA, MORB, 9.13 ± 3.57 RRA). Furthermore, these centres have Sr, Nd and Pb-isotopic ratios, which are different from FOZO and have incompatible trace element patterns that are consistent with a high share of recycled oceanic basalt in their source. This study compares the Sr, Nd, Pb, He-isotope ratios and trace element characteristics of MgO-rich alkaline lavas from Eyjafjall, Vestmannaeyjar, Snaefellsnes, Snaefell and Selardalur (NW Iceland) in order to assess whether the alkaline centres originate from different sources or variable mixtures thereof. Specifically, Snaefell and Selardalur are inspected in order to test whether the ³He/⁴He ratios and trace element characteristics are consistent with an origin from FOZO.

V22B-1026 1330h POSTER

Systematic Osmium Isotope Binary Mixing Arrays in Arc Volcanism

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Isotopic and geochemical studies on subduction-related lavas aim at constraining the nature of their mantle sources and the respective roles of source heterogeneity and petrogenetic processes in their compositions. Many components are potentially involved in producing the geochemical signatures of arc lavas: depleted mantle, subducted oceanic crust and sediments, and the overlying continental or oceanic crust. A further complication in characterizing mantle sources of arc lavas is complex mixing of some component parts via derivative fluids or melts released from the slab.

Os isotope ratios are potential tracers of slab contribution in arc lavas because 1) subducted sediments are very radiogenic in Os compared to the upper mantle, and 2) Re behaves as a moderately incompatible element during mantle partial melting, whereas Os is highly compatible. Therefore, MORB have much higher Re/Os ratios than peridotites. Consequently, old oceanic crust is likely to be extremely more radiogenic than the depleted upper mantle so that recycled basaltic components should be identified by their elevated ¹⁸⁷Os/¹⁸⁸Os ratios.

Os isotope ratios and Os and Re concentrations have been measured in 55 lavas coming from 10 different subduction zones. Samples span a large range of major element concentrations (from basalts to dacites) and Mg# (from 0.32 to 0.81). The 10 subduction zones, namely the Lesser Antilles, Java, Papua-New Guinea, the Philippines, Izu-Bonin, Kamchatka, the Aleutians, Mexico, Colombia and Peru-Chile, have a range of basement nature and thickness, as well as a range of age and sediment cover of the subducting plate.

Measured ¹⁸⁷Os/¹⁸⁸Os ratios range from 0.130 to 1.524 and Os concentrations range from 0.048 to 46 ppt. Re concentrations range from 37 to 915 ppt. Os initial isotope ratios are systematically positively and linearly correlated with the inverse of Os concentrations in arc lavas from a given volcano, indicating that the Os isotopic compositions always reflect a binary mixing process. All trends converge towards unradiogenic compositions similar to those of upper mantle peridotites. These mixing relationships might be ascribed to a general contamination process; however, a single shallow-level process of crustal assimilation is hardly reconciled with the diversity of basements (from oceanic crust to continental crust compositions) of the selected arc volcanoes, the occurrence of the mixing lines for both primary and differentiated samples, the temporal variations observed for a given volcano, and the absence of co-variations between Os contents, isotope ratios, and indices of differentiation. On the other hand, the radiogenic components may be simply explained by varying the amount of oceanic crust and sediments in the source of these arc lavas. Similar mixing relationships are also seen at the sample scale, which suggests that the Os distribution in the magma prevents the mantle unradiogenic Os to equilibrate with the radiogenic Os coming from the subducted materials transferred via fluids or melts.

V22B-1027 1330h POSTER

Hf Isotopic Geochemistry of Zircon by Multiple Collector-Inductively Coupled Plasma Mass Spectrometry (MC-ICP-MS): A New Chemical Procedure

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Zircon is the major reservoir of Hf in most crustal rocks and is characterized by low Lu/Hf. In situ analysis of zircon by laser ablation MC-ICP-MS is currently

gaining favor in the geochemical community due to the precise spatial control of analysis required for zircons with complex internal morphology. However, the disadvantages of the laser ablation technique include lower precision than MC-ICP-MS, increased isobaric interferences, important memory effects, and poor control of Lu-Hf fractionation. We present a new chemical and analytical method for determining the Hf isotopic composition of zircon specifically designed for a new-generation MC-ICP-MS instrument (Nu Plasma).

After dissolution, our chemical procedure involves chromatographic separation in two stages with an overall yield of ~80%. Hf-Zr are isolated from the REE using AG50W X8 resin and Lu-Yb are isolated from the lighter REE using HDEHP resin. Routine isotopic analysis of ¹⁷⁶Hf/¹⁷⁷Hf on the standard JMC-475 gives an internal precision of 19 ppm and an external precision of 40 ppm with a sensitivity of 20 volts/ppm for an uptake of 80 μl/min. The average ¹⁷⁶Hf/¹⁷⁷Hf value for JMC-475 is 0.282162 ± 3 (2se), which falls within error of the accepted value of 0.282163 ± 9. The isotopic composition of Lu was carried out using a mixed Lu-Yb standard solution (AAS, Alfa Aesar) of 50 ppb with an average value for ¹⁷⁵Lu/¹⁷⁶Lu of 37.72 ± 2 (2sd).

Preliminary results from low-U (<100 ppm) zircon in monzonitic intrusions of the 1.43 Ga Laramie anorthosite complex, Wyoming, USA, demonstrate the extreme sensitivity of Hf isotopes in magmatic zircon to crustal contamination. Initial ϵ_{Hf} values vary from -1 to +4 and are positively correlated with the whole rock Zr concentrations (299-2143 ppm) and negatively correlated with initial ⁸⁷Sr/⁸⁶Sr (0.70749-0.71295) for a constant value of initial ϵ_{Nd} (-2.5) in the whole rocks. These correlations clearly reflect the effects of contamination by Archean crustal rocks.

V22B-1028 1330h POSTER

A Study of Melt Inclusions in Tin-Mineralized Granites From Zinnwald, Germany

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We have analyzed silicate melt inclusions from drill core samples from the eastern Erzgebirge region, Germany, to investigate magmatic-hydrothermal and mineralizing processes in compositionally evolved, tin-bearing granitic magmas. Silicate melt inclusions are small blebs of glass that are trapped or locked within phenocrysts and may contain high concentrations of volatiles that usually leave magma via degassing. Quartz phenocrysts were carefully hand picked from crushed samples of albite-, zinnwaldite- ± lepidolite-bearing granitic dikes from Zinnwald and soaked in cold dilute HF to remove any attached groundmass. The cleaned phenocrysts were loaded into precious metal capsules with several drops of immersion oil to create a reducing environment at high temperature. The quartz-bearing capsules were inserted into quartz glass tubes, loaded into a furnace for heating at temperatures of 1025° and 1050°C (1atm) for periods of 20 to 30 hours, and subsequently the inclusions were quenched to glass. The inclusions were analyzed for major and minor elements (including F, Cl, and P) by electron microprobe and for H₂O, trace elements, and ore elements by ion microprobe.

The melt inclusion compositions are similar to that of the whole-rock sample from which the quartz separates were extracted. The average melt inclusion and whole-rock compositions are peraluminous, high in silica and rare alkalis, and low in MgO, CaO, FeO, MnO, and P₂O₅. Unlike the whole-rock sample, the melt inclusions contain from 0.5 to more than 4 wt.% F. The Cl contents of the inclusions are variable and range from hundreds of ppm to several thousand ppm. The variable and strong enrichments in F of the melt inclusions may correlate with (Na₂O/Na₂O+K₂O) in the inclusions which is consistent with crystal fractionation of feldspars which drives the residual melt to increasing Na contents.

Overall, the compositions of these melt inclusions are different from melt inclusions extracted from the highly peraluminous, tin-mineralized granites of the western Erzgebirge region. The latter represent extreme compositional evolution of P- and F-rich magmas. The inclusions from the albite-, zinnwaldite-, ± lepidolite-bearing granitic dikes of Zinnwald are more similar, compositionally, to those in tin-mineralized rhyolites of Mexico and New Mexico; the Erzgebirge dike melt inclusions contain comparatively greater abundances of Li, Sn, and F, however.

V22B-1029 1330h POSTER

Ca Isotopes Fingerprinting the Earliest Crustal Evolution

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The mechanisms of continent formation remain unclear and can be explained in two contrasting ways, using either a steady state crustal growth model involving massive crustal recycling or continuous crustal growth models. Recent developments in mass spectrometry manifest in the new Finnigan-Triton allow Ca isotopic measurements precise enough to use the K-Ca isotope system to address the problem of early Archaean crustal evolution. Due to a strong fractionation of ⁴⁰K and ⁴⁰Ca during continent formation and a non-linear growth of ⁴⁰Ca, Archaean continental crust should show radiogenic initial Ca isotopic composition if large volumes of it have already been existed 3.6 Ga ago. Simple 15-step calculations predict a difference in ⁴⁰Ca/⁴⁴Ca of 9 epsilon units at 3.6 Ga between the two crustal growth models. To test this, as well as to study the earliest crust formation processes, plagioclase separates from Archaean provinces reflecting the initial Ca isotopic composition and a range of different whole rock samples have been analysed. Preliminary data for ~ 3.6 Ga old TTCs from Zimbabwe show ⁴⁰Ca/⁴⁴Ca indistinguishable from the mantle. This is in agreement with rather chondritic initial Sr and Nd data and might reflect a short residence time of the juvenile mafic oceanic crust before partial melting forming the first continental crust. In contrast, the first results for 3.65 Ga old samples from the Itsaq Gneiss Complex of southern West Greenland yield a more evolved radiogenic Ca signature. This can be interpreted in two different ways. Either as partial melting of juvenile mafic crust shortly after its formation but incorporating already existing crust as also suggested by the existence of older inherited zircons in these rocks and negative eHf values. Partial melting of mafic oceanic crust long after its formation so that ⁴⁰K and ⁴⁰Ca had time to evolve would be an alternative explanation. Importantly, there is no evidence so far for high growth and recycling rates prior to 3.6 Ga as required by the most extreme 'big bang' model.

V22B-1030 1330h POSTER

Crustal decoupling of Hf and Nd isotope systems in high-grade metamorphic rocks

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In order to evaluate the effect of crustal processes on the Nd and Hf isotope systems granulite and amphibolite facies rocks from the Epupa Complex, NW Namibia, were investigated. The magmatometamorphic history of these rocks was obtained by SHRIMP zircon dating.

Both the granulite and amphibolite facies rock groups comprise a heterogeneous collection of rock types including meta-sedimentary as well as felsic and mafic meta-igneous samples. The granulite facies metamorphism was dated at 1519±6 Ma using metamorphic zircon grains and zircon rims surrounding inherited cores. These range in age between 1660 and 1800 Ma and indicate derivation from Palaeoproterozoic protoliths. The granulite facies rocks display a heterogeneous set of Sm-Nd isotope data with Sm-Nd isotope ratios ranging from 0.112 to 0.161 and present day epsilon-Nd values of -21.3 to -7.4. They define a Sm-Nd whole rock isochron age of 2.14±0.33 Ga (MSWD 0.74). This age corresponds well to the c. 2.2 Ga Nd model ages (TDM(Nd); calc. after Naegler & Kramers, 1998, Prec. Res., 91, 233-252) of the granulites. The Lu-Hf isotope signatures of the granulites also reflect the heterogeneity of rock types with Lu-Hf isotope ratios ranging from 0.0082 to 0.0205 and present day epsilon-Hf values of -24.6 to -8.4. The Lu-Hf whole rock data do not define an isochron but, nevertheless, the array points to a Mesoproterozoic age. The calculated Hf model ages (TDM(Hf); calc. after

Kramers et al., 2001, EUG XI, Abstr. Vol., 421-422) yield geologically insignificant results.

The amphibolite facies metamorphic event was dated at 1334±21 Ma using zircons from a leucosome and metamorphic zircon rims from ortho- and paragneisses. Inherited zircon cores range in age from 1640 to 2115 Ma, similar to the core ages of the granulites and also indicative for Palaeoproterozoic precursors. The Sm-Nd isotope ratios of the amphibolite facies rocks vary between 0.103 and 0.119 and the epsilon-Nd values range from -22.5 to -17.0. In spite of this small spread of data they define a Sm-Nd whole rock isochron age of 2.22±0.37 Ga (MSWD 1.05). This age agrees well with the c. 2.1 Ga TDM(Nd)'s of the amphibolite facies rocks and with the Nd isochron age and TDM(Nd)'s of the granulites. The Lu-Hf isotope ratios of the amphibolite facies rocks range from 0.0121 to 0.0316 and the present day epsilon-Hf values vary between -24.5 and -4.1. Again, the Lu-Hf whole rock data indicate a younger age range than the Sm-Nd and the calculated TDM(Hf)'s yield geologically insignificant results.

Conclusion: The Nd model ages of both the granulite and amphibolite facies rocks are somewhat older than the analysed zircon cores but still form a tight cluster of ages which reflect the Sm-Nd isotope signatures of the Palaeoproterozoic precursors. In contrast, the Lu-Hf isotope system of the granulite and amphibolite facies rocks is disturbed by the metamorphic events at 1519±6 and 1334±21 Ma, respectively. While the Hf isotope system was not reset completely it was clearly decoupled from the Nd isotope system due to high temperature crustal processes.

V22B-1031 1330h POSTER

Minor-element variations in lacustrine tufa, Miocene Barstow Formation, California

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U-rich lacustrine tufa formed around subaqueous springs in the middle Miocene Barstow Formation, Mud Hills, California, has significant potential for providing U-Pb age constraints for this terrestrial biostratigraphic reference section. Variations in minor-element incorporation in the tufa should provide insight into the process(es) that were responsible for the precipitation of tufa calcite, including mechanisms of U incorporation. Much of the internal fabric of the tufa consists of multiple layers of bladed calcite cement, 400 µm thick, separated by thin layers of micrite, 10 µm thick. Ca, Mg, Mn, Fe, Sr, and U were measured by electron microprobe in bladed cement (n=38) and in micrite (n=54) at widely spaced intervals from the oldest to youngest portions of the tufa. In addition, 17 line scans were made of bladed cement, with step intervals between 10 µm and 20 µm (n=543). The average and range of composition were similar in both micrite and bladed cement and in the younger and older portions of the tufa (Mg 1581 ppm, range 300-2500; Mn 1244 ppm, range 140-2340; Fe 671 ppm, range BDL-1725; Sr 2285 ppm, range 200-3770; and U 350 ppm, range BDL-780). The only consistent relationship between elements is a positive covariance between Sr and Mg. Within individual bands of cement, there are no trends in any element from base to top. Sr shows the largest (3000 ppm) and most frequent intraband variations, Mn and Fe the least. The abundance of Mn is generally at least twice that of Fe. Certain cement bands have higher abundances of U than others, but these bands are not correlated with position (relative age) in the tufa. The pristine appearance of the rock fabric, uniform red luminescence, and absence of consistent negative correlation between Sr and Mn and/or Mg and Mn show that the composition of the calcite has not been reset by diagenesis. The lack of a consistent relationship between Mn and Fe abundances suggests that Eh-pH conditions and/or supply of these two cations were variable within a limited range during precipitation of the tufa calcite. If the supply of both cations was relatively constant, the low level of Fe to Mn suggests the conditions were weakly oxic. Under these conditions, small changes in Eh and/or in pH could result in incorporation of slightly different ratios of these cations (though not enough to affect luminescence). The slightly oxic conditions also would allow transport of the uranyl ion. The low Eh conditions might have facilitated the incorporation of Eh-sensitive elements Mn, Fe, and U into the calcite.

V22B-1032 1330h POSTER

Distribution of Minor Elements in Calcite From the Unsaturated Zone at Yucca Mountain, Nevada

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Calcite is sporadically distributed in fractures and cavities in the volcanic rocks that form the 500- to 700-m-thick unsaturated zone at Yucca Mountain. Previous work has shown that the calcite precipitated from water moving downward through the unsaturated zone since the volcanic rocks were emplaced approximately 13 Ma. Calcite thus serves as a proxy for the chemistry and amounts of past percolation, two parameters that are important in predictions of the future behavior of the potential radioactive waste repository at Yucca Mountain.

Latest calcite, which began forming between approximately 5 and 2 Ma, typically displays fine-scale growth zoning defined by distributions of Mn (inferred from cathodoluminescence), Mg, and Sr. Electron microprobe (EPMA) mapping of outermost calcite reveals Mg growth zoning¹ and higher overall concentrations of Mg in late calcite than in older calcite. Micro X-ray fluorescence (micro-XRF) maps were obtained by slow rastering of the samples over a 100-watt X-ray source collimated through a final aperture of 100 µm. Although the spatial resolution of the micro-XRF mapping is much less than that of EPMA, this technique reveals distributions of some elements to which EPMA is less sensitive.

Micro-XRF maps show that Sr is spatially correlated with Mg; Sr concentrations range to 500 µg/g at the resolution of the 100-µm collimator. Because both Mg and Sr have similar calcite-water distribution coefficients much less than one, the Mg/Sr in calcite reflects the Mg/Sr of the water that precipitated the calcite. The distribution coefficient for Mn is greater than one and variations in Mn are not correlated with Mg and Sr. Covariation of Mg and Sr in the percolating water may be explained by reactions that affect the rate of uptake of chemical constituents from the overlying rock and soil, and/or evaporation. Late calcite has lower δ¹³C values, probably due to a regional change from wetter to drier climate conditions. The higher Mg and Sr concentrations in the late calcite may record lower deposition rates and decreased percolation fluxes due to the drier climate.

¹Wilson, N.S.F., Cline, J.S., and Lundberg, S.A.W., 2000, Paragenesis and chemical composition of secondary mineralization at Yucca Mountain, Nevada, Geol. Soc. Am. Abs. Prog., v. 32, p. A260.

V22B-1033 1330h POSTER

Redox induced transport of Uranium between the sediment and water interface in the seasonal anoxic and sulfidic lake Willersinweiher (Ludwigshafen/Germany)

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Uranium is a redox-sensitive trace element, with complementary redox-behaviour to manganese and iron. Under anoxic conditions is U immobile, while reduced Mn and Fe could be dissolved in pore-water of sediments. Lake Willersinweiher is a strong eutrophic disused quarry pond with high bioproductivity and organic rich sediments (up to 10%). Sedimentation rates are about 1.5 cm/y. It has a seasonal sulfidic hypolimnion in summer, in which strong precipitation and accumulation of Fe-sulfides occurs. The measurement of both, total and dissolved U and Fe concentrations of lakewater shows, that despite the SO₄²⁻ - reducing conditions and about 50% of the iron in particulate form (amorphous FeS) no significant co-precipitation of reduced U takes place in summer. In contrast, pore-water and sediment data show enrichment of U in the deeper parts (about 10 cm below the water-sediment interface) of the sediment column. Geochemical processes in sediments are mainly biological controlled compared to chemically induced processes in lakewater column. This indicates in this environment that reduction of

dissolved Uranyl and subsequently sedimentary deposition is mostly biologically controlled and thus restricted to sediments. In periods of ventilated bottom water (fall, winter and spring) oxygen diffuses in sediments, causes burn down of organic matter and diagenesis of Fe- and Mn- minerals. Deposited U is released to porewater and diffuses along concentration gradients to both directions: into bottom water and into deeper parts of the sediment. Below the redoxcline under sulfate reducing conditions at a depth of 8 - 10 cm U gets removed from porewater and precipitated. Altogether the net U balance of the sediment is positive and so the organic rich sediments represent an important sink for U in lakes.

V22B-1034 1330h POSTER

Geochemical Studies of Rare Earth and Redox Sensitive Elements in Meta-exhalites Associated With Sedex Deposits of the Southern Catalonian Coastal Ranges, NE Iberian Peninsula

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The Paleozoic series from the Southern part of the Catalonian Coastal Ranges contains several SEDEX deposits. The most important are hosted in Lower Silurian black shales and in Lower Carboniferous gray shales and sandstones. In the Silurian deposits the mineralized interval attains 30 m in thickness and consists of interbedded sulphide-rich shales (mostly pyrrhotite), feldspar rich layers and apatite beds. The ore mineralization is rich in Zn, Cu, Pb, Au, Ag and PGE (up to 0.6 ppm of Pd). The Carboniferous orebodies (up to 5 m in thickness) consist of massive sulphides (pyrrhotite, sphalerite and galena) interbedded within feldspar rich layers and chlorite beds. The ore mineralization is rich in Cu, Ag and Bi bearing minerals. The feldspar rich layers consist of fine-grained metasediments of cherty aspect, made up essentially of Ca-feldspar, quartz and chlorite. Feldspar layers and chloritites, are in all cases related with sulphide mineralization, and have been interpreted as meta-exhalites. Trace-element geochemical studies of these meta-exhalites are reported here. The REE content of Silurian and Carboniferous deposits has been normalized to NASC values. In the Silurian deposits, the REE patterns show a strong depletion in Ce and a low enrichment in La-Eu. Ce depletion reveals a major marine origin of REE, although there is a possible hydrothermal source for Eu-La. The defining characteristic of the REE profiles in the carboniferous deposits is a pronounced Eu enrichment. This fact suggests a hydrothermal origin for REE. Similarly, the content of some redox sensitive elements (V, Cr, Mn, Co, Ni, As, Mo, Th and U) and other related elements has also been normalized. In the Silurian deposits RSE profiles show great enrichments in V, Cr, Co, Ni, Mo and U. Part of the enrichment of these elements could arise from a direct precipitation from seawater, favored by the euhedral conditions of the Silurian basin. However, to explain the high V (up to 5444 ppm) and Cr (up to 640 ppm) it is necessary to consider additional sources. V and Cr could be scavenged from seawater by exhalative particles in a plume that accumulated on the seafloor. This hypothesis is supported by the absence of feeder zones, suggesting distal deposition of the mineralization. RSE patterns in Carboniferous deposits show enrichment in Co, Mo, Th and U, and a depletion in V and Mn. Co and Mo enrichments could be explained by a hydrothermal supply. The higher solubility of V in non-euhedral environments (like the Carboniferous basin) could explain the absence of this element. Elsewhere, Mn is found in syndimentary deposits of the Carboniferous basin, formed far away from sulphide deposits.

V22B-1035 1330h POSTER

Source of Metals and Genesis of Pb-Zn-Ag Deposits of Myanmar: Evidence from REE and Sulphur Isotopic Studies

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A total of thirty six samples from three famous Pb-Zn-Ag deposits namely: Yadanatheingi, Bawdwin and Bawsaing have been studied for their genesis by REE distribution and sulphur isotopic composition. Three galena samples from Yadanatheingi mine showed

chondrite-normalised patterns with strong enrichment in LREE but no Eu and Ce anomalies that will indicate low preferential substitution of HREE during its formation. In addition, the $\delta^{34}\text{S}$ values of galena, which vary from 0.2 to 8.6, and the value of 11.6 yielded by a pyrite mineral separate possibly suggest that mineralization occurred in fissure veins with some input of metal during metamorphic processes wall-rocks. In the Bawdwin mine three faults segmented the ore body as Chinaman, Meinghta and Shan Lode. Five galena samples show positive Eu anomalies although a few samples have negative Eu anomalies. The samples are enriched in LREE; some also display a decreased LREE/HREE ratio. The above features imply that ore was formed in seawater with an input from hydrothermal fluids containing excess Fe. Subsequently, the sample that has higher enrichment of LREE and negative anomalies would indicate that ores were formed by oxidation process. Two rhyolite host samples showed about 4 ppm of SREE and a moderate to strong positive Eu anomaly and low La/Lu ratio. These results coincide with those of the hydrothermal solution and indicate increased partition of REE in feldspar. In addition, $\delta^{34}\text{S}$ values of galena, sphalerite, chalcocopyrite and rhyolite from Shan Lode which are: (-1.5) - (6.5), 3.7 and 0.3-2.2 and 0.6, respectively. In addition, galena, chalcocopyrite and pyrite from Chinaman Lode in the same mine showed $\delta^{34}\text{S}$ values of (-0.6) - (0.69), 3.7 and 0.1 - 9.3, respectively. Galena and malachite indicated values of 0.8 and 0.3 while a barite sample indicated a value of 17.9. All these signatures indicate that the ore body at Bawdwin mine formed from hydrothermal fluids enriched with metals rather than the seawater. Limestone and cerussite from Bawsaing mine showed strong negative Eu with slightly negative Ce anomalies. On the other hand galena showed negative Eu anomaly with high enrichment of LREE. These are implications of the influence of seawater input during the formation of ores under marine condition. $\delta^{34}\text{S}$ values showed 15.3 to 16.9 for galena, 0.6 for malachite and 30.0 -30.2 for barite. These values of galena and barite suggest that the ore was contemporaneously deposited with limestone in a restricted and major evaporate basin.

V22B-1036 1330h POSTER

Alteration Processes Determined by Sr-Pb-Isotopes and U/Th-Radionuclides Along a Faulted Rhyolite-Granite Contact, Eastern Rhine Graben Shoulder, SW-Germany

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The aim of the project is to study the nature of fluid/rock interaction across a faulted rhyolite-granite contact by investigating the isotope and elemental distributions. The fault zone is situated along the eastern Rhine Graben shoulder, close to Heidelberg (SW-Germany). Rb/Sr-, Pb-isotopes and radionuclides were used to characterise isotopic changes, which reveal a signature reflecting the migration of ancient hydrothermal fluids along the fault, as well as the influence of recent weathering processes. Major and trace elements like Rare Earth Elements (REE) were used to quantify fluid/rock interaction (hydrothermal input, trace exchange and corrosion processes). Studied granite experienced a complex history of polyphase fluid/rock interaction following Permian volcanic extrusion, particularly during Jurassic thermal activities, and Tertiary/Quaternary formation of the Rhine Graben. Faults are particularly interesting systems because their frequently enhanced permeability, allowing infiltration of surface and subsurface fluids. Resultant alteration commonly occurs on both sides of the fault. So to get different alteration degree, the samples have been taken across the fault. Fault rocks have undergone a strong leaching of U ($^{230}\text{Th}/^{234}\text{U} > 1$), probably due to recent or sub-recent weathering. However, some U appears to be acquired from the aqueous phase ($^{234}\text{U}/^{238}\text{U} > 1$) in the rhyolite samples. Rhyolite samples had a more complex history of uranium loss and accumulation, whereas the granite samples show only leaching of uranium. Altered rocks that lie within distance on both sides of the cataclase are notably enriched in lead (250 to 1220 ppm). The lead isotope composition differs significantly from the background lead isotope composition of less altered granite at distant from the cataclase; providing evidence for a strong alteration event that increased the lead content and set up a new lead isotopic composition. The Rb-Sr data of the granite samples produces a whole rock isochron

that is in good agreement with the well-known Jurassic hydrothermal event that induced widespread formation of illite (sericite) in the regional basement.

URL: <http://www.uni-heidelberg.de/institute/fak15/geol/dc8/Graduiertenkolleg/Thierry/thierry.html>

V22B-1037 1330h POSTER

Diverse Seismicity and Anomalous Boron Fluid Geochemistry in the Japan Trench

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During Ocean Drilling Program (ODP) Leg 186, the forearc to the Japan Trench offshore Japan was investigated. The Pacific Plate, subducted at a rate of 8-10 cm/y beneath Eurasia, is more than 100 Ma old. Little accretion has occurred during the Neogene and subduction erosion has caused a decrease and subsidence of 6 km of the continental margin off Japan. The Japan Trench region has regularly suffered earthquake hazards in the past ($M > 7$). Two drill sites, which were installed at locations with diverse seismicity (Sites 1150 and 1151) each penetrated approximately 1200 m into subsea-floor sediments of the forearc and recovered Middle Miocene to Recent hemipelagic diatomaceous silty clays with variable degrees of consolidation. Site 1150 was positioned in the seismic zone, Site 1151 in the aseismic portion of the deformation front. The sediments show anomalous high porosities at >1km sub-sea-floor depth at both Sites with an average of >50%. High remaining initial and secondary (i.e. fracture) porosity may have profound effects on the fluid chemistry by possibly providing permeable fluid pathways. Part of that overpressure may be attributed to high sedimentation rates into the forearc basin and subsequent compaction, which may have hindered pore water expulsion. Interstitial pore waters from both sites were analyzed for B, and $\delta^{11}\text{B}$ isotopes. Here, the highly volatile element boron is used to shed light on origin and mechanism of fluid mobilization, as well as the influence of the overall tectonic framework. Boron concentrations cover a wide range from 329 microM to 3920 microM (0.8 to 9.3 times seawater) with an overall increase with depth at both sites. This B enrichment as well as isotopic changes from $\delta^{11}\text{B} = +23$ to $+46\text{‰}$ in the drilling locations may be related to a deep fluid influence of B mobilization from minerals. Cl concentrations are also diluted to approximately 300mM at the same depth intervals. In the deep portion of the aseismic Site 1151, the $\delta^{11}\text{B}$ data show a negative shift ($\delta^{11}\text{B} = 23\text{‰}$), attesting an enrichment in ^{10}B in the fluid as a result of B desorption from clay minerals due to burial and tectonic stress. However, the B enrichment is approximately 30% more pronounced at Site 1150 in the seismic portion of the forearc and the isotopic signatures show an enrichment in ^{11}B ($\delta^{11}\text{B} = 46\text{‰}$). These signatures coincide with an interval of abundant fractures and shear zones, which may represent deep-seated, permeable out-of-sequence thrusts that drain the forearc. However, it is not clear, how the difference in fluid chemistry and porosity link to the variable seismicity in the Japan Trench forearc.

V22B-1038 1330h POSTER

Sulfur Isotope Systematics of the 1982 El Chichón Trachyandesite: An Ion Microprobe Study

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Sulfur isotopic compositions were obtained by ion microprobe for 36 spots on anhydrite crystals in trachyandesitic pumices erupted from El Chichón volcano in 1982. In contrast with earlier conventional sulfur isotopic analyses of bulk anhydrite separates ($\delta^{34}\text{S} = +9.0\text{‰}$ to $+9.2\text{‰}$) the ion-microprobe results reveal that individual anhydrite crystals are roughly homogeneous isotopically, but that crystal-to-crystal variations are large ($+2.5\text{‰}$ to $+10.9\text{‰}$; mean and $1\sigma = +6.4\text{‰} \pm 2.1\text{‰}$). Isotopic variations show no correlation with complex textures reflected by cathodoluminescence color. Two models for the origin of this wide isotopic variability among anhydrites are considered viable: mixing of magmatic anhydrite with isotopically heavier hydrothermal anhydrite, and mixing of anhydrite crystals precipitated from different domains of the magma reservoir that were variably depleted in sulfur and enriched in ^{34}S through progressive degassing prior to eruption. No evidence

supports assimilation of sedimentary sulfate as an explanation for the high sulfur content of the El Chichón magma or for the wide variability in $\delta^{34}\text{S}$ of anhydrite. Ion-microprobe analyses of $\delta^{34}\text{S}$ were also obtained on six magmatic ovoid-shaped inclusions of pyrrhotite, chalcopyrite, and/or intermediate sulfide solid solution hosted by silicate or oxide crystals ($\delta^{34}\text{S} = -0.1\text{‰}$ to $+2.7\text{‰}$; mean and $1\sigma = +0.7\text{‰} \pm 1.0\text{‰}$) and four irregularly shaped multiphase sulfide fragments in the matrix interpreted as xenocrystic, which range widely in $\delta^{34}\text{S}$ (-3.7‰ to $+5.5\text{‰}$). The difference between mean $\delta^{34}\text{S}$ values for anhydrite and magmatic sulfides ($\Delta = 5.7\text{‰}$) indicates equilibration at a pre-eruptive temperature of $\sim 850^\circ\text{C}$, consistent with temperature estimates based on oxygen isotopic exchange and laboratory phase-equilibrium experiments. The results of this study and other recent investigations lead to a revision of the bulk magmatic $\delta^{34}\text{S}$ value for the 1982 El Chichón trachyandesite of $+4.1\text{‰}$, lower than the previous estimate of $+5.8\text{‰}$, but typical of the relatively heavy sulfur isotopic compositions that characterize subduction-related magmas.

V22B-1039 1330h POSTER

Temperature-Induced Aluminum Zoning in Hornblendes of the Fish Canyon Magma, San Juan Volcanic Field, Colorado

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An extensive electron microprobe survey of amphibole compositions in the Fish Canyon magma (2146 analyses), more than 80% of which are from high-resolution (<10 mm step) core-to-rim traverses across large euhedral phenocrysts, provides: (1) temporal constraints on the immediately pre-eruptive P-T evolution of the magma, and (2) a means of testing recent calibrations of Al-in-hornblende thermo-barometry. The low-variance phase assemblage of the Fish Canyon magma (11 mineral phases + melt \pm vapor) is ideal for an assessment of the influence of P and T on hornblende chemistry, particularly as it has been reproduced experimentally at $X_{\text{H}_2\text{O}} = 0.5$, 760°C , 2.4 kb and $f_{\text{O}_2} = -11.4$ by Johnson and Rutherford (1989; JH89). Hornblende phenocrysts are variable for most major elements (e.g., 5-9 wt.% Al_2O_3), due primarily to two T-sensitive coupled substitutions: (1) $\sim 50\%$ of the total Al variation (~ 0.8 atoms p.f.u.) is due to the edenite exchange and (2) $\sim 25\text{-}30\%$ is due to a Tschermak-type Ti-Mn exchange. The P-sensitive Al-Tschermak substitution did not play a significant role.

In order to constrain the ranges of absolute P and T over which these hornblendes crystallized and to assess the sensitivity of the recent thermo-barometric algorithms of Blundy and Holland (1990; BH90), Holland and Blundy (1994; HB94) and Anderson and Smith (1995; AS95), we have calculated P and T for two populations of analyses wherein Al_2O_3 contents are within analytical error (6.00 ± 0.05 wt.% Al_2O_3 , N=78 and 7.75 ± 0.05 wt.% Al_2O_3 , N=40). The barometric formulation of AS95 gives a mean P of 2.24 ± 0.05 kb for the high-Al population at 760°C , which is indistinguishable from the 2.4 ± 0.5 kb estimate of JR89. An excessive sensitivity to T at low P is suggested by the implausibly shallow depths calculated for the low-Al population (<1 kb at 760°C). The two thermometric formulations give reasonable results between 680° and 810°C , but the HB94 calibration gives a mean T higher by $\sim 50^\circ\text{C}$ and is overly sensitive to small analytical differences ($\sim 100^\circ\text{C}$ spread for each population).

Nine out of 14 traverses across large phenocrysts from different stratigraphic horizons of the Fish Canyon magmatic system display rimward increases in Al^{T} , $(\text{Na}+\text{K})^{\text{A}}$, and $\text{Ti}^{\text{M1-M3}}$, compensated by decreases in Si^{T} , and $\text{Mn}^{\text{M1-M3}}$. Using the BH90 algorithm, the low-Al population, typical of near-core compositions, gives a mean T of $680 - 700^\circ\text{C}$, which is slightly above the water-saturated granite solidus at 2-2.5 kb. The high-Al population, typical of the rim composition, gives a value $\sim 760 - 770^\circ\text{C}$, which is indistinguishable from independent T determinations using coexisting Fe-Ti oxides and Qtz-Mgt oxygen isotope thermometry. These profiles suggest that Fish Canyon hornblendes crystallized during near-isobaric reheating over a T range of $\sim 80^\circ\text{C}$, which is consistent with the model of rejuvenation and remobilization of a pre-existing near-solidus crystal mush of batholithic dimensions via shallow intrusion of more mafic magma, as we have postulated for the Fish Canyon magma on the basis of independent textural/chemical evidence. Crystallization during reheating requires an open system, in which both heat and mass, in particular volatiles, are transferred from the underlying mafic magma.

AS95: Am. Min. 80, 549-559. BH90: Contrib. Min. Pet. 104, 208-224. HB94: Contrib. Min. Pet. 116, 433-447. JR89: J. Pet., 30, 711-737.

V22B-1040 1330h POSTER

To estimate the Continental growth rate on the Earth; (1) Age distribution of detrital zircons from Mississippi River sand, North America

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In order to understand the continental growth history of the Earth, we must evaluate the recycled granitic materials to their protolith ages, because the Phanerozoic orogenies occupy the continents more than 50% on the Earth and are composed of dominantly sedimentary rocks over 90%. To overcome this difficulty, the age population of detrital zircons from river sand is critical, because of (1) resistance of zircon against recrystallization, (2) common occurrence in granitic rocks, and (3) high blocking temperature (ca. 900°C) of U-Pb isotope system. We initiated systematically to analyze those zircons from major 25 rivers over the world. The remained unknown parameter is the statistic analysis to obtain how many analysis satisfactorily represent the space ratio of provenance with different ages. As a first step, we investigated U-Pb ages of zircons (1000 grains) from Mississippi River sand, North America. Th/U ratio was also analyzed to distinguish the origin of zircon, either metamorphic or igneous, simultaneously. The Mississippi River and its tributaries cover North American continent about 40%, and transport the sediment into the river mouth. Age distribution of zircon is compared with spatial ratio of basement with different age (Hoffman, 1991). The results indicated that zircon age ranges from 3.6 Ga to 0.2 Ga with a strong peak at 1.5-1.9 Ga occupying 45% among total analysis of 125 grains. This overall pattern is very similar to that of space ratio of basement rock with different ages (Hoffman, 1988). Slight difference appears on the peak at 2.7 Ga and 3.2 Ga calculated from space ratio on basement, i.e., no strong peaks on zircon ages. Metamorphic source zircons (Th/U ratio is above 4) are less than 1% of all. It may be tentatively concluded that the number of analysis of zircon may be 100 enough to conclude the general tendency as a first order of approximation.

V22B-1041 1330h POSTER

High-Resolution Stable Isotope Variation of Aeolian Sediments over a Wind-Eroding Playa Surface

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Geochemical and isotopic compositions have been used to trace the origin of mineral dust to its source. An inherent assumption in such studies is that geochemical signatures are preserved during dust formation and transport. Here we test this premise by examining the stable isotopic ratios of carbonate in dusts from Owens (dry) Lake, California, a large desiccated playa subject to wind erosion of unconsolidated surface sediments. In the Lake Owens Dust Experiment (LODE) of 1993, aeolian sediments were captured during their generation at 6 heights above the surface in 7 sites along a 1 km linear transect during 3 dust events over a 2-week period, as the lakebed evolved from an evaporite-covered to a clastic-covered surface. Dust samples were obtained from several collection sites at the respective ends of the transect. At each site up to 5 heights were measured for isotopic composition (10, 20, 50, 60, 100 cm). Dust samples, free of organic C, were digested in phosphoric acid and the CO_2 produced from carbonates at 25.2°C was analyzed for C and O stable isotopes. The acid fractionation factor for calcite (1.01025) was assumed in calculating the O isotopic composition of the carbonate. The overall variation in delta values among the samples is $+1$ to $+4$ and -5.5 to -3 per mil (V-PDB) for C and O, respectively. The relatively high oxygen isotope values are consistent with hydrologically closed system conditions for the carbonate generation. Both isotope systems show variations with sampling height, collection site, and time. The first storm (3/11- N wind) produced carbonates with the lowest delta O and C values and generally the most extreme depletion in heavy isotopes with height at the four sites studied. The

dust becomes enriched in the heavy isotopes downwind with a constant shift of nearly 2 per mil independent of height. The second storm (3/17 S wind) shows depletion of heavy isotopes with increasing height at each locality, though less pronounced than in the first event. There is less variation between sites (1 per mil) than in the first storm but the order of enrichment among the sites is still the same. The third storm (3/23 - S wind) produced the smallest variation with height at each site and the smallest variation between sites (0.5 per mil). Overall, there is a positive 1:1 correlation between C and O isotopes for the carbonates and they become more enriched in the heavy isotopes with each successive dust emission event. There are several possible sources of the dust carbonate. To the north of the collection area is located a large salt pan and to the south, sand dunes. These, however, do not appear to have contributed significant carbonate dust to the collectors during the storms since the isotopic enrichment does not appear to depend on wind direction. A more likely source of the carbonate is the lake bed sediment itself. During the flooding of the lake detrital carbonate was brought in and subsequently during evaporation authigenic carbonates have formed. The change in the isotopic composition of the carbonates thus appears to reflect a change in the source from authigenic (evaporitic) type to a more clastic type consistent with the physical changes to the wind-exposed playa surface observed during the sequence of dust storms. The isotopic composition of the dust could thus be considered a mixture between these sources, reflecting the changing chemistry of the lake bed sediments. Our study suggests that it may be possible to trace the origin of carbonate dust using stable isotopes as long as the sources differ by at least several per mil from each other.

V22B-1042 1330h POSTER

Detailed Paleotemperature Profiles of the High Arctic from Perennial Spring Tufa Deposits

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The Canadian High Arctic is a sensitive indicator for global climate change. As such, historical records of recent fluctuations in arctic temperature may provide insights into the effect of anthropogenic activity on global climate. Active calcite deposits from perennial springs at Expedition Fiord on western Axel Heiberg Island potentially provide a historical record of environmental conditions in the form of crusts having alternating dark (50 microns) and light (150 microns) laminae when thin sections of material are viewed in cross section under transmitted light. The laminae grow on pre-existing rip-up clasts in mineral-rich spring waters, which maintain a nearly constant temperature (6°C) and flow rate (1.3 L/s) throughout the year.

High resolution isotopic records (carbon and oxygen) of mineral growth were obtained from polished thick sections (150 microns) of the crust using a computer controlled X-Y-Z micro-positioning stage to drill trenches (100 microns wide) along transects perpendicular to the accretionary laminae. Carbonate powders (approximately 75 micrograms) were collected from trenches with a microspatula and transferred to reaction vessels where they were reacted with orthophosphoric acid to produce CO_2 . Samples were then analyzed using the automated sampling device (GasBench) and a Delta +XL isotope ratio mass spectrometer operating in continuous flow mode. Stable isotope profiles were constructed over 50-100 laminae couplets and interpreted within the context of changing temperature regimes using the oxygen isotope paleotemperature equation for calcite.

V22B-1043 1330h POSTER

Geologic Mapping of Medicine Lake Volcano, CA, USA

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Medicine Lake volcano is a broad, shield-shaped edifice located behind the main axis of the Cascade Range at its interface with the Basin and Range province in northern California. Subduction-related, but strongly influenced by an east-west extensional environment, the volcano has erupted frequently during its half million year history. Approximately 250 units have been mapped, only half a dozen of which are thin surficial units such as alluvium. Most units represent eruptive events and include a lava flow and its vent (dome, cinder cone, spatter cone, etc.). Some cinder cones have not been matched to lava flows, which are apparently buried, and some lava flows cannot be correlated with vents.

The geologic mapping exists as digital data in ArcInfo. Querying of the database indicates that the total area covered by Medicine Lake volcano is about 2200 km². Sixty percent of that area (1322 km²) is covered by basalt (<53% SiO₂). About 26% of the area is comprised of basaltic andesite (53.0-56.9% SiO₂) and andesite (57.0-62.9% SiO₂) together. Basaltic andesite covers 270 km², whereas andesite covers 305 km². The total area covered by silicic lavas is 117 km², or about 5% of the total. Dacite (63.0-69.9% SiO₂) accounts for 66 km², but three-quarters of that area consists of the tuff of Antelope Well, the only ash-flow tuff, which thinly covers (<1 m to a few m thick) a significant area low on the northwest flank of the volcano. Rhyolite (>69.9% SiO₂) covers 51 km². Slightly more than half of the rhyolite (26 km²) was erupted in post-glacial time. Surficial deposits are mapped over 35 km², <2% of the total. Older volcanic and sedimentary units within the map boundary account for 154 km², about 7% of the total area.

The map uses color to indicate composition. In addition, products of 16 post-glacial eruptions are shown with a pattern in order to highlight them. They cover 316 km², about 14% of the map area. The largest single units on the map are all basaltic in composition, including one of the post-glacial units, the basalt of Giant Crater (198 km²). The largest single unit is the late Pleistocene basalt of Yellowjacket Butte (296 km² exposed), whose area is partly covered by a late Holocene andesite flow.

V22B-1044 1330h POSTER

Oxygen Isotope Record of Hydrothermal Flow along Normal Faults, Comstock Lode, NV.

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Normal faults in the Comstock Lode mining district, Nevada are delineated by low ¹⁸O belts along strike and strong isotopic gradients perpendicular to strike. These low ¹⁸O belts suggest that the faults were contemporaneous with the meteoric paleohydrothermal system that produced a regional pattern of low ^δ¹⁸O values at Comstock. A series of cross-sections through the district show that the Comstock, Occidental, and Corvett faults are each bound by an approximately 200 m wide, fault-parallel zone of low ¹⁸O rocks in the hanging wall. Enhanced fluid-rock interaction near the faults is due to hydrothermal flow during and after periods of active deformation. Displacement that post-dates the hydrothermal system juxtaposes fault blocks that were altered under different conditions. Consequently, by comparing the isotopic character of rocks across fault boundaries it is possible to constrain the relative timing between convective hydrothermal flow and dip-slip displacement along normal faults.

Oxygen isotope transects across normal faults in the Comstock district indicate periods of simultaneous faulting and hydrothermal flow, and additionally record the displacement that has occurred after the main period of hydrothermal activity. A mathematical model based on the fundamental solution for diffusion away from a plane source, when coupled with a step function to account for post-hydrothermal displacement, provides a good fit to the observed ^δ¹⁸O data. Deconvolving the observed oxygen isotope patterns in this way quantifies the magnitude of enhanced fluid-rock interaction caused by faulting, the width of the high-flow zone, and the effects of post-hydrothermal displacement.

V22B-1045 1330h POSTER

Rare Earth Element Tracing for Bamsar, Revesht and Nezam-Abad Tungsten Deposits in Central Iran

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Bamsar, Revesht and Nezam-Abad tungsten deposits are located southwest of Shazand in central Iran. Rare Earth Element (REE) and other trace elements in samples of scheelite (CaWO₄) from these deposits have been determined by Neutron Activation Analysis in order to constrain the composition and sources of the mineralizing fluids.

Paleozoic and Triassic volcano-sedimentary rocks and upper Triassic-Jurassic detrital-chemical and volcanic units outcrop in the Shazand region. The intrusives in the region have granitic and granodioritic compositions that have caused metamorphic haloes in

the upper Triassic-Jurassic units. Six ore-bearing skarn horizons have been identified at Bamsar, while granodioritic intrusives host vein-type mineralization at Revesht and Nezam-Abad.

Revesht and Nezam-Abad scheelites have higher total REE and Na concentrations than Bamsar samples. Bamsar scheelites show flat chondrite-normalized REE (REE_N) patterns, whereas scheelites from Revesht and Nezam-Abad exhibit hump-shaped REE_N patterns with maximum REE_N concentrations displaced towards Dy.

Following the findings of Ghaderi et al. (1999) on scheelites from Western Australian gold deposits, it is suggested that Bamsar scheelites have variable Eu anomalies and trivalent REE concentrations and thus appear to contain mostly Eu²⁺ and to have formed under reduced conditions. Revesht and Nezam-Abad scheelites, on the other hand, exhibit no changes in the size of the Eu anomaly with REE concentration, implying a predominance of Eu³⁺ and crystallization under relatively oxidized conditions. Bamsar scheelites have (Ce/Lu)_N > 1 and are interpreted to have crystallized from LREE-enriched fluids, whereas Revesht and Nezam-Abad scheelites with (Ce/Lu)_N < 1 formed from LREE-depleted fluids. The elevated Na contents of Revesht and Nezam-Abad scheelites compared with Bamsar samples, suggest crystallization from hydrothermal fluids with higher Na activities.

Reference:
Ghaderi, M., Palin, J.M., Campbell, I.H., & Sylvester, P.J. (1999). Rare earth element systematics in scheelite from hydrothermal gold deposits in the Kalgoorlie-Norseman region, Western Australia. *Economic Geology*, v. 94, p. 423-437.

V22B-1046 1330h POSTER

Erosion by Flowing Lava: Geochemical Evidence in the Cave Basalt, Mount St. Helens, Washington

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Lava erosion is thought to have been responsible for the modification of some lava tubes and channels on the Earth, the Moon, Mars, Venus, and Jupiters moon Io. It may include both thermal erosion (melting and assimilation of country rock into lava) and mechanical erosion (physical removal of unconsolidated rocky materials by flowing lava). The search for unequivocal morphological and geochemical evidence of erosion has been hampered by the inaccessibility of lava/substrate contacts in active (and most inactive) tubes and the potential for deformation, metamorphism, and mobilization of elements in ancient lava flows. Thus, the best circumstances for identifying evidence of lava erosion are in Holocene tubes and channels where lava/substrate contacts can be studied and sampled, and where the rocks have not been greatly altered.

We collected samples from lava/substrate contacts in the lava tubes of the ~1900 year old, relatively unaltered Cave Basalt flows, Mt. St. Helens, to assess whether the lavas contain geochemical evidence of lava erosion. Previous studies have found morphological evidence indicating that both thermal and mechanical erosion occurred during tube formation. Basaltic tube linings in contact with the dacitic wall rock have whole-rock major and trace element compositions intermediate between those of uncontaminated lava and the substrate, and therefore appear to be contaminated by the wall rocks. In contrast, basaltic tube linings that are closest to the tube interior appear to be uncontaminated. There is no evidence that the lavas become increasingly contaminated downstream. Some distal linings contain wall rock xenoliths and others contain wall rock xenomelts, indicating that mechanical and thermal erosion were operating simultaneously. There are two possible interpretations of these relationships: 1) the lava may have been flowing laminarily, resulting in contamination of only the boundary layer adjacent to the contact, or 2) the lava may have initially been flowing turbulently, resulting in a well-mixed and contaminated interior, but that the interior of the tube was replenished by uncontaminated lava, preserving contaminated lava only along chilled margins. Thermal and fluid dynamic models support the former interpretation. Regardless, the interior tube flows that have been sampled obviously represent the waning stages of the eruption, in which flows erupted at lower flow rates only partially fill pre-existing tubes and have not been able to melt through existing basaltic tube linings to come in contact with the underlying substrate.

V22B-1047 1330h POSTER

²³⁸U - ²³⁰Th - ²²⁶Ra Ages of Crystals in Recent Mt. St. Helens Lavas: Implications for Crystal Residence and Recycling

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The ages and chemical characteristics of crystals relative to the melts in which they were erupted have bearing on the processes and timescales of magma differentiation and storage; in particular, ²²⁶Ra-²³⁰Th disequilibria in mineral and groundmass separates can provide average crystallization ages in young (< 8 ka) systems. Open-system behavior in the form of addition of Ra to the magma after crystal formation has been inferred for recent (<2 ka) Mount St. Helens lavas based on apparent deviations from isochronous ²²⁶Ra-²³⁰Th behavior [Volpe and Hammond, 1991]. An alternate possibility is that the deviations reflect differential fractionation of Ra from Ba (used as a proxy for initial ²²⁶Ra) during crystal growth. We evaluated these effects using calculated partition coefficients and ion microprobe analyses of crystals in the same samples and found that the relative abundances of ²²⁶Ra-²³⁰Th-Ba in all but the youngest sample (1982 AD) are largely consistent with closed-system crystallization. However, the ages calculated from ²²⁶Ra-²³⁰Th are significantly younger than those calculated from ²³⁰Th-²³⁸U disequilibria in the oldest samples. We show that decoupling of ages inferred from the two systems can be explained by a combination of introduction of old xenocrystic material and young crystal growth during ascent and eruption. Rapid crystal growth during ascent may also account for the anomalously high ²²⁶Ra/Ba in plagioclase from the 1982 dacite. If the model crystallization ages of the "well-behaved" samples largely reflect the timing of crystallization from the melt in which the crystals were erupted, the implied magma storage times were on the order of 1-3 ky for these samples, which would suggest that at least some of the magmas erupted within the past ~2 ka were stored simultaneously beneath the volcano. Because these magmas are compositionally diverse, this would suggest that the reservoir system beneath Mt. St. Helens consists of a collection of physically distinct magma bodies rather than a single magma chamber. Alternatively, the similarity between crystal ages in the younger samples could indicate repeated entrainment of xenocrysts of the same age by successive magma batches.

V22B-1048 1330h POSTER

Argon Isotopic and Experimental Petrologic Evidence for Phenocrysts Versus Xenocrysts in the Youngest Toba Tuff

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One of the largest known eruptions is that of the 74 ka Youngest Toba Tuff (YTT), which vented more than 2800 cubic km of magma from the Toba Caldera in Sumatra, Indonesia. The YTT was preceded by the 501 ka Middle Toba Tuff, and it has been proposed that the hiatus between them represents the time needed to develop a large magma body (Chesner, 1998). A controversial aspect of the YTT is that the aluminum content of the amphiboles in the magma indicates growth at pressures of ca. 300 MPa, whereas water contents in glass inclusions suggest much lower pressures, implying that the magma was greatly water undersaturated before eruption (Chesner, 1998).

To develop a fuller understanding of the YTT magma's petrogenesis, we investigated the experimental phase equilibria of the magma and measured the argon isotopic signatures of sanidine, biotite, amphibole, and plagioclase. We find that biotite, plagioclase, and quartz are stable under almost all pressure-temperature conditions investigated, with sanidine crystallizing at low temperatures. Amphibole does not crystallize at temperatures and pressures recorded by the natural mineral assemblage and we can find no conditions under which amphibole is stable. Biotite and sanidine ⁴⁰Ar/³⁹Ar isochron ages are concordant at about 77 ka, similar to previous age determinations. Amphiboles and some plagioclases show significantly older ages, some as great as 1.5 Ma.

Our results suggest that the YTT magma contained phenocrysts of biotite, plagioclase, quartz, and sanidine, and resided at nearly water saturated pressures

of 100 - 150 MPa. All amphiboles and some plagioclases were xenocrysts and were entrained throughout the entire 2800 cubic km of magma. Diffusion loss modeling of the xenocrysts indicates that these phases could not have resided in the magma chamber since the Middle Toba eruption, and that some were incorporated into the YTT magma perhaps only a few years prior to eruption. This study indicates that combining petrologic and isotopic information is crucial in identifying phenocrystic versus xenocrystic phases, which then allows magmatic conditions and residence times to be estimated.

Chesner, C.A., 1998, Petrogenesis of the Toba Tuffs, Sumatra, Indonesia: *Journal of Petrology*, v. 39, p. 397-438.

V22B-1049 1330h POSTER

Multiple Uses of Hydrogen Isotopes as a Tracer of Rehydration Processes in Glassy Lavas

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Silicic lava flows contain zones of enhanced vesicularity with high total H₂O contents. This relationship between volatile content and vesicularity has promoted the monitoring of active lava domes using remote sensing techniques in an effort to forecast explosive activity. A persistent complication in attempts to relate surface texture to H₂O content and explosivity was the confounding effect of meteoric H₂O. Glassy and vesicular lavas exposed at the surface of the Earth for prolonged periods readily interact with meteoric H₂O. Rehydration is a time-, temperature-, and porosity-dependent process governed by the slow diffusion of molecular H₂O into the glass. This inevitable addition of secondary H₂O obscures the spatial distribution of juvenile H₂O in lava flows. The ability to distinguish magmatic from meteoric H₂O in glassy lavas would help identify regions of overpressure on active domes and thereby improve hazard assessment.

Three types of hydrogen isotopic studies of glassy lavas have been utilized to disentangle rehydration processes from primary magmatic ones. First, bulk hydrogen isotopic data on variably textured lava flows reveal enrichments in both δD and total H₂O as vesicularity increases. Mixing between a degassed magmatic and a partially evaporated meteoric H₂O best explains the observed trend from lower δD values in the interior massive obsidian samples to higher δD in the most surficial vesicular pumice. Second, step-heated hydrogen isotopic analyses further prove that the vesicular samples contain a high percentage of meteoric H₂O. Whereas dense massive obsidian samples release a large fraction of deuterium-depleted H₂O at temperatures above 600°C, the bubble-rich pumiceous samples lose a majority of their H₂O at temperatures below 400°C. Lastly, the Cameca 6f ion microprobe at ASU was used to measure hydrogen isotope transects into the vesicle-melt interface. The gradation from depleted δD values in the glassy interstices to more enriched δD values near the interface supports the rehydration hypothesis. Moreover, the δD value of the rehydrated glass adjacent to the vesicle-melt interface closely matches the composition of the meteoric H₂O component revealed by the step-heated extractions.

V22B-1050 1330h POSTER

Open System Processes in Basaltic Magma Genesis: Evidence from High-Precision U-Th-Pb Isotopic Measurements of Phenocrysts

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The Pb isotopic compositions of phenocryst phases in young mafic lavas have been investigated using the Getty-DePaolo (GCA, 1995) method. This approach may complement melt inclusion studies and help in the evaluation of the significance of isotopic heterogeneity in basaltic systems. In addition, if magmatic phases have a uniform Pb isotopic composition upon eruption,

the method can be used for geochronology. Although U is commonly subject to disturbance in surface environments, Th and Pb are not. The method uses ²⁰⁷Pb as a (quasi) stable isotope ratio which allows the ²⁰⁶Pb/²⁰⁴Pb and ²⁰⁸Pb/²⁰⁴Pb to be determined to < 100 ppm.

The samples for this study include ~16 Myr-old Innaha basalt, a zero-age MORB, a ~260-kyr-old tholeiite from Mount Etna, and a ca. 5 Myr-old tholeiite from Kauai. Plagioclase feldspar is a low-U/Pb phase in each of these samples. U-Pb and Th-Pb ages in all but the Kauai basalt are anomalously old (by 1-3 orders of magnitude), due to low ²⁰⁶Pb/²⁰⁷Pb and ²⁰⁸Pb/²⁰⁷Pb values for the plagioclase feldspar, which range in size from 2 cm for the Innaha basalt to 1-2 mm for the Etna sample. The isotopic heterogeneity must be a reflection of either magma mixing ± assimilation processes just prior to eruption, or melt inclusions, which could reflect mixing earlier in the magma evolution. The fact that the isotopic heterogeneity in the MORB is as large as in the continental basalts indicates that assimilation may not be the main issue. The Innaha basalt and MORB also have Rb/Sr heterogeneity, but the Mt. Etna basalt does not. The Kauai basalt does not show disequilibrium and an age assignment is possible. Microprobe studies are underway to attempt to determine the importance of inclusions. The results reinforce the conclusions from *in situ* inclusion studies that cryptic isotopic heterogeneity is common, but do not yet help identify where in the magma generation and transport process it originates.

V22B-1051 1330h POSTER

Ashes Ashes All Fall Down! Reconstructing Volcanic Eruption Rates From ⁴⁰Ar/³⁹Ar Ages of Contaminated, Ashes, Mono Lake California

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Probabilistic volcanic hazard assessments can be determined by the product of a series of conditional probabilities. The first parameter of this conditional probability, the probability of a volcanic eruption, can be determined by simply counting the number of volcanic eruptions in a given amount of time, thereby deriving an eruption rate. Radiometric dating of the relevant volcanic units is paramount in this endeavor. In addition, volcanic ashes deposited into lakes record volcanic events and can also be used to determine eruption rates.

The Wilson Creek FM, Mono Lake, CA, contains 19 ash layers, recording volcanic eruptions from the Mono Craters Long Valley region. The top of the Wilson Creek FM is approximately 11 ky old and the base of the section is constrained to be greater than 50 ka, and may be as old as 75 ka. This yields an eruption rate of 2.9 to 4.8 events per 10,000 years. In addition, we have dated sandine from four volcanic ash layers in the Wilson Creek FM, Mono Lake, CA, by the single crystal laser fusion ⁴⁰Ar/³⁹Ar method (ashes 8,15,16 of Lajoie, 1968 U.C. Berkeley Ph.D. thesis). These data and single crystal ⁴⁰Ar/³⁹Ar results from Chen et al. (1996, *Science*) from ashes #5 and 12 all show a significant degree of contamination from older volcanic material.

Analysis of the population distribution of these data are used to extend the record of volcanic events beyond the 40 to 65 ky time interval sampled by the Mono Lake sediments to about 120 ka. The age distribution of the single crystal ⁴⁰Ar/³⁹Ar results also indicate an episodic nature for the volcanism in the Mono Craters Long Valley region. Approximately 4-5 additional volcanic events between 60 and 120 ka are implied by the extra sandine populations. In addition, the ⁴⁰Ar/³⁹Ar ages of the single crystal data also indicate a limited volcanic activity between 760 ka (Bishop tuff?) and 120 ka.

V22B-1052 1330h POSTER

Laboratory synthesized oxygen isotope zonings in plagioclase

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Stable oxygen isotope behaviors in high-temperature melt have been poorly understood due to lack of crystal-synthesis experiment with O-isotope evaluation. The distribution of trace elements along with ¹⁸O in volcanic mineral should provide important information about growth history under various conditions (e.g., supercooling, convection, and volatile-degassing). For interpretation of naturally grown volcanic minerals, it is especially necessary to understand the formation mechanism of O-isotope zoning for synthesized crystals. We performed crystal growth experiments of anorthite by FZ method that can realize the control of the growth velocity and stirring rate individually and aid to interpret the formation process. We have conducted two different experiments: (1) anorthite growth in varied growth velocity; (2) growth in varied stirring rate. Obtained crystals were profiled along the growth direction by CO₂-laser and electron microprobe analyses.

A single- to poly-crystal of anorthite crystal synthesized by experiment (1) showed a visible negative shift in δ¹⁸O value (-0.5‰/‰) with a tiny change in growth velocity from slow to fast (V = 0.310 to 0.344 mm/hr). Across this gap, major impurity of MgO (initial content: 0.1 wt%) showed a slightly positive fluctuation in fast growth zone (0.05 to 0.1 wt%). Another result of experiment (2) exhibited a large shift in δ¹⁸O (+1.5‰/‰) with change in melt-stirring rate from slow to fast (50 to 70 rpm). Across this gap, MgO was more enriched in fast-stirred zone (0.05 wt%) than in slow-stirred (0.01 wt%).

It is concluded from these above results that ideal equilibrium isotope fractionation factor between crystal and liquid anorthite α_{x-l} may not be 1.0 but > 1.0 even at melting temperature, and that growth kinetics may play an important role to modify the resultant δ¹⁸O in crystal. Probably, change in interfacial concentration of ¹⁸O by diffusional isotope transport is the most dominant cause for the formation of O-isotope zoning. Fast growth causes slight δ¹⁸O decrease in crystal by δ¹⁸O-depletion in the interfacial melt, and slow growth increases δ¹⁸O by attaining the equilibrium against bulk melt. Fast and slow stirrings provide similar situation to the case by slow and fast growth, respectively. Fast melt-stirring decrease the thickness of diffusion layer near the interface. In contrast, incorporation of impurity MgO into crystal can be promoted by dominant control of interface kinetics when the melt is stirred. Difference in growth in dynamic or static magma may be isotopically reflected in natural volcanic plagioclase having MgO-coupled or decoupled δ¹⁸O zonings.

V22C MC: Hall D Tuesday 1330h Developments in Geochronology

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V22C-1053 1330h POSTER

Ion Microprobe U-Pb Dating of Calcium Phosphates in Martian Meteorites

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Studies of the SNC (Shergottite, Nakhlites, Chassignite) meteorites, which are thought to be impact ejecta from the planet Mars, have contributed significantly to the understanding of the igneous history of the planet. So far, an intensive work on the radiometric dating of Martian meteorites has been carried out, and it is well documented that some isotopic systems had been disturbed by the impact shock, which could be related to the ejection from Mars. Since the U-Pb isotopic system in phosphate is more resistant to secondary process, U-Th-Pb dating could be a reference for the comparison of the date of the pre-shock igneous event via other dating techniques. We have attempted to investigate the U-Th-Pb systematics of phosphates in various Martian meteorites (basaltic Shergottite, Nakhlite, Chassignite) using the Sensitive High Resolution Ion MicroProbe (SHRIMP) installed at Hiroshima University,