

# *EUG XI*



Symposium MS04

## Deciphering the Chemical Signal of Oceanic Basalts

Convenors

Kevin W. Burton  
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## Sunday PM Session

## MS04 : SUPm26 : F6

## MORB Petrogenesis – Confused Signals from the Mantle

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The gabbro layer beneath the ocean floor implies crustal magma chambers. Earliest MORB descriptions stressed magma mixing and fractionation. Experimental petrology denies MORB are primary melts. MORB have olivine joined by plagioclase as the low pressure crystallisation sequence. Up-pressure this sequence is replaced first by olivine joined by clinopyroxene, then by clinopyroxene and ultimately garnet as liquidus phases. The lherzolite-harzburgerite mineral assemblage nowhere appears on the liquidus, hence MORB cannot be primary liquids. Most MORB have Mg# lower than in equilibrium with mantle residual olivine, requiring chemical evolution after separation. MORB features are consistent with crustal modification by olivine loss and partial crystallisation of gabbro from more primitive liquids. The trace element 'clinopyroxene signal' supports this. Evidence of magma chamber processes warn of undisclosed adventures - "Please, Sir, it was only a very small baby".

Many papers report major element data briefly; petrography and field relations are scarcely mentioned. This is like slaughtering the buffalo for the sake of its tongue. Basalts are probes of mantle and crust processes but they are economical with the truth. The processes cannot be adequately modelled as isobaric gabbro removal superimposed upon dunite removal from a primary magma. Such 'restoration' of parental magmas modifies compositions towards the olivine-clinopyroxene-plagioclase plane of the simplified basalt tetrahedron (Herzberg and O'Hara 1998). Mg# will increase away from, not towards, compositions of potential initial primary partial melts. This 'restoration' is opposed to the effects of variations in mass fraction of melting which move compositions away from those of potential initial primary partial melts towards the olivine-clinopyroxene-quartz face of the basalt tetrahedron. Mg# will increase in a direction opposed to that of 'restoration'. Pressure changes and variable olivine extraction can superimpose the major element ratios of liquids from both trends in the erupted liquids. We must consider the complications of 'shaped' partial melting regimes; realities of the phase equilibria such as the greater amount of melt of close to initial composition which will form at higher pressures; polybaric crystallisation in the uppermost mantle and through the magma chamber contents; wall and roof-rock interaction processes; failure of parental magmas to homogenise completely before arrival in the crust; magmatic evolution in a periodically recharged, periodically tapped magma 'chamber' whose solidification products seem to be widely in evidence yet whose physical identification remains elusive; magmatic processes in a crystal mush; and the probable inevitability of recycling of hydrothermally altered roof into even the freshest-looking MORB liquids.

Herzberg, C., and O'Hara, M.J., 1998., *Earth Science Reviews*, **44**, 39-79, (1998).

## MS04 : SUPm27 : F6

## Experimental Determination of Melting Reactions and Liquid Compositions Produced by Small Degree Melting of Depleted Mantle

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The chemistry of Mid-Ocean Ridge Basalts (MORB) is controlled largely by the stoichiometry of the melting reaction of the upper mantle (i.e. the relative proportions of mantle phases which enter the liquid upon partial melting). Estimates of this melting reaction may be derived independently from i) experimental simulation, ii) the variation of mineral proportions in abyssal peridotites. However, for Cpx-poor lherzolites, and harzburgites (<5% clinopyroxene), the melting reactions inferred using these two methods are very different, although it should be noted that

few experimental data exist for such compositions. We have therefore undertaken an experimental study of the partial melting of depleted mantle compositions at melt fractions less than 10%.

A new experimental protocol was developed for this study, presented in detail by Laporte et al. (this volume). First of all, orthopyroxene, clinopyroxene and spinel were extracted from harzburgites (opx Mg# 0.905 ; spinel Cr# 0.25) from the MARK area on the Mid-Atlantic Ridge. These minerals were mixed with olivine (Fo91) in the proportions 76.4 wt% olivine, 18.2 wt% Opx, 3.5 wt% Cpx and 1.9 wt% Sp. Experiments were performed in a piston cylinder apparatus in the pressure range 0.6 to 1.5 GPa.

An excellent approach to textural equilibrium was achieved. A pool of glass not affected by quench crystallization was present in each experiment (Laporte et al., this volume), and measured by electron microprobe. All liquids are basaltic in composition (49-49.5 wt% SiO<sub>2</sub>) even at melt fractions estimated to be as low as 2%. Sandwich experiments are planned to confirm that the analysed glasses really do represent liquids in equilibrium with a harzburgite residue.

Mass balance calculations have small residuals and were used to calculate the stoichiometry of the melting reaction. At 1 GPa where we have the most data, the stoichiometry of the melting reaction is found to be approximately: 0.6 Opx + 0.6 Cpx + 0.2 Sp = 0.4 Ol + 1 Liq. These melting coefficients are similar to experimental values reported in the literature for more fertile compositions at the same pressure. Therefore, the discrepancy between experimental simulations and studies of abyssal peridotites cannot be explained simply by differences in fertility. Pressure may play a much more important role and we are currently determining the melting reaction at 0.6 GPa.

## MS04 : SUPm28 : F6

## Vesiculation and Vesicle Loss in Normal MORB: Pressure Influence on He, Ne, Ar Elemental Fractionation

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The degassing mechanism at ridges remains somewhat obscure because we still have poor understanding of the behavior of some key trace elements, in particular the rare gases. Although elemental ratios like <sup>4</sup>He/<sup>40</sup>Ar are known to be commonly fractionated (from 1.5 to more than 100), no model has ever been shown to fit both rare gas concentrations and elemental ratios.

Vesiculation is expected to produce two phases, a rare gas depleted melt with highly fractionated abundance ratios, and a gas phase, in the form of vesicles, having most of the rare gas inventory and abundance ratios close to those in the melt before vesiculation. If vesicles are lost after vesiculation, one expects binary mixing systematics to occur for total gas data (i.e. melt + vesicles), for example a negative correlation between He concentration and the He/Ar ratio, because concentration must act as a proxy for vesicle abundance. Such systematics have never been found.

We show that using Ar or Ne instead of He, the expected binary mixing curves are present, with the smaller the Ar concentration the most elevated the He/Ar or He/Ne ratio. This means that He is not a good proxy for vesicle abundance, certainly because its solubility in melt is too high, so that a substantial fraction of it remains in the melt.

We use the classical vesicle-melt budget together with Henry's law to describe vesiculation as a function of vesicularity. We then simply describe vesicle loss using a mixing equation between depleted melt and vesicles. This model fits the data when vesicularities are set between 5 and 20% and vesicle loss is higher than 90%. This is perfectly consistent with current observations of MORB vesicularities and with the idea that most MORB are highly degassed lavas.

However, the model only works if the solubility ratios S<sub>He</sub>/S<sub>Ar</sub> and S<sub>He</sub>/S<sub>Ne</sub> are higher by a factor of 4-10 than predicted based on laboratory measurements. We propose that this is a pressure effect, since laboratory measurements of rare gas solubilities have been performed at 1 atm. This is consistent with estimates of CO<sub>2</sub> vesicles growth rate, which show that large, millimeter-sized vesicles must have nucleated at depth in the mantle. The dependency of rare gas solubility on total

pressure is not well known. From the work of Carroll and Stolper (1993), who give relationships between rare gas solubility, size distribution of host voids and ionic porosity, and that of Chamorro-Pérez et al. (1998), who model the effect of pressure on the size distribution of voids, we estimate that vesiculation starts at a few tens of km depth in the mantle. This is reasonable compared to melting depth estimates.

Carroll M & Stolper EM, *Geochim. Cosmochim. Acta*, **57**, 5039-5051, (1993).

Chamorro-Pérez E, Gillet P, Jambon A, Badro J & McMillan P, *Nature*, **393**, 352-355, (1998).

## MS04 : SUPm29 : F6

## The Two-Stage Melting Hypothesis for the Relationship between the OIB and MORB Sources also Provides a Nice Resolution to the 'He-Paradox' (+Ne +Ar)

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Absolute abundances of helium in MORB glasses are systematically higher than in OIB glasses, which apparently contradicts what would be expected if OIBs come from the melting of a source which has less-degassed and more 'primitive' rare-gas components. This so-called 'helium paradox' (Anderson, 1998) has been confirmed by recent compilations (Matsuda and Marty, 1995; Honda and Patterson, 1999; Ozima and Igarashi, 2000). There is systematic elemental fractionation of He from Ne and Ar, with anomalously high He/Ne and He/Ar ratios in MORB and back-arc-basin basalts, and complementary, anomalously low He/Ne and He/Ar ratios in OIB samples.

We previously presented a hypothesis for the complementary nature of the OIB and MORB sources (Phipps Morgan and Morgan, 1999). In this scenario, the OIB source is a finely layered plum-pudding mixture of recycled basalts, sediments and surviving 'primitive' mantle, all embedded within a matrix of variously depleted restite residues to previous OIB and MORB melt extraction. Highly-depleted residues to previous MORB melt-extraction form a large refractory fraction of the mantle (>50%) that can only melt if it rises to relatively shallow depths beneath a ridge. Characteristic isotopic Hotspot Array Tubes (HARTs) for each hotspot (Hart et al., 1992) will be produced if the fractions and mean ages of the different mantle plum components vary slightly between the source-regions of each plume (Phipps Morgan, 1999), each HART reflecting progressive amounts of melt-extraction from its characteristic upwelling plume material. The MORB-source is simply the end-residues to the hotspot melting process - the leftovers to ~3% OIB melt-extraction from the upwelling plumes that feed the asthenosphere.

This world-view offers a simple solution to the "He-paradox" if we allow He to diffuse between the different mantle components. At mantle temperatures, He will diffuse ~1 km in ~1 Ga (Trull and Kurz, 1993), while most other elements (e.g. Nd) may diffuse less than a cm within this time. Thus, if mantle plum components are distributed as the cm-dm-thick pyroxenite layers found in orogenic lherzolites, significant <sup>4</sup>He will be able to diffuse ~1 km from its U+Th-rich plum source into adjacent depleted restites, while radiogenic Ne and Ar will diffuse much more slowly into adjacent components. During OIB melting, only the most fertile plums and most 'primitive' lherzolites melt, contributing their noble gases to OIB-melts. Relatively large amounts of He can thus 'hide' from OIB-melting within refractory non-melting restites, to be tapped by the subsequent stage of MORB melting. We present numerical examples that illustrate the feasibility of this effect. Furthermore, if correct, this analysis suggests that the 'most-primitive' surviving mantle must be distributed in >500 m-size regions, so that its low <sup>4</sup>He/<sup>3</sup>He material would not completely equilibrate with surrounding plume and restite material.

Anderson, D. L., *Proc. Nat. Acad. Sci.*, **95**, 4822-4827, (1998). Matsuda, J. & Marty, B., *Geophys. Res. Lett.*, **22**, 1937-1940, (1995).

Honda, M & Patterson, D, *Geochim. Cosmo. Acta*, **63**, 2863-2874, (1999).

Ozima, M & Igarashi, G, *EPSL*, **176**, 219-232, (2000).

Phipps Morgan, J & Morgan, WJ, *EPSL*, **170**, 215-239, (1999).

Trull, TW & Kurz, MD, *Geochim. Cosmo. Acta*, **57**, 1313-1324, (1993).

**MS04 : SUPm30 : F6**  
**Nb, Zr and Y Systematics in the Kerguelen Large Igneous Province and Indian MORB**

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Nb, Zr and Y systematics have been important in evaluating source heterogeneity and mixing processes for Iceland plume-related volcanism. In this study, we present a compilation of geochemistry from Indian MORB and OIB, with particular attention focused on incompatible elements such as Nb, Zr and Y. The concentrations of these elements and their ratios allow us to characterize the sources, the extents of partial melting, and the effects of fractionation involved during the genesis of the Kerguelen Large Igneous Province (LIP) basalts, including the Ninetyeast Ridge, the Broken Ridge, the Kerguelen Plateau, and the Kerguelen Archipelago.

Compared to the rest of the Indian Ocean basalts, Indian MORB have distinctly lower Zr/Y (2.4-3.5) and Nb/Y (0.03-0.17), which reflects their depleted mantle source. In a log Nb/Y vs. log Zr/Y plot, Kerguelen plume-related basalts show a linear trend that results from the different behavior of Zr and Nb during mantle melting. This trend is located along the lower boundary of the Iceland plume-related basalt field. Some of the Indian ridge basalts that have interacted with a hotspot (e.g. Saint Paul on the Southeast Indian Ridge, and Bouvet on the Southwest Indian Ridge) share compositional characteristics of Kerguelen-related basalts. Basalts from the Kerguelen LIP that are contaminated by a continental component deviate from the melting trend and have a distinctly lower slope. In Nb vs. Zr concentration diagrams, the Kerguelen LIP basalts define three distinct trends with decreasing slopes that correspond to decreasing ages (115-40 Ma, 30-25 Ma, and 25-22 Ma). The trends reflect different parental magma compositions (tholeiitic to alkaline), and variable amount of mixing between depleted mantle and the enriched Kerguelen Plume, as supported by Sr-Nd-Pb-Hf isotopic systematics. In addition, depending on the main fractionating phases, the Zr intercept is either zero for the Kerguelen Plateau, the Ninetyeast Ridge and the Oligocene basalts from the Kerguelen Archipelago (olivine + plagioclase) or positive for the lower Miocene basalts from the Kerguelen Archipelago (clinopyroxene) as Zr is more compatible than Nb in clinopyroxene. Finally, Nb, Zr, and Y systematics indicate that from the Cretaceous to the Oligocene, the degree of partial melting of the source to the Kerguelen-related basalts decreases, which correlates with decreasing magma production rates for the construction of the Kerguelen LIP.

**MS04 : SUPm33 : F6**  
**Hf Isotope Evidence for Garnet Depletion in the Source of some Barberton Komatiites: Real or Artifact?**

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We report new Lu-Hf isotope data for komatiites from the 3.45 Ga old Barberton Greenstone Belt in South Africa. All analyzed samples come from a single komatiite flow (Carl's Flow) in the Schapenburg Greenstone Remnant. Compared with Barberton komatiites analyzed previously by Blichert-Toft and Arndt (1999), the new samples show a much larger variation in Hf isotope compositions and Lu/Hf ratios. Their <sup>176</sup>Lu/<sup>177</sup>Hf ratios are all higher, ranging from 0.0393 to 0.0516, and their <sup>176</sup>Hf/<sup>177</sup>Hf ratios significantly more radiogenic, ranging from 0.283135 to 0.283966.  $\epsilon_{\text{Hf}}$  values at the emplacement age (3.45 Ga) range from -1.7 to -3.0. The samples define a statistically significant isochron (MSWD = 0.14) with an age of 3.4 ± 0.1 Ga and an initial <sup>176</sup>Hf/<sup>177</sup>Hf composition of 0.280479 ± 0.000083 corresponding to  $\epsilon_{\text{Hf}}(T) = -1.8$ . The observed variation in Lu/Hf ratios and the negative initial  $\epsilon_{\text{Hf}}$  contrast with the remarkably homogeneous Sm/Nd ratios of these samples (Lecuyer et al., 1994), which do not define a Sm-Nd isochron, and the positive  $\epsilon_{\text{Nd}}(T)$  of about +2.2.

Because only olivine is on the liquidus of komatiites, the large Lu/Hf fractionation of Carl's Flow samples cannot be magmatic in origin. Diagrams of MgO versus major and trace elements demonstrate that the more MgO-rich olivine cumulates have unusually low Hf as well as low Ti and light REE contents compared with spinifex samples, but normal Lu contents. These features could reflect alteration or contamination. The fact that the isochron age is within error of the accepted emplacement age indicates that the process that changed the Lu/Hf ratios must have occurred at the time of emplacement. If the range of Lu/Hf ratios resulted from contamination, the contaminant must have had the same Hf isotopic composition as the komatiite magma because variable degrees of contamination by low-<sup>176</sup>Hf/<sup>177</sup>Hf material would have resulted in a too-old isochron age. In this case the initial isotopic composition represents that of the magma. Alternatively, if a two-stage process was involved such that the change in Lu/Hf ratios followed, and was unrelated to the contamination, then the isochron age could still be correct but the initial ratio could be wrong. However, in such a case, a negative  $\epsilon_{\text{Nd}}$  should accompany the negative  $\epsilon_{\text{Hf}}$ .

If the negative initial  $\epsilon_{\text{Hf}}$  of the Carl's Flow samples does indeed reflect that of the komatiite source, melting of material with long-term low Lu/Hf is required. This may be explained by garnet depletion, an interpretation opposite to that reached by Blichert-Toft and Arndt (1999) for other Barberton komatiites. Such an interpretation is inconsistent, however, with the positive initial  $\epsilon_{\text{Nd}}$ . A possible alternative explanation is addition or subtraction of perovskite, which fractionates Lu/Hf without significantly changing Sm/Nd.

Blichert-Toft J & Arndt NT, *Earth Planet. Sci. Lett.*, **171**, 439-451, (1999).

Lecuyer C, Gruau G, Anhaeusser CR & Fourcade S, *Geochim. Cosmochim. Acta*, **58**, 969-984, (1994).

**MS04 : SUPm34 : F6**  
**Plume-Ridge Interaction Inferred by Osmium Isotopes in MORB from the Southern Mid-Atlantic Ridge**

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This study focuses on Re-Os systematics for MORB glasses from the Mid-Atlantic ridge (45°-50°S). Previous studies by J-G. Schilling and others (Douglass et al, 1999; Moreira et al, 1995) have shown Sr-Nd-Pb-He isotopic signatures which are distinct from the asthenosphere signature.

Glass samples have been analysed with the N-TIMS technique developed by Birck et al (1997). Blanks were 0.06 pg/g and 1-15 pg/g for Os and Re respectively. Os concentrations range from low values (less than 1 ppt) to 6.5 ppt; Re concentrations are between 364 and 1450 ppt. These concentrations are in the same range as MORB values. By contrast, <sup>187</sup>Os/<sup>188</sup>Os ratios for our samples are more radiogenic than typical MORB, ranging from 0.131 to 0.230.

Five ridge segments can be distinguished based on He-Pb-Sr-Os systematic and interpreted as reflecting different contributions: one represents the Shona plume with low <sup>4</sup>He/<sup>3</sup>He, low <sup>187</sup>Os/<sup>188</sup>Os, intermediate Pb and Sr; one represents the segment between the two plumes with MORB like He, Os and Sr isotope ratios but higher <sup>206</sup>Pb/<sup>204</sup>Pb; one represents a segment with a Dupal signature; one represents the Discovery plume with low <sup>4</sup>He/<sup>3</sup>He, high <sup>187</sup>Os/<sup>188</sup>Os, low <sup>206</sup>Pb/<sup>204</sup>Pb but higher <sup>87</sup>Sr/<sup>86</sup>Sr compared with Shona; one is characterised by MORB like He,Os,Pb ratios but variable <sup>87</sup>Sr/<sup>86</sup>Sr (0.703-0.706).

In <sup>187</sup>Os/<sup>188</sup>Os vs 1/Os diagram, our samples define a positive linear correlation interpreted as a binary-mixing trend between an unradiogenic peridotitic upper mantle and a radiogenic end-member. Regardless of their Pb-Sr-Nd-He signature, all the samples plot on the trend. This effect can be explained by the superposition in this diagram of mixing trends between mantle and recycled oceanic crust and sediment recycled components.

In order to further constrain these different signatures, the isotopic data are used with a multispace approach. The nature of the various geochemical end-members present in this ridge segment will be discussed at the meeting.

Birck J-L, Roy Barman M & Capmas F, *Geostand Newslett.*, **20**, 19-27, (1997).

Douglass J, Schilling J-G & Fontignie D, *JGR*, **104**, 2941-2962, (1999).

Moreira M, Staudacher T, Sarda P, Schilling J-G & Allègre CJ, *Earth Planet Sci Lett.*, **133**, 367-377, (1995).

**MS04 : SUPm35 : F6**  
**Extreme Os Isotopic Heterogeneity in Magmatic Sulfides of Oceanic Peridotites**

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Abyssal peridotites represent our most direct sampling of the convective mantle (MORB source). Therefore, the geochemical fingerprint of this reservoir is of special significance in geochemistry and has been intensively investigated mainly for the abundances and isotopic composition of lithophile elements. Because of their highly siderophile properties, platinum group elements (Au<sup>+</sup>Re<sup>+</sup>) offer a different perspective on mantle processes. Recent investigations of PGEs in abyssal peridotites from various locations revealed supra-chondritic Pd/Ir ascribed to sulfide precipitation during adiabatic partial melting (Rehkämper et al., 1999). Laser ablation ICP-MS analyses of sulfides (Kane Fracture Zone: Mid-Atlantic Ridge; South-West-Indian Ridge) confirm this interpretation, while showing large variations in Pd/Ir, from supra-chondritic in precipitated sulfides to lower than chondritic in residual sulfides (Luguet et al., 2000). Using a similar LAM system but coupled to a Nu-Plasma Multicollector-ICP-MS (Pearson et al., 2000) we have determined *in-situ* Os isotopic compositions of those sulfide grains. This study was also extended to the Bracco ophiolite (Internal Ligurides Italy), considered to represent an obducted oceanic mantle segment. In abyssal peridotites and Bracco ophiolitic peridotites, the <sup>187</sup>Os/<sup>188</sup>Os ratio for all sulfides ranges from 0.1113±0.0008 up to 0.1382±0.0014. These Os compositions are significantly less radiogenic and more radiogenic, respectively, than estimated for the Primitive Upper Mantle (?0.129). Sulfides with supra-chondritic Pd/Ir may show either unradiogenic or radiogenic Os composition, while sulfides with infra-chondritic Pd/Ir show Os compositions less radiogenic than the Primitive Mantle estimate. Therefore, care must be exercised in interpreting whole-rock Os analyses of oceanic peridotites, especially for interpretation of Re-Os ages. The unradiogenic sulfides yield Re-depletion ages (minimum ages) as old as 2.4 Ga. Ages older than 1.2 Ga are obtained for all localities. These old ages are in line with recent whole-rock Os-isotope analyses of abyssal peridotites (Brandon et al., 2000), and with Pb-isotope studies of MORBs from the East Pacific Rise (Galer et al., 2000), and suggest that the MORB source mantle comprises domains depleted at least 1 Ga ago. The fact that the precipitated sulfides show both unradiogenic and radiogenic Os compositions suggests that their melt source region was characterized by extreme heterogeneity, including material with both low Re/Os or high Re/Os. Given the extremely long half-life of <sup>187</sup>Re, these small-scale heterogeneities must have been preserved for a relatively long period of time. These results indicate that some portions of the MORB source mantle are protected for long periods of time against re-homogenisation by convection.

Brandon AD, Snow JE, Walker RJ, Morgan JW & Mock TD, *Earth Planet. Sci. Lett.*, **177**, 319-335, (2000).

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Luguet A, Alard O, Lorand JP, Pearson NJ, Ryan C & O'Reilly SY, *Science*, submitted, (2000).

Pearson NJ, Alard O, Griffin WL & Jackson SE, *J. Conf Abs (Goldschmidt Conf.)*, **5**, (2000).

Rehkämper M, Halliday AN, Alt J, Fitton JG, Zipfel J & Takazawa E, *Earth Planet. Sci. Lett.*, **172**, (1999).

## MS04 : SUPm36 : F6

**Os-Isotopic Composition of Basalts and Picrites from the Galapagos Hotspot**

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We have measured the Os-isotopic composition of high-MgO lavas from 7 Galapagos Islands which cover the observed range of Sr, Nd, and Pb isotope compositions. These isotope variations suggest that the upper depleted mantle is a principal component of the magma sources which became entrained in a heterogeneous plume material (White et al., 1993).

The analyzed tholeiitic to alkaline basalts and picrites have MgO contents ranging from 7.2 to 14.3 wt.%. The Os concentrations decrease with MgO from 0.227 to 0.021 ng/g and all samples have radiogenic Os isotopic compositions as the <sup>187</sup>Os/<sup>188</sup>Os ranges from 0.138 to 0.184. Overall the Os isotopic ratios correlate positively with Nd, but negatively with Sr and Pb isotope ratios. The best correlation is observed for the Os-Pb pair which defines a linear trend with a high correlation factor ( $R^2 = 0.9408$ ) indicating a 2 component mixing relationship between the different volcanic rocks. One endmember of the mixing trend comprises the samples from Floreana. They likely represent one plume component characterized by the most radiogenic Pb and Sr and unradiogenic Nd isotopic compositions. They have the lowest <sup>187</sup>Os/<sup>188</sup>Os ratios of 0.134 to 0.138 among the samples studied here. These isotopic fingerprints are consistent with the idea that the plume material contains old subducted oceanic crust. Volcanic rocks from Santiago and V. Ecuador have intermediate Sr, Nd, Pb, and Os isotopic compositions. These samples appear to be contaminated with the second endmember component, represented by basalts from Genovesa and Santa Cruz. In terms of their Sr-, Nd- and Pb isotopic signatures they represent the depleted mantle component. But these samples have the most radiogenic Os isotopic compositions (<sup>187</sup>Os/<sup>188</sup>Os: 0.180-0.184). Assimilation of gabbro from the lower oceanic crust can explain the isotopic fingerprint of this endmember. Such gabbros should have Pb, Nd and Sr isotope compositions typical for the depleted mantle. They also have high Re/Os ratios which generate a radiogenic Os signature with time. Hofmann (in prep.) noted that the MgO-rich lavas from the Galapagos Islands have marked positive Sr anomalies, and he suggested that plagioclase-rich material, such as gabbros, is assimilated by the parental magmas.

An open question is whether the gabbroic component is an intrinsic feature of the plume material or has been picked up during the rise of the parental magma through the lithosphere. This can be tested by studying gabbro xenoliths brought to the surface by Galapagos melts and by determining the oxygen isotope composition of the lavas and gabbros.

## MS04 : SUPm37 : F6

**Plume Sources and Processes:****A Combined Os, U-series, Sr, Nd and Pb Isotopic Study of the Azores**Bruce Schaefer (b.f.schaefer@open.ac.uk)<sup>1</sup>,Simon Turner (simon.turner@bristol.ac.uk)<sup>2</sup>,Ian Parkinson (i.j.parkinson@open.ac.uk)<sup>1</sup> &Nick Rogers (n.w.rogers@open.ac.uk)<sup>1</sup><sup>1</sup> Dept of Earth Sciences, The Open University, Walton  
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Increasingly sophisticated isotopic and geochemical techniques are being applied to deciphering mantle plume derived basaltic magmatism. This study presents for the first time an integrated isotopic study encompassing short lived decay schemes (U-series; specifically U, Th and Ra) and compatible (Re-Os) and incompatible element (Sr, Nd, Pb) for a suite of 16 alkalic lavas from the Azores, and is coupled with existing datasets [1,2,3].

The data show two distinct components within the Azores plume, one dominant on Sao Miguel at the periphery of the active plume, and that present in Pico and other islands closer to the plume axis. The "Sao Miguel" component has

a narrow range of <sup>187</sup>Os/<sup>188</sup>Os, (~0.130 - 0.138) and accompanying low Nd and high Sr isotope signatures, with smaller degrees of Th and Ra excess. They also preserve the greatest degree of LREE enrichment and have lower Mg number. By contrast, the "Pico" component contains consistently low Os isotope signatures (~0.120 - 0.128) with high Nd and low Sr isotopes, and the greatest degree of Th and Ra disequilibria. The higher (<sup>230</sup>Th/<sup>238</sup>U) ratios in the Pico endmember may therefore reflect the presence of garnet eclogite in the source rather than lower melting rates compared to Sao Miguel. Os and Pb isotopes in both groups are positively correlated.

The unradiogenic Os signature in the Pico component is unlikely to reflect contamination by modern oceanic lithosphere since a) some samples are less radiogenic than the most depleted abyssal peridotites reported to date, and b) the oceanic crust in the Azores is young, implying oceanic lithospheric mantle has had insufficient time for evolution to strongly subchondritic values. Coupling with radiogenic Nd and unradiogenic Sr isotopes argues against a strongly metasomatised subcontinental lithospheric mantle origin and is more likely to reflect a source which has a protracted depletion history, such as recycled ancient oceanic lithosphere. This would suggest that low buoyancy flux plumes are able to sample ancient oceanic lithosphere which has foundered within the upper mantle. By contrast, Os isotopes in the "Sao Miguel" component are consistent with a small contribution from a time integrated radiogenic component, possibly derived from recycling of material which has experienced a crustal prehistory and returned to the upper mantle by subduction. Subducted sediment would be a likely candidate.

Although decoupling of Os and lithophile isotope systems is possible, the range and systematic variation between these schemes suggests they are preserving source features. One possible interpretation is that the Azores mantle plume directly samples highly depleted, ancient oceanic lithosphere, and the corresponding sedimentary package associated with its subduction.

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## MS04 : SUPm38 : F6

**Os Isotope and Source Characteristics of the Iceland Plume**Yvonne Smit (y.smit@open.ac.uk)<sup>1</sup>,Ian J. Parkinson (i.j.parkinson@open.ac.uk)<sup>1</sup>,David W. Peate (dwp@dlc.ku.dk)<sup>2</sup>,A. S. Cohen (a.s.cohen@open.ac.uk)<sup>1</sup> &

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In order to assess the possible interaction of the MORB source with the Iceland Plume, a series of lavas was collected along a transect that represents a radial cross section of the plume. This section runs west to east from the Snæfellsnes off-axis zone to the Western Rift zone. To complete the sample set, a selection of basalts from two other Neovolcanic zones, Theistareykir (northern axial zone) and Vestmannaeyjar (southern off-axis zone), were included. As all these samples are Post-glacial (<10 ka) they provide a snapshot of the current plume composition.

A comprehensive set of Osmium, Neodymium and Strontium isotope data has been obtained for these lavas as well as major and trace elements in order to determine their source characteristics and evolution. Neodymium and Osmium isotopic data indicate that most volcanics are derived from one of two sources. However, there are some magmas that are formed by mixing of melts from these two sources. The source nearer to the centre of the plume (sampled by the main rift zone) generates tholeiitic basalts and has a radiogenic Os isotope signature with <sup>187</sup>Os/<sup>188</sup>Os ranging from 0.132-0.136, relatively high eNd (8-9.5) and low <sup>87</sup>Sr/<sup>86</sup>Sr. The source for most off-axis volcanics generates alkali-basalts and has near chondritic <sup>187</sup>Os/<sup>188</sup>Os ratios ranging from 0.127 to 0.131, lower eNd (5.5-6.5) and relatively more radiogenic <sup>87</sup>Sr/<sup>86</sup>Sr. Tholeiites from

Theistareykir plot in a similar field as the samples from the Western Riftzone in a <sup>γ</sup>Os<sub>i</sub>-eNd<sub>i</sub> diagram and the more alkalic basalts from Vestmannaeyjar plot in the same field as the mixed magmas. These data suggest that a MORB source has not been involved in the generation of any of the Icelandic lavas analysed in this study which is consistent with extensive trace element modelling. Moreover, 63 Ma West-Greenland picrites generated by the Iceland plume have both of the two identified plume components in <sup>γ</sup>Os<sub>i</sub>-eNd<sub>i</sub> space, clearly indicating that these two components have been present in the Iceland plume source since its inception.

## Sunday PO Session

## MS04 : SUpo01 : PO

**Characterization of Primary Mantle Melts Preserved as Inclusions in Peridotite and Pyroxenite Minerals, Beni Bousera, Morocco**

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Orogenic ultramafic massifs are segments of the mantle emplaced in the continental crust by tectonic uplift. As their primary features are fairly well preserved, they can be used to study directly mantle structure and petrology.

The aim of this study was to identify and characterize primary mantle melts preserved as inclusions in peridotite and pyroxenite minerals from the ultramafic massif from Beni Bousera, Morocco. These rocks contain three types of inclusions hosted by olivine and pyroxene. These are silicate melt inclusions (composed of daughter minerals and quenched glass), dense (vapour and/or liquid) CO<sub>2</sub>-fluid inclusion and multiple inclusion consisting of both CO<sub>2</sub>-rich fluid and silicate melt.

Petrological observations suggest a cogenetic relationship between fluid and melt inclusions. Inclusions are always outlined in secondary fractures planes, formed during periods of shearing. Distribution (and perhaps formation) of these secondary inclusions is accompanied by several phases of shearing motion, while signs of compressional strain are rare or absent.

Electron microprobe analysis of residual glasses and daughter minerals in inclusions trapped in pyroxenite indicates that trapped melts are characterized by silica-undersaturated and CaO-rich compositions. This is consistent with the hypothesis that melt inclusions represent intermediate (10-20%) partial melts of the host pyroxenites generated at moderate pressures (<30 kbars). Such a hypothesis is supported by comparison between the composition of model melts produced by a pyroxenite calculated using the MELTS algorithm and melt inclusions compositions measured in this study.

Compositional differences between silicic melts trapped as inclusions in ultramafic xenoliths from oceanic and continental regions (Schiano and Clocchiatti, 1994) and the silica-undersaturated melt inclusions in pyroxenites from Beni Bousera suggest that limited exchange occurs between the two types of melts.

Key words: orogenic massif, inclusion, pyroxenite, melting, primary melts.

Schiano P & Clocchiatti R, *Nature*, **368**, 621-624, (1994).

## MS04 : SUpo02 : PO

**Enriched Tholeiites Formation in the Region of The Bouvet Triple Junction**

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The region of the Bouvet Triple Junction (BTJ) is situated in Southern Atlantic and is associated with the evolution of three spreading zones: Mid-Atlantic Ridge, American Antarctic Ridge and Southwest Indian Ridge (SWIR). In this region there is an active "hotspot" (island Bouvet). The Spiess Ridge is the western end of the SWIR and it is a large volcanic rise obliged to the Mid-Atlantic Ridge. The basalts and glasses were studied from the segments of SWIR near the island Bouvet and Spiess Ridge.

The variations of major elements in glasses sampled from the Spiess Ridge are almost similar to those in glasses sampled from the Bouvet segment. The glass composition for both regions is strongly dependent on the changes in melt during fractional crystallization of the main mineral phases: olivine, plagioclase, clinopyroxene. The erupted magmas in the Bouvet segment are always more differentiated than those from the Spiess Ridge.

We have determined that parental tholeiitic melts for both regions were analogous to the liquids received in the experiments for partial melting of mantle peridotite (MPY) under the pressures about 15 kbar, 1348°C and the degree of melting 15-20% (1). On the other side these melts received from the MPY have the similar composition to the primary liquid TOR-1 (Tholeiites of Ocean Ridge) which was earlier suggested as parental for this region. The computer simulation for processes of fractional crystallization (COMAGMAT (2)) and using the several methods by Nimis (3), and by Yang (4) has showed that there might have taken place the processes of crystallization in the magma chamber in the depth about 12 km under the temperature 1100-1300°C.

The melts from both regions were forming from enriched with trace elements sources, but the primary melts from the Spiess Ridge were produced from the more enriched mantle. The melts from the Spiess Ridge and Bouvet segment have their own specificities (little minimum on U, Th, Sr and maximum on Zr, Hf compared to primitive mantle).

Isotopic analysis of the glasses from Bouvet segment and Spiess Ridge are analogous. Melts of these regions perhaps are connected with the enriched mantle source which is probably relative to the composition of the parental source of recent eruptions in the Antarctica Peninsula. The ratio <sup>208</sup>Pb/<sup>204</sup>Pb in glasses from Bouvet segment range from 18.4 to 19.0. The same ratio in glasses from Spiess Ridge is from 18.7 to 19.2. The variations of ratios <sup>207</sup>Pb/<sup>204</sup>Pb and <sup>206</sup>Pb/<sup>204</sup>Pb are characterized by these values: 15.55-15.65 and 38.32-39.01. The analogous ratios for the Spiess Ridge are: <sup>207</sup>Pb/<sup>204</sup>Pb = 15.61-15.67, <sup>206</sup>Pb/<sup>204</sup>Pb = 38.76-39.23. This work has been supported by the grant RFFI 00-05-64465.

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## MS04 : SUpo03 : PO

**Remnants of Gondwana Continental Lithosphere in Oceanic Upper Mantle: Evidence from the South Atlantic Ridge**

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The occurrence of MORB with unusually low <sup>206</sup>Pb/<sup>204</sup>Pb (<17.5) has been reported from several localities in the Indian Ocean and in the South Atlantic. Apart from low <sup>206</sup>Pb/<sup>204</sup>Pb, they also have low <sup>143</sup>Nd/<sup>144</sup>Nd, high <sup>87</sup>Sr/<sup>86</sup>Sr and variable <sup>207</sup>Pb/<sup>204</sup>Pb. In an attempt to explain such compositions, Douglass et al. (1996) proposed a new mantle component, LOMU, assumed to have 204/206/207/208=1/16.5/15.70/38.75, <sup>87</sup>Sr/<sup>86</sup>Sr = 0.7100 and <sup>143</sup>Nd/<sup>144</sup>Nd = 0.51100. Because of its isotopic similarity with lamproites and kimberlites, LOMU was considered to represent passive mantle heterogeneities eroded from the continental lithosphere.

A suite of fresh MOR basaltic glasses dredged from the southern Atlantic Ridge (within 400 km of the LOMU type locality, the Discovery Ridge Anomaly at 50°S) contains a glass with unique major and trace element concentrations and an almost pure LOMU-type Sr-Nd-Pb isotopic composition (17.19, 15.70, 38.77, 0.71209, 0.51166). It is a high-Mg (Mg# 67.8), high-Ni (230 ppm) andesite which is depleted in highly incompatible and heavy REE. The glass also has elevated δ<sup>18</sup>O (6.8 permil). Because of its fresh glassy nature, chemical and isotopic composition and geological context, we consider the glass to be derived from LOMU-type mantle; other possible sources (glacial erratics,

late-stage assimilation of sediment, alteration) can be ruled out. Furthermore, the apparent purity of this LOMU derivative allows us to go beyond hypotheses previously proposed to explain the nature and origin of LOMU. Based on the compositions of the glass and associated microphenocrysts of olivine, orthopyroxene and spinel, we propose an origin from melting of a Precambrian garnet-bearing, mafic lithology, possibly related to lower crustal blocks stranded in the upper mantle during opening of the Atlantic. Our discovery is a striking confirmation of the existence of LOMU-type heterogeneities in the shallow mantle and an excellent example of crustal recycling into the mantle. Mixing of LOMU-type mantle with other types of mantle material (e.g. Douglass et al., 1999) can explain anomalous geochemical features of oceanic rocks in the southern hemisphere.

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## MS04 : SUpo04 : PO

**Constraints on the Geochemical Identity and Evolution of an Enriched Mantle Signature: Precise Pb Isotope Analyses from the Pitcairn Hotspot**Jürgen Eisele (eisele@mpch-mainz.mpg.de)<sup>1</sup>,

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We report precise Pb isotope analyses to constrain the geochemical identity, age and time of mixing of an enriched end member composition present in the mantle (EM1 of Zindler and Hart, 1986), of which the Pitcairn hotspot represents the most extreme example.

Pb isotopes were analysed using a triple spike for correction of mass fractionation (Galer, 1999). The isotope ratios range from <sup>206</sup>Pb/<sup>204</sup>Pb=17.4665 to 17.9612, <sup>207</sup>Pb/<sup>204</sup>Pb=15.4728 to 15.5134 and <sup>208</sup>Pb/<sup>204</sup>Pb=38.7904 to 39.0328 in lavas from Pitcairn Island and seamounts. They show a tight linear data array in <sup>207</sup>Pb/<sup>204</sup>Pb-<sup>206</sup>Pb/<sup>204</sup>Pb and a roughly horizontal array in <sup>208</sup>Pb/<sup>204</sup>Pb-<sup>206</sup>Pb/<sup>204</sup>Pb. The linear data array can be interpreted as a binary mixing line. Radiogenic Os isotopes and a Hf-Nd isotope correlation with a slope shallower than the mantle array indicate a recycled pelagic sediment component in the source (Eisele et al., 2000).

The Pb isotope evolution of the recycled component can be described by a two stage development, in which the first stage is described by the Stacey-Kramers model and the second by an evolution with low μ and high ω (Rehkämper and Hofmann, 1997). The Pb isotope composition of the samples allows for a second stage μ between 2 and 6, and an ω between 33 and 42. The mixing line of the Pitcairn data array in <sup>207</sup>Pb/<sup>204</sup>Pb-<sup>206</sup>Pb/<sup>204</sup>Pb intersects the model curves for ages between 1.5 and 2 Ga, putting limits on the age of the recycled sediment. The model calculations yield second stage κ values between 5.5 and 21, showing that the measured κ up to 14.1 is not unreasonably high.

The Pb-isotope-Th/U systematics of Pitcairn Island lavas allow us to place age constraints on the time of the mantle mixing event. The Th/U ratio correlates with Nd and Sr isotopes, indicating that it was changed during mixing. However, the <sup>208</sup>Pb/<sup>206</sup>Pb ratios are rather uniform given the large range in Th/U from 4.4 to 14.1. This could be explained if the Th/U was changed during mantle mixing and the <sup>208</sup>Pb/<sup>206</sup>Pb was left largely unaffected because of the high Pb content of the recycled sediment. The correlation in <sup>208</sup>Pb/<sup>206</sup>Pb vs. Th/U would then be the result of the mixing event, and the slope would correspond to the maximum age of mixing. The shallow slope shows that this age is ~180 Ma or less, indicating a relatively recent time of mixing.

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**MS04 : SUPO05 : PO**  
**Geochemical Stratigraphy of Basalts from the Hawaii Scientific Drilling Project: Evidence for Fluctuating Magma Production Rates**

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The 3.1 km hole drilled by the Hawaii Scientific Drilling Project provides an unprecedented opportunity to study the magmatic evolution of a Hawaiian volcano as it passes over the Hawaiian hotspot. The drill hole has sampled 246 m. of Mauna Loa lavas, 832 m. of subaerial Mauna Kea lavas and 2032 m. of submarine Mauna Kea pillow lavas and hyaloclastites. The Mauna Loa lavas are chemically distinct from the underlying Mauna Kea lavas. The upper Mauna Kea lavas (246-369 m.) contain two alkali basalt flows (units 42 and 48) inter-layered with transitional tholeiites, indicative of waning magma production rates of the shield-building stage. Below this depth, all the Mauna Kea lavas are tholeiitic. Apart from large fluctuations in MgO content (6-29 percent), the subaerial section of the Mauna Kea lavas are relatively uniform in composition, becoming slightly more tholeiitic with depth. Two distinct inter-layered lava types can be identified in the submarine Mauna Kea section: one is similar to the overlying subaerial lavas, whereas the other is lower in SiO<sub>2</sub> at a given MgO content, with slightly higher alkalis, TiO<sub>2</sub> and Nb contents. These lavas also have distinctly lower Zr/Nb than typical Mauna Kea tholeiites (about 10 versus 12-13). Chemically, they are very similar to Loihi tholeiites. Three possible explanations for these low SiO<sub>2</sub> lavas are: (1) They are late-stage lavas from Kohala volcano; (2) they reflect melting of distinct source components; or, (3) they are a consequence of fluctuating magma production rates from a relatively homogeneous source. The data are most consistent with this third alternative.

**MS04 : SUPO06 : PO**  
**Geochemical Variations in Hawaiian Magmatism since 85 Ma**

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Lavas from the Hawaiian-Emperor Seamount Chain in the northern Pacific Ocean provide an 85 Ma record of the geochemistry of Hawaiian magmatism. We measured major and trace element concentrations, and Sr, Nd and Pb isotope compositions of 50 lavas from 10 different seamounts. The samples include both tholeiitic (shield stage) and alkalic (post-shield and post-erosional) lavas, and range in age from 85 to 27 Ma. We find that there have been systematic temporal changes in both incompatible trace element chemistry and isotope composition of Hawaiian magmatism over this period. Tholeiites from Meiji Seamount (85 Ma) at the northern end of the ESC have depleted trace element and isotope ratios (initial <sup>87</sup>Sr/<sup>86</sup>Sr 0.70292-0.70320), compared to young (<5 Ma) lavas from the Hawaiian Islands. Tholeiitic lavas from Detroit Seamount (81 Ma) are even more depleted (Keller et al., 2000). The concentrations of highly incompatible trace elements such as Th are about 7 times lower in these lavas compared to tholeiites from the Hawaiian Islands. Chondrite-normalised La/Yb (0.76-0.81), and initial <sup>87</sup>Sr/<sup>86</sup>Sr (0.70263-0.70276) are similar to Pacific mid-ocean ridge lavas. However, initial Pb isotope compositions (measured using a triple spike) are more similar to young Hawaiian lavas, than to EPR MORB. Younger lavas (62-27 Ma) have incompatible trace element patterns similar to those of lavas from the Hawaiian Islands, but initial <sup>87</sup>Sr/<sup>86</sup>Sr ratios extend to lower values (0.70324-0.70347). Between 81 and 43 Ma, there was a systematic increase in initial <sup>87</sup>Sr/<sup>86</sup>Sr of the shield lavas, although none of the Emperor samples have the very radiogenic Sr compositions characteristic of Koolau tholeiites. Lavas from Suiko Seamount (62 Ma) have some of the highest <sup>206</sup>Pb/<sup>204</sup>Pb ratios of all Hawaiian-Emperor lavas. Compared to Pacific MORB, the Suiko lavas have lower <sup>207</sup>Pb/<sup>204</sup>Pb for a given <sup>206</sup>Pb/<sup>204</sup>Pb, which indicates that the Kea component is not Pacific oceanic lithosphere (Abouchami et al., 2000). Between 62 and 85 Ma, an additional component with unradiogenic Sr and Pb (but with different Pb isotope systematics from Pacific MORB), contributed to Hawaiian magmatism. The age of the underlying oceanic crust, at the time each seamount was constructed, decreases northwards along the ESC, and the oldest Emperor Seamounts were

formed on relatively young, thin lithosphere close to a spreading center. Lithospheric thickness, which is a function of age, may control the extent of decompression melting of the underlying mantle. Beneath relatively old, thick lithosphere, melting is less extensive, and the compositions of the melts formed are dominated by enriched, easily-melted mantle components. Lavas from seamounts built upon younger, thinner lithosphere are more depleted because they were formed by larger degrees of melting, with a greater contribution from incompatible element-depleted, refractory mantle material (Phipps Morgan, 1999).

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**MS04 : SUPO07 : PO**  
**Comparison of Gaseous Species in Submarine and Subaerial Basalt**

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The fluid content of melts should reflect origin and tectonic regime of melt genesis, however, our access is usually limited to quenched melts, i.e., glasses. The question therefore is to what extent information about the original gas household may be retrieved from basalt glasses. Specifically, one concern in this regard is a possible interaction between the melt and water or air, in submarine and subaerial extrusions, respectively. To address these problems, we compared vitreous rims from pillow basalt from the Mid Ocean Ridge and from the ocean island basalt, Loihi (drill core), Hawaii, with hammer-dipped and air-quenched basalt lava from active Pu'u O'o, Kilauea, Hawaii. We carried out degassing experiments using a special high-vacuum-hot-extraction method DEGAS (Heide et al., 2000) combined with a quadrupole mass spectrometer. Controlled heating from room temperature up to 1500°C leads to degassing of the sample. Gaseous species are analyzed in a multiple ion detection mode by the mass spectrometer. Quantitative determinations are possible based on a correlation with the total pressure change in the sample chamber during the heating process (Heide, 1974; Stelzner et al., 1996).

Degassing profiles of submarine samples, taken between 700 and 1400°C, show the formation of H<sub>2</sub>O, CO<sub>2</sub> and SO<sub>2</sub>. CO<sub>2</sub> escapes in a two step process of diffusion and bubble formation. Looking at CO<sub>2</sub> and H<sub>2</sub>O, a weak correlation is found at best. Helium bubbling is detected in traces. The oxygen partial pressure decreases with heating between 1200 to 1350°C. In contrast, subaerial lava was almost completely degassed at the time of emplacement. Volatiles detected suggest a reduced redox conditions. We find no indication of no He. These results suggest that any chemical interaction between the melt and environmental gases or fluids is insignificant if it occurs at all.

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**MS04 : SUPO08 : PO**  
**Development of a New Melt Extraction Technique to Separate Basalt from Peridotite in Partial Melting Experiments**

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Mid-ocean ridge basalts are produced by polybaric, near-fractional melting of peridotite source rocks. Therefore, it is fundamental to be able to get reliable analyses of experimental liquids resulting from small degree melting of peridotites. We performed a series of partial melting experiments in a piston-cylinder apparatus to characterize the liquid compositions and phase relations of a depleted peridotite ( $P = 1$  GPa,  $T$  in the range 1240-1360°C; Seyler et al., this volume). We succeeded in separating the liquid from the source rock without placing diamond or vitreous carbon in the sample chamber. Our experiments differ from preexisting work by the following respects:

(1) The starting material was a very fine mineral powder made by mixing orthopyroxene, clinopyroxene and spinel from an abyssal peridotite and gem-quality olivine (Fo<sub>91</sub>). To reduce the time scale of chemical equilibrium, the mineral powder was ground to a grain size of 2-4 µm in a micronizing mill. Significant grain growth occurred in all the experiments and resulted in near-equilibrium textures with a grain size of 10-15 µm (for olivine and pyroxenes).

(2) In the experiments run above the solidus temperature, the basaltic liquid was injected into a small number of microdikes that formed in the inner graphite container. The microdikes were up to 20 µm thick and a few hundreds of µm long (but they never reached the outer platinum container). The basaltic liquid in the microdikes was separated from the partially molten peridotite by a layer of quenched clinopyroxene, 20 µm thick.

The two main advantages of our separation technique are that (1) there is no underpressurized porous space present in the sample chamber at the beginning of the experiment; and (2) the volume of segregated liquid is very small (typically 0.01-0.001 mm<sup>3</sup> compared with a peridotite volume of 10 mm<sup>3</sup>) so that the technique can be used at degrees of melting <1%. A drawback of the technique is that the development of fractures in the graphite container and the thickness of the microdikes cannot be controlled by the operator. However, basaltic microdikes sufficiently wide to be analysed with the electron microprobe have been obtained in all the experiments run so far. A series of basalt sandwich experiments will be performed to check that the liquids analysed in the microdikes are in equilibrium with the neighbouring peridotite matrix.

**MS04 : SUPO09 : PO**  
**Sulfur Anomaly in Mid Ocean Ridge Basalts from the Indian Ocean**

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Fresh Mid Ocean Ridge Basaltic glasses from the Pacific (N=51), Atlantic (N=48) and Indian oceans (N=111) have been analyzed for major and trace elements concentration, sulfur and Fe<sup>2+</sup> content. Oxygen and sulfur fugacities have been calculated for the entire data set in order to depict any large scale anomalies for these parameters.

In a FeO vs S diagram samples from the Atlantic and the Pacific oceans define a nice positive trend. In contrast, those from the Indian ocean are scattered and generally shifted toward low S concentration for a given FeO. There is no statistical differences between the Atlantic, Pacific and Indian oceans for Fe<sup>2+</sup>/ΣFe ratios nor with the calculated fO<sub>2</sub> (ΔNNO=-1.37±0.16 ; -1.15±0.12 and -1.26±0.25 respectively). Log(fS<sub>2</sub> range from -0.84±0.15 (Atlantic and Indian) up to -0.55±0.12 (Pacific). In order to quantify the sulfur depletion in the basalts, we have used the Wallace and Carmichael's (1992) formulation. We have shown that more than 75% of the Indian Ocean samples (SWIR, CIR

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and SEIR) are sulfur undersaturated. The absence of magmatic sulfides globules in the analyzed Indian ocean samples confirm the calculation. Considering that the mean depth of eruption is deeper than 1000 meters for all the studied samples any degazing can be rule out. Furthermore, sulfur speciation is not the parameter driving the sulfur depletion in the studied MORB because of the homogenous oxygen fugacity. A sulfur depleted source seems to be the most probable explanation. A two stage melting process allows to explain the sulfur depletion but incompatible elements are not depleted in Indian ocean Basalt. A significant trend between isotopic ratios (Sr, Nd) and S content corrected for fractionation have been evidenced suggesting that S anomaly in the Indian Ocean is an old event.

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### MS04 : SUpo10 : PO Equilibration Conditions of High-Ca Primitive Liquids: An Experimental Approach using Multiple Saturation

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Primitive CaO-rich, Al<sub>2</sub>O<sub>3</sub>-poor melts have been recently documented as whole-rock samples and olivine-hosted glass inclusions in many geodynamic settings including mid-ocean-ridges, back-arc basins, oceanic islands and volcanic arcs (e.g., Kamenetsky et al., 1997, Schiano et al., 2000). They may be either hypersthene-normative or nepheline-normative, depending on their geodynamic setting. The high CaO contents (up to 19 wt%) and CaO/Al<sub>2</sub>O<sub>3</sub> ratios (up to 1.7) of these melts contrast with experimental melts of lherzolite under anhydrous (and also hydrous) conditions, which have less than 13.5 wt% CaO and CaO/Al<sub>2</sub>O<sub>3</sub> ratios around 0.8. In most cases, the high CaO concentrations cannot be explained by simple crystal fractionation, and the hypothesis of clinopyroxene accumulation as proposed for some cpx-phyric, CaO-rich lavas cannot account for the CaO-rich glass inclusions. It has thus been suggested that these ubiquitous CaO-rich melts reflect implication of a non-peridotitic source (i.e. pyroxenites) or the role of a CO<sub>2</sub> rich fluid phase during melting.

Here, we present results of multiple saturation experiments performed on CaO-rich compositions, in order to characterize their equilibrium conditions (i.e.: P, T, Pfluid and liquidus phases chemistry). A model composition corresponding to the most MgO-rich melts (14.5wt% MgO, 14.8wt% CaO, hypersthene-normative) was first used for the experiments. Saturation with a wherlitic assemblage (diopsidic augite with Mg#92 and olivine Fo89) is obtained between 1425 and 1450°C at 1.2 GPa. Orthopyroxene is not a liquidus phase. These results are incompatible with a volatile-free lherzolititic source and, at first sight, suggest that CaO-rich (hypersthene-normative) magmas represent primary melts of wherlites (see also Kogiso and Hirschmann, 2000). Addition of 2.5 wt% H<sub>2</sub>O lowers the liquidus temperature by only 50°C. Thus, liquidus temperatures remain much higher than those typically required for picritic mantle magmas. This temperature discrepancy could be accounted for if either the primary CaO-rich magmas had very high volatile element contents (>> 2.5wt%) or the investigated parental high-Ca compositions do not correspond to true primary melt compositions. On the other hand the temperatures necessary for the generation of high-Ca liquids could suggest that also picrites are generated at higher temperatures than previously thought (Green, 2000).

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