

V12G-04 1425h

Diffuse Rift Zones: Subaerial and Submarine Satellite Vents at Wolf Volcano, Galapagos

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Wolf Volcano is one of the type-locality Galapagos shields, characterized by steep upper slopes, circumferential fissures near the summit, and a large and deep caldera. Fissures on the flanks of the volcano are radially distributed. Although the radial vents are concentrated in the northwest, northeast, and southern sectors of the volcano, the individual fissures are not aligned in sharp rift zones. Our preferred interpretation is that instead of being classic volcanic rifts, sectors of the volcano are absent vents, owing to gravitational stresses exerted by the caldera walls, neighboring volcanoes, and unusually steep slopes. The lack of vents in these areas concentrates vents in other sectors of the volcano. In contrast, bathymetry and sidescan sonar reveal that submarine Wolf has two volcanic rifts, one to the northwest and another that extends to Roca Redonda volcano. These submarine rifts are marked by linear alignments of vents and fissures and have produced young unconsolidated lava. The submarine lavas are compositionally identical to those erupted from the subaerial part of the volcano, indicating that they intrude laterally from the subcaldera magma chamber. All of the lavas erupted from the volcano are similar in composition, indicating thermal and chemical buffering of the magma in a well-mixed, steady-state system. Wolf lavas are unusual in that their isotopic composition is indistinguishable from that of depleted MORB erupted from the nearby Galapagos Spreading Center. Their trace element concentrations, however, are nearly that of E-MORB. Thus, we believe that Wolf magmas are produced by low degrees of melting of nearly pure asthenosphere, either from the margins of or entrained within the Galapagos plume.

V12G-05 1440h

Magmatic Consequences of Failed Rift Zones: Examples from the Eastern Pacific

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The aseismic Cocos Ridge, one of the most prominent bathymetric features in the eastern Pacific, records 20 million years of interaction between the Galapagos hotspot and the Galapagos Spreading Center. Two major clusters of seamounts are located along the northern flanks of the ridge, one near the Costa Rican coast and the second around Cocos Island. The Costa Rica and Cocos Seamount Provinces (including Cocos Island) have produced alkalic lavas accompanied by enrichment in incompatible trace elements beyond any observed in the Galapagos Archipelago today or in samples from the crest of the Cocos Ridge. Cocos Island is known to be millions of years younger than the hotspot track on which it lies, and the other seamounts likely share this characteristic. Trace element data determined by ICP-MS from over 90 dredged samples from the ridge and seamounts suggest that the compositions of the lavas are strongly controlled by the history of rift jumping in the region. The lavas are the result of small degrees of melting of a Galapagos plume-like source, predominantly in the garnet stability field. In the case of both seamount fields, their eruption immediately follows the failure of a rift zone at each province's location. Thus we attribute the anomalously young alkalic lavas of the seamount provinces to post-abandonment volcanism following either a ridge jump or rift failure, and not to the direct activity of the Galapagos plume. The seamounts and Cocos Island are instead the result of passive upwelling caused by a major tectonic rearrangement, such that the seamounts are significantly younger than their supporting lithosphere or the hotspot trace. The failed

rift tapped mantle that had previously incorporated Galapagos plume material when the lithosphere was produced at the plume-affected GSC. Fundamentally, the hotspot's variable interaction with the Galapagos Spreading Center, coupled with rift failures associated with tectonic rearrangements of the ridge itself may be the dominant factors in controlling regional magmatism and may be responsible for the formation of some enigmatic oceanic volcanoes such as Cocos Island.

V12G-06 1455h

A Comparison of two Northeastern Atlantic Rift Systems With Hawaiian Rift Systems

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Models on magma transport within and beneath rift zones are largely based on Hawaiian volcanoes and are not necessarily transferable to other oceanic islands. We carried out comparative studies on the active Cumbre Vieja rift zone of La Palma (Canary Islands) and on the fossil Madeira and Desertas rift systems (Madeira Archipelago) representing shield stage volcanoes at hotspots less productive than the Hawaiian. Different barometers were used to constrain magma pathways beneath the Madeira and La Palma rift systems and to compare the results with models for Hawaiian rift zones. Pressures obtained by cpx-melt barometry are interpreted to reflect major fractionation levels and generally indicate depth ranges within the uppermost mantle: 16-27 km for Cumbre Vieja, 15-32 km for Madeira and 16-28 km for Desertas. In contrast, microthermometry of CO₂-rich fluid inclusions yields pressures within the lowermost crust to uppermost mantle (Cumbre Vieja: 7-14 km, Madeira: 8-10 km, Desertas: 9-17 km) that are interpreted as temporary stagnation levels. Further stagnation within the upper crust that may reflect shallow rift pathways was only found for the Desertas rift at 2-4 km depth. Our models of the magma plumbing systems beneath La Palma, Madeira and Desertas are thus characterized by (i) major fractionation levels in the upper mantle, (ii) temporary stagnation levels in the lower crust to the Moho, and (iii) local rift pathways. In none of the investigated volcanoes there are any indicators of a high-level magma reservoir feeding the rift zones. This is an important difference to models for Hawaiian rift zones characterized by shallow subcaldera magma chambers from where rift zones emanate. For Hawaii there is also evidence for prior magma storage and fractionation near the mantle/crust boundary and within the upper mantle, similar to the situation at the Atlantic rift systems studied. The lack of long-lived shallow magma chambers at La Palma and Madeira is best explained by their lower eruption rates as compared to Hawaii and the lower buoyancy fluxes of the respective mantle plumes.

V12G-07 1510h

Magma inflow into Katla, one of Iceland's most hazardous volcanoes

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Katla is one of Iceland's most active volcanoes, with twenty large eruptions in the last 1100 years. A seismic survey suggests the presence of a magma chamber under the volcano at 4-5 km depth. The volcano is ice-capped, thus making Katla eruptions phreatomagmatic and capable of triggering jokulhlaups. A minor jokulhlaup in July 1999 associated with an episode of continuous seismic tremor was probably the first sign of resumed magmatic activity under the volcano. GPS measurements on nunataks at the rim of the subglacial caldera, have revealed steady inflation due to magma accumulation from 1999 onwards. These measurements show uplift and horizontal displacement of the nunatak stations at a rate of up to 2 cm/yr, and horizontal displacement of the far field stations at about 0.5 cm/yr

away from the caldera centre. Findings suggest progressive caldera inflation over time. Inflation was modeled with a point-source, giving an uplift rate of about 2 cm/yr since 2000. Recent magma inflation falls below the volume of that previously extruded in 1918. The agitated state of the Katla volcano is further expressed by increased earthquake activity that has remained abnormally high and continuous since 2001. Historic Katla eruptions have initially been explosive, allowing high rates of enthalpy extraction due to profuse melting of the glacier base. Floodwater gathers rapidly in a large and inherently unstable water reservoir that bursts suddenly to produce a cataclysmic jokulhlaup that peaks within a few hours. The proximity of the Katla volcano to populated areas and international flight paths makes this volcano one of Iceland's most potent geological hazards.

V12G-08 1525h

Magma-tectonic interaction at Mauna Loa, Hawaii: Earthquake stress change influence on direction of dike propagation at rift zones

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There is ample evidence for earthquake volcano interaction at Mauna Loa. An M 6.6 earthquake at the eastern flank of the volcano preceded the 1984 eruption. An M 6.3 earthquake at the western flank preceded the 1950 eruption. An M 7.0 earthquake at the southeastern flank of Mauna Loa preceded the 1868 eruption. Earthquake focal mechanisms suggest a cause by gravitational spreading and fault slip near the base of Mauna Loa. The eruptions that followed initiated at the summit caldera, from where the fissures propagated along the northeast rift zone NERZ (1984) or along the southwest rift zone SWRZ (1868, 1950). Using three-dimensional boundary element models we calculate stress changes associated with earthquakes larger than magnitude 6. The earthquakes caused a decrease of Coulomb stress at the magma chamber, probably triggering the eruption. Moreover, the patterns of extensional normal stress for the rift zones coincide with the locations of the eruptive fissures (SWRZ or NERZ) at Mauna Loa. This suggests that the propagation of dikes is controlled by the change in stress related to gravitational spreading earthquakes.

V12H MCC: 3008 Monday 1600h

Volcanic Emissions to the Troposphere: Budgets, Sources and Impacts (joint with A, B)

Presiding: D Pyle, Cambridge

University; C (de Hoog, University of Gothenburg

V12H-01 1600h INVITED

Volatile Emissions from Subduction-related Volcanoes: Major and Trace Elements

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Present-day volatile emissions associated with subduction zone volcanism can be estimated in two ways. One approach is to assume magma production rate at arcs is 20% that of MOR and scale to the MOR ³He flux (1000 mol/yr) to obtain a mantle-derived arc He-3 flux of 200±40 mol/yr. This flux and measured gas ratios (x_f /³He is the gas species of interest) obtained from volcanic and hydrothermal samples is then used to calculate volatile emissions. A global arc CO₂ flux of 0.3 to 3.1 x 10¹² mol/yr has been obtained in this way. Another approach is to use individual arc volcano SO₂ fluxes (determined by remote sensing) in combination with CO₂/SO₂ ratios of high temperature fumaroles to calculate volcanic CO₂ fluxes. Integrating over an individual arc, and using a power-law distribution to include non-measured volcanoes, it is possible to produce a volatile flux estimate for a particular arc. Summing over all arcs allows a global estimate (e.g. ~ 1.6 x 10¹² mol/yr for arc CO₂).

There are caveats with both methods. In the former case, it is assumed that the mantle wedge is characterized by a similar ^3He content to MORB-source. In the latter case, the distribution of SO_2 fluxes is decidedly uneven necessitating poorly-justified extrapolations. For example, there is little data available from the I-B-M, Lesser Antilles and Philippines whereas Central American volcanoes have numerous published SO_2 fluxes. A further issue (in addition to geographical bias), is the absence of volatile fluxes from submarine arcs. Despite these problems, global estimates of SO_2 and CO_2 fluxes by both methods vary by only one order of magnitude [1]. It is emphasized that these are present-day estimates as paleo-degassing rates of arc magmas are poorly constrained and depend entirely on estimates of magma intrusion and extrusion rates [2]. The same approach has been used for other species although the flux of magmatic N_2 , H_2O , HCl , HF from arcs remains poorly constrained (N_2 : $\sim 6 \times 10^8$ to 2×10^{10} mol/yr; H_2O : $\sim 8 \times 10^{12}$ mol/yr; HCl $\sim 1 \times 10^{10}$ to 4×10^{11} mol/yr, HF : $\sim 3 \times 10^9$ to 3×10^{11} mol/yr)[1,3]. Due to the preferential partitioning of HCl and HF into volcano hosted hydrothermal systems, fluxes from magma bodies are probably much larger than what is emitted into the atmosphere. Trace element emissions from subduction related volcanoes are also poorly constrained but are potentially significant. High temperature ($>700^\circ\text{C}$) volcanic gas samples show that concentrations of Be, Rb, Sr, Ru, Rh, Pd, Cd, W, Re, Pt, Pb, Bi, Se, Sc are in the 5 to 1300 $\mu\text{g/L}$ range and up to 25000 $\mu\text{g/L}$ of B have been measured [4,5]. Using these concentrations and the global arc SO_2 flux gives estimates of trace element fluxes on the order of 3×10^4 to 8×10^6 mol/yr (and 3×10^9 mol/yr of B). These flux estimates are certainly upper limits because low temperature ($<200^\circ\text{C}$) gases that make up the majority of emissions have much lower trace element concentrations. Further work is needed to better constrain volatile contributions of volcanoes to the atmosphere, and to improve global geochemical models which assess the impact of volcanic gases on the atmosphere.

[1] Hilton, Fischer & Marty (2002) Rev. Min. vol 47 for review [2] Kerrick Rev. Geophys. (2001) vol. 39 #4. [3] Symonds, Rose & Reed (1988) nature vol 334, p. 415 [4] Fischer, Shuttleworth & O'Day (1998) Fres. J. Anal. Chem. vol 362, p. 457 [5] Taran et al., (1995) Geochim. Cosmochim. Acta vol. 59, p. 1749

V12H-02 1615h

A Melt-Inclusion Study of Trace-Metal Behavior During Degassing of Basaltic Magma at Miyake-Jima Volcano (Izu-Bonin Arc, Japan)

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Following its eruptions in the summer of 2000, Miyake-jima volcano discharged on average 40 kton SO_2 /day for over a year, the highest SO_2 flux in the world at the time. We used juvenile pyroclastic fragments of the June 27 (submarine) and August 18 (subaerial near the summit) eruptions to study trace-element behavior during degassing. The fragments are medium-K calc-alkaline basalts (51-53 wt% SiO_2 , 4% MgO , 9-11% CaO , 2.1-2.7% Na_2O) with high concentrations of chalcophile elements, most notably Cu. Sulfides have not been observed in these samples. Melt inclusions (5-300 μm) are common in plagioclase phenocrysts and consist of brown glass with occasionally vapor bubbles. They show little compositional variation (52 wt% SiO_2 , 5.1% MgO , 9.5% CaO , 2.3% Na_2O) and no significant differences between subaerial and submarine samples. Sulfur concentrations in melt inclusions are high, ~ 900 ppm, compared to those in groundmass glass, ~ 70 ppm, indicating significant sulfur loss after the entrapment of melt inclusions. However, no decrease is observed for the concentrations of any trace elements, not even the chalcophile or volatile elements (such as Cu, Zn, As, Sb, and Pb), except Bi. We conclude that large-scale open-system degassing at Miyake-jima did not mobilize trace elements in significant amounts. Comparable K/Cl ratios of melt inclusions and groundmass glass imply that little or no chlorine was lost from the magma, in accordance with its high solubility in mafic melts at low pressures. High-T fumarole studies and thermodynamic modeling indicate that many metals are transported as volatile chloride-complexes, which may explain the limited mobility of trace metals reported here. Our findings indicate that, at magmatic temperatures, sulfur only plays a limited role in the transport of metals across the melt-vapor interface.

V12H-03 1630h

Extreme ^{210}Pb - ^{226}Ra Disequilibria Observed in arc Lavas: Implications for the Time Scales of Magma Degassing

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We have undertaken α -counting measurements of ^{210}Pb activity in 39 arc lavas previously analysed by TIMS for U-Th-Ra and, more recently, U-Pa disequilibria from the Lesser Antilles, Tonga, Vanuatu, Philippines, Marianas, Sunda, Kamchatka and the Aleutians. The lavas were erupted between 1953 and 1999 and show extreme variation in ^{210}Pb - ^{226}Ra disequilibria with age corrected ($^{210}\text{Pb}/^{226}\text{Ra}$) activity ratios ranging from 0.36 to 3.14. In detail, the majority (25) of the lavas analysed preserve ^{210}Pb deficits with 17 having ($^{210}\text{Pb}/^{226}\text{Ra}$) < 0.9 and 7 ($^{210}\text{Pb}/^{226}\text{Ra}$) < 0.8 whilst 5 are below ($^{210}\text{Pb}/^{226}\text{Ra}$) = 0.6. Of the 14 lavas that have ^{210}Pb excess, 6 have ($^{210}\text{Pb}/^{226}\text{Ra}$) > 1.2 . Whereas ^{210}Pb deficits are found across the compositional spectrum of lavas analysed (silica = 47-65 percent), ($^{210}\text{Pb}/^{226}\text{Ra}$) appears to increase with increasing silica in those lavas that have ^{210}Pb excesses. The ^{210}Pb deficits are most readily interpreted in terms of protracted magma degassing and the numerical model of Gauthier and Condomines 1999 (EPSL 172: 111-126) suggests that the typical duration of degassing is on the order of 10's of years but may reach 45 years in the case of the largest ^{210}Pb deficits at Yasur in Vanuatu, Mt Mayon in the Philippines, Avachinsky in Kamchatka and Spurr, Redoubt and Shishaldin in the Aleutians. These estimates for the duration of degassing represent minimum time scales since they assume 100 percent efficient degassing of ^{222}Rn and no magma replenishment during that period. Therefore, it appears that the majority of arc magmas undergo efficient and protracted degassing for decades prior to eruption. By contrast, there is no simple model for explaining the ^{210}Pb excesses. Mass balance calculations indicate that plagioclase accumulation cannot account for the observed excesses. Instead, we suggest that inefficient gas release and/or sublimation of ^{210}Pb produced by decay from ^{222}Rn during gaseous transport through the magma may be responsible for the observed ^{210}Pb excesses. The increasing viscosity of higher silica magmas may act to slow bubble transport and increase the likelihood of sublimation and the development of ^{210}Pb excess leading to the observed correlations.

V12H-04 1645h

Volcanic SO_2 Emissions During the 2002/2003 Eruption of Stromboli

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Stromboli, an island in the Aeolian archipelago northeast of Sicily, Italy is well known for the persistent, frequent and small explosions emitted from its summit craters, a type of activity that is synonymous with the volcano. On December 28th 2002, after several months of higher than usual eruptive activity a partial collapse of the crater structure occurred and lava began to flow from fissures within an old collapse feature on the western flank known as the Sciarra del Fuoco (scar of fire). The last major effusive eruption from Stromboli occurred in 1985. Two days later, on 30th December 2002, approximately 7 million m^3 of material collapsed from the Sciarra into the sea, together with a similar magnitude of material displaced under sea level. This collapse produced a tsunami wave that severely damaged parts of the coast of Stromboli, as well as other islands in the archipelago. Lava effusion continued until July 2003, constituting one of the longest continuous effusive periods in the modern period from this volcano. During most of the effusive period, daily measurements of the SO_2 flux from Stromboli were performed with a COSPEC instrument, from helicopter and from boat. These measurements allow an unprecedented insight into the magma degassing process before, during and after a rare effusive eruption. Typical

pre-eruptive fluxes were on the order of 200 tonnes/day of SO_2 . Average SO_2 fluxes during the eruption were 500 tonnes/day. Using the original dissolved sulfur content of strombolian magma we calculate the volume of magma required to generate this SO_2 flux, and determine a mass flow rate of approximately $0.5\text{m}^3/\text{s}$, comparable with estimates of the lava effusion rate for much of the eruption. We conclude that during the effusive eruption the typical magma circulation with the conduit of stromboli effectively ceased and was replaced by a simple flow with all magma entering the system at depth eventually exiting at the summit. These conclusions allow empirical constraints to be placed on petrological observations of crystal growth processes under both circulation and flow regimes.

V12H-05 1700h

The Impact of Etna's Volcanic Gas Emissions on Soils and Vegetation

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Mt. Etna is considered to be at present, on long time average, the major volcanic gas emitter in the world, accounting for about 10 percent of world-wide average volcanic emissions of CO_2 and SO_2 . Hydrogen Chloride and HF emissions are proportionally high with measured values of 750 and 190 tons day respectively. Such huge emissions, significantly overwhelming the regional anthropogenic mass output, have a strong impact at least on local scale. Its strong influence has been assessed for example on rainwater chemistry, which display increasing contents of F (up to 227 mg/l), Cl (up to 1410 mg/l) and SO_4 (up to 481 mg/l) with decreasing distances from the summit craters. The corresponding high wet deposition values (up to 72 mg/m^2 day for SO_4 , 226 mg/m^2 day for Cl and 21 mg/m^2 day for F) are comparable or even higher than those measured in heavily polluted areas of central Europe. Dry deposition, estimated with a network of passive samplers, represents an additional load on the local environment especially for sulfur. The geographical pattern of wet and dry deposition reflects the dilution of the volcanic plume with increasing distance and its prevailing displacement to the east by atmospheric circulation. To study the impact on Etnean soils, 52 soil-sampling sites were chosen all around Mt Etna in areas with minor anthropic disturbance, at distances from the summit craters between 3.7 and 16 km. At each sampling site, a composite sample of the first 5 cm of the soil profile of at least 4 points within an area of about 100 m^2 was collected. Samples were analyzed for bulk chemical composition and for leachable anion and cation content. Although the results display a large variability, the strong impact of crater emissions can be seen especially in fluorine content and in pH of soil solutions, which closely resemble the deposition pattern. But despite the huge acidic deposition, Etnean soils do not show the adverse effects noted in the heavily polluted areas of Central Europe because of the high acid buffering capacity of these young volcanic soils. Furthermore about 60 samples of leaves and needles of 6 different plant species were collected for the study of the impact of Etna gaseous emissions on its vegetation cover. Preliminary results indicate fluorine and sulfur content, which are sometimes higher than in heavily polluted areas, and with generally higher contents in conifers with respect to broad-leaved species. But the effects on vegetation at Etna seem significantly low, likely because: i) the acidity of the emitted sulfur and halogen compounds is buffered by the presence of large quantities of volcanic silicate ash and/or carbonate dust; ii) local vegetation species has developed some kind of resistance to the "volcanic pollution".

V12H-06 1715h

Volcano emissions of trace metals, atmospheric deposition, and supply to biogeochemical cycles

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Quiescently degassing (not exploding) volcanoes inject into the troposphere plumes that have remarkably high concentrations of ordinarily-rare, volatile trace metals. In pre-industrial times, these emissions appear to have accounted for the strong "enrichments" (relative to concentrations in crustal material or in ocean solute) of many such trace metals in the material deposited from the atmosphere. This has been shown by measuring the source strength of the emissions of metals from volcanoes, and comparing that to the amounts of the metals (excess over amounts accounted for by rock dust and sea salt) deposited onto high-latitude ice sheets: volcano degassing outputs of metals and deposition masses of metals to ice are comparable, on the basis of the masses (fluxes) and proportions of the metals, and from the proportions of lead (Pb) isotopes. There is indication that in modern industrial times the elevated trace metal fractions in the atmospheric material that has small particle size and long atmospheric residence time is still more strongly influenced by volcano emissions than by industrial emissions. Throughout earth's history it is likely that volcano emissions were a major control on the environmental background levels of trace elements, in which plants and animals evolved their tolerances to these mostly-poisonous substances.

V12H-07 1730h

Element fluxes from Copahue Volcano, Argentina

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Copahue volcano in Argentina has an active volcano-magmatic hydrothermal system that emits fluids with pH=0.3 that feed a river system. River flux measurements and analytical data provide element flux data from 1997 to 2003, which includes the eruptive period of July to December 2000. The fluids have up to 6.5 percent sulfate, 1 percent Cl and ppm levels of B, As, Cu, Zn and Pb. The hydrothermal system acts as a perfect scrubber for magmatic gases during the periods of passive degassing, although the dissolved magmatic gases are modified through water rock interaction and mineral precipitation. The magmatic SO₂ disproportionates into sulfate and liquid elemental sulfur at about 300 C; the sulfate is discharged with the fluids, whereas the liquid sulfur is temporarily retained in the reservoir but ejected during phreatic and hydrothermal eruptions. The intrusion and chemical attack of new magma in the hydrothermal reservoir in early 2000 was indicated by strongly increased Mg concentrations and Mg fluxes, and higher Mg/Cl and Mg/K values. The hydrothermal discharge has acidified a large glacial lake (0.5 km³) to pH=2 and the lake effluents acidify the exiting river. Even more than 100 km downstream, the effects of acid pulses from the lake are evident from red coated boulders and fish die-offs. The river-bound sulfate fluxes from the system range from 70 to 200 kilotonnes/year. The equivalent SO₂ output of the whole volcanic system ranges from 150 to 500 tonnes/day, which includes the fraction of native sulfur that formed inside the mountain but does not include the release of SO₂ into the atmosphere during the eruptions. Trace element fluxes of the river will be scaled up and compared with global element fluxes from meteoric river waters (subterranean volcanic weathering versus watershed weathering).

V12H-08 1745h INVITED

Sources, Fluxes and Cycling of Trace Metals on Global and Regional Scales

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The latest assessment of anthropogenic sources of trace metals globally and the results of the 2000 emission estimates for these sources are presented. Stationary fossil fuel combustion continues to be the major source of Cr, Hg, Mn, Sb, Se, Sn, and Tl with respect to the coal combustion and the major source of Ni and V with respect to oil combustion. Combustion of leaded, low-leaded and unleaded gasoline continues to be the major source of atmospheric Pb emissions. The third major source of trace metals is non-ferrous metal production, which is the largest source of atmospheric As, Cd, Cu, In and Zn. The largest anthropogenic emissions of atmospheric trace metals were estimated for Asia. This can be explained by growing demands for energy in the region and increasing industrial production. As a result, the Asian emissions are not only larger than the emissions on other continents, but also showing an increasing trend. Another factor contributing to high emissions in Asia is the efficiency of emission control which is lower than in Europe and

North America. Concerning the two latter continents, emissions of trace metals show a decreasing tendency over the last two decades. A comparison of global anthropogenic emission estimates with the global natural emission estimates suggests that anthropogenic emissions of Pb and V are by one order of magnitude higher than the natural emissions of these metals. Anthropogenic emissions are a factor of 2 to 3 higher than the natural emissions for Cd and Ni, while they are comparable for Cu, Hg, Mo, Sb and Zn. The comparison also indicates that global natural emissions of As, Cr, and Se are larger than the global anthropogenic emissions of these elements by a factor of 2 to 3. Finally, the natural sources are far more significant than the anthropogenic sources for Mn.

V12I MCC: 3010 Monday 1600h

Many Facets of Garnet: Recorders of Crust and Mantle Dynamics II (joint with T)

Presiding: D Vance, University of London; R Spiess, Universitat di Padova

V12I-01 1600h

Combined High-Precision Garnet Ages and Garnet Ionprobe Data from Granulite-Facies Migmatites and Granites -Implications for Element Redistribution During High-Grade Metamorphism and Melting

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Migmatitic and metapelitic garnet from the granulite-facies (5-6 kbar/750oC) part of the Damara orogen (Namibia) has been used to date high-grade regional metamorphism and yielded high-precision Sm-Nd grt-whole rock ages that range from 523 to 509 Ma similar to the U-Pb monazite ages (531 - 517 Ma) from the same rock. All garnet species show significant variation in Pb isotope composition, Nd/U-Th/U and U/Nd-Sm/Nd space suggesting a significant contribution of minute accessory phases (i.e. monazite and zircon). Trace element variations in the metapelite garnet show no core-rim REE variation. The negative Eu anomaly is less pronounced than in migmatite garnets. These garnets show no pronounced core-rim variations in Zr (9-6 ppm) and Sr (0.12 ppm) and moderate concentrations of Ti (30 ppm), V (40 ppm) and Cr (100 ppm) suggesting variable contributions of zircon, monazite and ilmenite during garnet growth. Garnets from in-situ migmatites show REE, Sr, Zr, Ti and Cr depletion and increasing negative Eu anomalies from core to rim suggesting the presence of a REE and HFSE-enriched granitic melt during melting. Garnets from intrusion-related migmatites show REE, Zr and Sr depletion from core to rim similar to garnet from in-situ migmatites. The decreasing negative Eu anomaly from core to rim is a result of decreasing LREE concentrations relative to HREE concentrations at constant Eu. These garnets have overall low concentrations of V, Cr and Sr similar to igneous garnets. These features suggest initial growth of garnet during in-situ melting with plagioclase present followed by growth of garnet in an intrusive trace element-depleted granitic melt. Igneous garnet is one order of magnitude less enriched in REE than the other garnet species but shows enrichment in HREE and depletion of LREE in the core relative to the rim. This igneous garnet is depleted in Sr, Zr, V and Cr compatible with the trace element-depleted nature of the host leucogranite. All garnet species show distinct (Sm/Gd)N and Eu/Eu* covariations which are discussed together with previously published trace element systematics of amphibolite-facies, granulite-facies and igneous garnets.

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Isotope Dilution and LA ICPMS Study of Trace Elements in Garnets: Implications for Sm-Nd and Lu-Hf Dating.

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One of the main advantages of garnet geochronology is a possibility of establishing a direct link between isotopic ages and PT conditions. However, both Lu-Hf and Sm-Nd garnet dating can strongly be affected by submicroscopic inclusions capable of dominating the Sm-Nd and Lu-Hf budget. We investigated possible effects of various inclusions on Sm-Nd and Lu-Hf systems by combined isotope dilution and LA ICPMS studies. Internal isochrons obtained for 6 high-grade blocks of metabasites from the Franciscan complex yielded highly precise Lu-Hf ages ranging from 114 to 170 Ma, but failed to provide Sm-Nd dates. The main reason for failure of the Sm-Nd dating was a rather large amount of matrix silicate inclusions, which contained > 100 times more Nd than analyzed "impure" garnet fractions. The same inclusions had very limited influence on the Lu-Hf budget. This is mainly due to strong enrichment of garnets in heavy REE and due to much lower Hf concentrations in rock forming silicates. The ¹⁷⁶Lu/¹⁷⁷Hf ratios obtained for the analyzed garnets are typically between 1.5 and 8, but for two samples with spessartine-rich garnets, values range between 21 and 28 and are the highest yet reported. Small amount of zircon and rutile inclusions did not notably suppress ¹⁷⁶Lu/¹⁷⁷Hf ratios. This is mainly due to their small size (<10 μm) and low abundance, but also because of their limited dissolution during sample digestion on a hotplate. Our results demonstrate that even samples with significant amounts of inclusions can yield precise and accurate Lu-Hf dates.

For upper amphibolite facies metapelites from Vietnam, we obtained well defined Sm-Nd ages of 52.1±2.5 and 31.4±1.0 Ma, which are grossly discordant with the corresponding Lu-Hf dates of 84.1±1.6 Ma and 77.9±1.6 Ma, respectively. We therefore conducted LA ICP MS measurements on 4 selected samples.

Sm/Nd ratios show rather flat zonation profiles throughout most of the crystal, with an up to 30% increase in the rims. The zonation closely follows Fe and Mn profiles. Lu/Hf ratios, on the other hand, show very large variations with low values in the rims reaching up to several hundreds in the cores and shows closer association with Y, Ca and Mg. Preservation of very strong zonation pattern of heavy REE together with Lu-Hf ages significantly older than corresponding Sm-Nd dates suggest higher closure temperature for the former system and possible inheritance problems in the analyzed samples.

Sm/Nd ratios obtained by isotope dilution for garnets leached with sulphuric acid (SAL) were only about 10% lower than those estimated by LA ICPMS. This demonstrates high efficiency of SAL leaching in purifying garnets from monazite inclusions, which is of fundamental importance for achieving reliable ages. The same leaching technique had very different influence on Lu-Hf system. Garnets with ¹⁷⁶Lu/¹⁷⁷Hf ratios >20 after leaching yielded even higher ratios after leaching. On the other hand, SAL applied to garnets with more typical ¹⁷⁶Lu/¹⁷⁷Hf ratios were brought down even by up to 50% relative to the unleached fractions. The latter case demonstrates removal of inclusions with Lu/Hf ratios higher than those in garnet. The most likely mineral with such high ratio in analyzed metabasites is apatite and in the case of metapelites- xenotime.

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Sm-Nd Dating of Spatially Controlled Domains of Garnet Single Crystals

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Ganguly and Tirone have recently presented a method of determining the cooling rates of rocks from the difference between the core- and bulk-ages of a crystal as determined by a single decay test. We present the first application and successful test of the method using the core and bulk ages of garnet single crystals, according to the Sm-Nd decay system, in two rock samples with contrasting cooling rates, which can be constrained independently. The samples belong to the metamorphic core complex, Valhalla, British Columbia, and the granulite facies mid-crustal magmatic arc of the Salinian terrane, California. We have micro-sampled the garnet crystals over specific radial dimensions, and measured the Nd isotopes of these