The trace elements compositions for the core of these phenocrysts are Ba 182-229 ppm, Sr 726-920 ppm, and Ba/Sr ratios 0.22 -0.25. The composition of the rim are distinctly different - Ba 36-55 ppm, Sr 943-1057 ppm, and Ba/Sr ratios 0.04-0.05. Sr/Ca ratios for core are higher (Sr/Ca*$10^{-3}$ 12.9-15.0 core) than those of the rim (Sr/Ca*$10^{-3}$ 7.7 to 8.9).

Microphenocrysts in the inclusions typically contain 80-83% An in the center to 55-58% An on the rim. The rim of these phenocrysts is too thin for laser ICP-MS probing, but the cores of these microphenocrysts contain Ba 75-125 ppm, Sr 876-1096 ppm, Ba/Sr ratios 0.07-0.11 and Sr/Ca*$10^{-3}$ ratios and 7.9-10.3 respectively.

Phenocrysts from the dacitic hosts are usually rimmed with plagioclase of higher anorthite content, lower Ba and higher Sr than the cores. Rims have lower Ba/Sr ratios. Microphenocrysts from the basaltic inclusions are rimmed with lower anorthite content. Ba and anorthite content of the cores of these microphenocrysts overlap those of the rims of the host phenocrysts. However, the Ba concentrations of the microphenocrysts are not as low as those in the rims of the phenocrysts from the dacite.

Our interpretation of these data is that sieved and rimmed host phenocrysts reflect a close encounter with basaltic magma during the injection of basaltic magma into a dacitic, crystal-rich crustal reservoir. Ba concentrations and Ba/Sr ratios of the dacitic host magma are higher than those of the mafic inclusions, whereas Sr concentrations of the inclusions are higher than those of the host. The plagioclase rims in the dacitic host plagioclase reflect the composition of the basaltic magma that was injected. The trace-element concentration (Ba) of the cores of microphenocrysts from the basaltic inclusions are somewhat modified, perhaps because it was easier to mix liquid from the dacitic host into the lower viscosity basaltic inclusions.

## V51C-12 1135h

### Integrating isotopic fingerprinting with petrology: how do igneous rocks evolve?

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In the title of his seminal work, N.L. Bowen recognized the fundamental importance of magmatic evolution in producing the spectrum of igneous rocks. Indeed it is difficult to imagine a hot highly reactive fluid passing through c. 100 km of a chemically distinct medium (lithosphere) without evolving through cooling, crystallization and interaction with the wall rocks. The fact that magmas evolve - almost invariably through open system processes - has been largely marginalized in the past 30 years by the desire to use them as probes of mantle source regions. This perspective has been driven principally by advances offered by isotope geochemistry, through which components and sources can be effectively fingerprinted. Two fundamental observations urge caution in ignoring differentiation effects; 1) the scarcity of truly primary magmas according to geochemical criteria (recognized long ago by petrologists), and 2) the common occurrence of petrographic criteria attesting to open system evolution.

Recent advances in multicollector mass spectrometry permit integration of the powerful diagnostic tools of isotope geochemistry with petrographic observations through accurate and precise analysis of small samples. Laser ablation and microdrilling enable sampling within and between mineral phases. The results of our microsampling investigations give widespread support for open system evolution of magmas, and provide insights into the mechanisms and timescales over which this occurs. For example; 1) core-rim decreases in $^{87}Sr/^{86}Sr$ in zoned plagioclase crystals from 1982 lavas of El Chichon volcano, Mexico, argue that the zoning and isotopic changes are in response to magma recharge mixing with an originally contaminated resident magma; 2) Single grain and intra-grain isotopic analyses of mineral phases from Ngauruhoe andesites (New Zealand) are highly variable, arguing that bulk rock data reflect mechanical aggregations of components which have evolved in discrete domains of the magma storage and delivery system; 3) $^{87}Sr/^{86}Sr$ variations within feldspars from a single ignimbrite exceed the entire rhyolite bulk rock range of $^{87}Sr/^{86}Sr$ recorded from the Taupo volcanic zone, New Zealand; arguing that the isotopic heterogeneity encountered during differentiation is greater than that erupted; and 4) Gabbros from the Rum intrusion (NW Scotland) exhibit inter and intra-grain isotopic heterogeneity arguing that accumulation involved mixing of crystal populations which evolved in different domains of an open system magma chamber.

These studies suggest that isotopic modification of magmas in the crust (according to P-T estimates of plagiocalse stability) is the rule rather than the exception. Although it is conceivable that isotopic signatures are all inherited from mantle-derived melts which interacted before, during and after crystal growth, it is more likely that the isotopic diversity reflects contamination and mixing which obscures the signature of the mantle contributions. Furthermore, it is perhaps unrealistic to think of the evolution of a particular igneous rock. Rather each rock appears to be an aggregate of components with separate evolutionary histories. Because isotopic composition is leveraged by the mass balance of these components (Sr is typically concentrated in plagioclase, Nd in glass and accessories, Hf in zircon, Pb in feldspar and glass), the isotopic systematics of bulk rocks can become decoupled from each other. Thus the isotope characteristics of the rock components give a more faithful record of evolution processes than the bulk rock itself.

## V51C-13 1150h

### Magma Migration Through the Continental Crust 3-D Seismic and Thermo-mechanical Constraints on Sites of Crustal Contamination

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Current understanding of the processes and pathways by which magma travels from its mantle source, through the crust to the Earths surface is limited by the lack of continuously exposed sections through fossil magmatic systems. We report results from a 50 x 30 km 3-D seismic reflection survey of part of the Voring rifted continental margin of Norway which provide the first detailed images of an entire crustal magmatic plumbing system, from a Moho-level magma chamber, through complexes of sills and dykes in the mid to upper crust, to lavas and vent fields extruded at the early Tertiary paleosurface.

The Voring margin of Norway formed during a period of Late Cretaceous to early Tertiary (Eocene) continental break-up when Greenland rifted away from Eurasia, resulting in the opening the NE Atlantic Ocean. Rifting was accompanied by widespread magmatic activity, inferred to be related to the impingement of the Iceland mantle plume on the base of the continental lithosphere. Regionally, magma migration occurred in at least two pulses: 62-59 Ma (main initial phase) and 57-54 Ma (continental break-up phase).

Wide-angle seismic experiments indicate the presence of a laccolith-like high-velocity body (HVB) in the lower crust beneath most of the outer Voring Basin with P-wave velocities (Vp 7.1-7.4 km/s) characteristic of basaltic igneous rocks, overlying typical mantle rocks with Vp of over 8 km/s. The HVB locally reaches 8 km thickness and at break-up (54 Ma) measured 300 km x 500 km corresponding to a volume of 450,000 cubic km of basaltic magma. It is interpreted as a magmatic underplate formed over a period of several million years as rising basaltic magmas ponded at the Moho at their level of neutral buoyancy.

A laterally extensive sill complex (1000 m thick) occurs at the interface between thinned crystalline basement and the overlying Mesozoic sedimentary sequence. This is interpreted as one of the main intra-crustal magma storage reservoirs and is the most likely site for magmatic differentiation and wall-rock assimilation. Magma migrating up through the sedimentary section from this mid-crustal magma storage system appears to flow from sill to sill via a complex system of narrow, dyke-like feeders. Locally boat-shaped nests of sills occur within the Mesozoic sediments. Individual sills are about 15 km long, 10 km wide and may reach 100 m thick. The boat shape is controlled by the half-graben tilt-block geometry: on one side magma follows dipping strata, on the other the oppositely dipping fault.

The thermal structure of the crust becomes altered by the intrusion of successive batches of basaltic magma, which induces rheological weakening of the lower crust and enhances the potential for crustal assimilation.

Bowen had a strong interest in the process of crustal contamination of magmas, as illustrated by Chapters X and XVII of the Evolution of the Igneous Rocks. He would have undoubtedly been fascinated by our ability to image fossil crustal magma storage systems and to use geophysical data to constrain petrogenetic processes.

# V52A MCC: Hall C Friday 1330h

## MORB and More Posters

*Presiding:* **K M Haase,** Universität Kiel

## V52A-1271 1330h POSTER

### Accepted U-Series Constraints on MORB Melting are Invalid

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Prevailing models of basalt formation under ridges impose severe restrictions as to depth and flow rate because of mistaken interpretations of U-series disequilibria observed in MORB. The observed radioactivity excesses of radium and protactinium daughters relative to parent uranium cannot be explained on the basis of the assumed incompatible behavior of uranium and thorium during mantle melting. Rather, application of fundamental mass balance principles shows that when basalt migrates to the surface, most of the U and Th remains behind, probably sequestered in residual accessory minerals. Daughter diffusion and alpha recoil across the accessory grain boundaries would result in daughter deficiencies in the accessory minerals and daughter excesses in surrounding major mantle minerals. The two complementary disequilibrium phases exist as a steady-state condition in the outer mantle prior to the onset of melting. Preferential melting of the silicates can thus produce basalt with extreme daughter/parent activity ratios regardless of depth or partial melt fraction.

## V52A-1272 1330h POSTER

### Cycling of Volatiles at Mid-ocean Ridges: Magma-Seawater Interactions at Three Regions of the Northern EPR (8-10°N, 12-14°N & 15-18°N)

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The extent of magma contamination by seawater-derived components or magma assimilation of altered crust beneath mid-ocean ridges is generally ill-defined but thought pervasive, especially at fast-spreading ridges. Three regions of the northern East Pacific Rise (EPR) (8-10°N, 12-14°N & 15-18°N) were selected for intensive study aimed at identifying, quantifying and relating such magma-seawater interactions to fine-scale tectonic and morphological ridge features. These EPR sections have extensive, existing glass collections, with well-constrained general geochemistry and petrology. Significant differences in spreading rate, axial depth and axial morphology differentiate these EPR sections. Geophysical surveys also indicate sub-axial magma chambers (AMC) at various crustal depths in each region.

Volatile, halogen and light-element data of basaltic samples from these northern EPR regions exhibit variable over-enrichments (i.e. above that due to crystallization). Mostly off-axis 8-10°N samples have over-enriched $H_2O$, F, Cl, Be & B; on- and off-axis 12-14°N samples are similarly, but less, over-enriched; but 15-18°N samples have little significant over-enrichments (over-enrichments decrease northward). High Cl/K ratios are not correlated with incompatible element ratios, e.g. K/Ti, precluding enriched or variable mantle source compositions as the origin of over-enrichments. Cl and $H_2O$ data in 8-10°N & 12-14°N samples indicate variable magma contamination with <0.75wt% seawater-derived brines (15-50wt% NaCl equivalent). In the 15-18°N region (spreading rate 8.4cm/yr) vapor super-saturated magmas indicate rapid ascent from as deep as the shallowest regional AMC (~1400m), with no significant contamination. In the 12-14°N region (spreading rate 10.4cm/yr) magma degassing and contamination occurred at depths <1200m, above the AMC (~1500m). In the 15-18°N region (spreading rate 12.0cm/yr) magma degassing and contamination occurred above 900m crustal depth, above the deepest regional AMC (~1800m). Preliminary $^{11}B/^{10}B$ data ($2\sigma$ precision as low as ~1$^o/_{oo}$) for selected samples will be used to further investigate magma contamination in these EPR regions.

V

## V52A-1273 1330h POSTER

### Geochemical and Pb and Nd Isotopic Characteristics of the Tethyan Asthenosphere: Implications for the Origin of the Indian MORB-type Mantle

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It is unclear why the Pb, Nd, and Sr isotopic composition of the modern mid-ocean ridge basalts (MORB) from the Indian Ocean is different from that of the North Atlantic and Pacific Oceans. A possible explanation for this is that the Indian MORB-type isotopic signature is a long-lived regional feature of the mantle, as evidently shown by the isotopic composition of the 350 Ma MORB-like crust of the Tethys Ocean, which existed in the same region presently occupied by the Indian Ocean (Xu et al., Earth Planet. Sci. Lett. 198, 2002). However, this hypothesis is in conflict with the lack of Indian MORB-type isotopic signature in a number of 150 Ma Tethyan and Indian Ocean crusts (Mahoney et al., J. Petrol. 39, 1998; Weis and Frey, J. Geophys. Res. 101, 1996). To further constrain the origin of the Indian MORB-type isotopic signature, we analyze the chemical and Pb, Nd, and Sr isotopic composition of representative mafic rocks from four Tethyan ophiolites ranging in age from 90 to 360 Ma. The Sr isotopic composition of the samples is unreliable due to alteration, but the alteration resistant trace element and age-corrected Nd and Pb isotopic results indicate that these Tethyan rocks were derived from a geochemically depleted asthenospheric source that had a clear Indian MORB-type isotopic signature. We therefore conclude that the bulk of the Indian suboceanic mantle was most probably inherited from the Tethyan asthenosphere. A few regions in both the Tethyan and Indian Oceans, however, are most probably underlain by North Atlantic and Pacific MORB-type mantle (and vice-versa) because of the flow of the asthenosphere in response tectonic plate reorganizations that lead to openings and closings of ocean basins (e.g., Flower et al., Tectonophys. 333, 2001).

## V52A-1274 1330h POSTER

### Testing Binary Mixing Models for Lavas Erupted Along the Reykjanes Ridge: Insights From C-He Relationships

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We report new $CO_2$ abundance and isotope data for 36 basalt glasses erupted along the Reykjanes Ridge between latitudes 57.5 and 63°N. Lavas can be divided into (a) water-rich samples (~0.4 wt.%), erupted at depths < 775m north of 61.5°N, and (b) samples with water ~ 0.2 wt.%, erupted at depths of 620 - 2060 m and located between 57.5 and 61.5°N. Based upon He-Pb isotope systematics (Hilton et al., EPSL, 2000), deeper samples (category b) lie along binary mixing trajectories between plume-like ($^3He/^4He \sim 30R_A$; $^{206}Pb/^{204}Pb \sim 18.7$) and MORB-like endmembers ($^3He/^4He \sim 8R_A$; $^{206}Pb/^{204}Pb \sim 18.0$). Shallow samples (category a) do not fall on mixing trajectories: consistent with volatile loss followed by addition of a crustal contaminant, resulting in lower $^3He/^4He$ ratios. The aim of this study is to test whether binary mixing trends are observed using C-He relationships.

All samples were analyzed using incremental heating techniques which allows for resolution of vesicle-sited $CO_2$ from $CO_2$ dissolved within the glass matrix. Results show that samples north of 61.5 °N (category a) have low $CO_2$ contents in both the vesicle (2-37 ppm) and dissolved (15-61 ppm) phases. The isotopic composition of the $CO_2$ varies between -8 and -34$^o/_{oo}$ (vesicle) and -6 and -10$^o/_{oo}$ (glass). The combined effect of low $CO_2$ concentrations and low $\delta^{13}C$ values are consistent with extensive gas loss ± contamination of volatile-poor magmas with an isotopically-light C component. In contrast, samples in category b have significantly higher $CO_2$ abundances (vesicles: 7-318 ppm; glass: 9-200 ppm) and higher and less variable $\delta^{13}C$ values (vesicles: -5 to -26$^o/_{oo}$; glass: -4 to -11$^o/_{oo}$). This suggests that category b samples have not been subjected to the same degree of degassing and/or contamination as samples in category a.

By combining the vesicle-sited $CO_2$ abundances with He-contents determined by crushing (Hilton, op. cit), $CO_2/^3He$ ratios for the vesicle phase can be derived. We observe high ratios ($3\times10^9$ to $2\times10^{10}$) in the more degassed category a samples. Category b $CO_2/^3He$ ratios show a trend from low $CO_2/^3He$ values ($3\times10^8$) and MORB-like $^{206}Pb/^{204}Pb$ to high $CO_2/^3He$ values (up to $2\times10^{10}$) and more radiogenic $^{206}Pb/^{204}Pb$. There are two possible explanations for the observed trends: 1) degassing followed by contamination with a high $CO_2/^3He$ crustal component. This process controls C-He relationships in low concentration (highly degassed) samples close to Iceland. 2) mixing between a MORB-like source ($CO_2/^3He \sim 2\times10^9$) and an enriched source with a higher initial $CO_2/^3He$ value. This process controls samples in category b.

## V52A-1275 1330h POSTER

### Binary Mixing Processes at a Ridge Segment as Shown by Historic Reykjanes Peninsula Lavas, Iceland

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Binary mixing between compositionally distinct melts has been recognised as an important process in generating the compositional diversity of oceanic magmatism at several length scales, and it has been argued that local variations in $^{238}U$-$^{230}Th$ of MORB lavas are controlled by such a process. Additional information about the melting behaviour of the mixing end-members that might potentially be provided by $^{226}Ra$ is limited by the lack of precise age control for most MORB samples. The Reykjanes Peninsula (SW Iceland) is essentially an onshore, 80 km long, plume-influenced 'mid-ocean' ridge segment, but with a well-dated record of historic basaltic lavas (MgO 6.5-9.2 wt%) erupted between c. 940 AD and 1340 AD. Sr-Nd isotope data indicate minimal shallow-level crustal assimilation. Coherent linear trends shown by high-precision (double-spike) Pb isotope data and correlations with incompatible element ratios (e.g. La/Yb) provide evidence for binary mixing between a 'depleted' end-member with $^{206}Pb/^{204}Pb < 18.7$ and $La/Yb_N <$ 1.3 and an 'enriched' end-member with $^{206}Pb/^{204}Pb$ > 18.9 and $La/Yb_N > 2.7$. The historic lavas are dominated by the 'enriched' end-member (~ 50-90 %), and the 'depleted' end-member is only found in a relatively undiluted form in picrites erupted during the last deglaciation. Work is in progress to obtain U-Th-Ra disequilibria data on these historic lavas to see if they preserve systematic correlations with Pb isotope and trace element data and thus place critical constraints on the melt generation processes.

## V52A-1276 1330h POSTER

### Generation of Highly Silicic Lavas Along the Pacific-Antarctic Ridge (PAR): Insights into Magma Chamber Processes Along a Hotspot Influenced Ridge Section

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A sample suite comprising rocks ranging from basalt via basaltic andesite and andesite to dacite has been dredged along the fast spreading (10 cm/a) N'PAR at its intersection with the Foundation Seamount chain, denoting the current position of the Foundation Hotspot, between latitudes 36.5 and 41.5°S. Andesites and dacites occur along the section of the N'PAR being mainly influenced by the hotspot (36.5° to 39.8°) and are not related to propagating rifts. Major and trace element data as well as Sr-, Nd- and Pb-isotope composition reveal that the magmas generated along the PAR are (1) derived from a heterogeneous source and (2) are related by multiple differentiation trends.

Fractional crystallization modeling shows that the basaltic rocks are controlled by low-pressure fractionation of olivine, plagioclase, clinopyroxene and Ti-magnetite. Two differentiation trends can be defined: (1) basalts erupted between 37 and 39.50°S are controlled by crystallization of olivine -> olivine + plagioclase -> olivine + plagioclase + clinopyroxene and (2) basalts erupted between 40 and 41°S are controlled by the crystallization sequence plagioclase -> plagioclase + olivine -> plagioclase + olivine + clinopyroxene. This difference in differentiation trends is caused by higher crystallization pressures of the melts along the PAR section between 37 and 39.50°S. The $H_2O$-content does not vary significantly along axis, thus a higher $H_2O$ -content, which would delay plagioclase crystallization, can be ruled out as a cause for the development of these different differentiation trends.

The andesites and dacites are not related to their basaltic parents by simple low-pressure fractional crystallisation. The existence of clinopyroxene xenocrysts, ranging in Mg# from 40 to 87, and plagioclase xenocrysts, ranging in An form 22 to 87, in the andesites shows that they have been generated by mixing between basaltic and dacitic melts. Although the andesites and dacites are dominated by low-pressure mineral assemblages, their $TiO_2$-, $FeO_{tot}$- and Cl-content cannot be achieved by normal low-pressure fractional crystallisation. Elevated Cl/K and $^{87}Sr/^{86}Sr$ ratios indicate that assimilation of altered oceanic crust has been involved in andesite and dacite generation.

The thicker crust associated with the hotspot leads to polybaric crystal fractionation. A complex plumbing and magma storage system is active beneath the PAR. Abundant hydrothermal activity in the area of andesite volcanism suggests a relation to the formation of evolved melts and results in an effective alteration of the crust.

## V52A-1277 1330h POSTER

### Late Stage MORB Volcanism at the Cuesta Ridge Ophiolite Remnant: Evidence for Ridge Collision or Back-arc Basin Spreading?

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The origin and significance of ophiolites has been a major focus of research over the past three decades, with most attention focusing on whether they form at mid-ocean ridges or above subduction zones. The termination of igneous activity in ophiolites has received far less attention, since it is assumed that igneous activity ends when the ophiolite is obducted. The middle Jurassic Coast Range Ophiolite (CRO) of California provides an excellent opportunity to study not only the origin of ophiolites, but also the termination of igneous activity related to ophiolite formation.

Geologic mapping of the Cuesta Ridge ophiolite remnant of the CRO reveals an ophiolite sequence in thrust contact with the underlying Franciscan assemblage. The section consists of a 1.5 km thick mantle section of serpentinized harzburgite and a MTZ consisting of dunite, wehrlite, and pyroxenite. The mantle section is overlain by isotropic gabbro, with sills of wehrlite and pyroxenite, a sheeted sill complex of quartz-hornblende diorite, and a 1.3 km thick volcanic section comprising massive flows, pillow lava, and volcanic breccias with calc-alkaline and boninitic affinities, all capped by tuffaceous radiolarian chert. Late stage dikes of tholeiitic basalt cross-cut the quartz diorite sheeted sill complex, and similar basalts occur as flows at the top of the volcanic section, below the tuffaceous cherts.

The majority of the volcanic rocks at Cuesta Ridge have low Ti/V ratios (11-21) and other trace element characteristics (e.g., low HFSE, low Zr/Y) that are atypical of MORB and suggest formation in an SSZ setting. High MgO and SiO2-Cr plots show that about 40 percent of the volcanics have strong boninitic affinities, consistent with formation in the fore arc region of an island arc. The quartz-hornblende diorites, which cut the lower volcanics, have SiO2 ranges of 52-75 percent, much too high for rocks formed at mid-ocean spreading centers. In contrast, the late stage dikes and uppermost flows, which cut the sheeted sill complex and overlie the main volcanic section, have a MORB-like affinity with enriched HFSE and TiO2, and high Zr/Y and Ti/V ratios (20-27).

These relations are similar to those observed in other CRO remnants such as Elder Creek, Del Puerto, and Mount Diablo, where late dikes with MORB geochemistry cross-cut older plutonic and volcanic rocks with calc-alkaline or arc tholeiite geochemistry.

The field and chemical data from Cuesta Ridge and other CRO remnants point toward formation in a SSZ setting above an east-dipping proto-Franciscan subduction zone. This is supported by the abundance of calc-alkaline volcanics and intrusive quartz diorites, the widespread occurrence of lavas with boninitic affinities, and the lack of an emergent arc complex west of the ophiolite.

Emplacement of these late stage MORB dikes and flows signify the end of ophiolite formation and require a significant change in tectonic setting that occurred shortly before deposition of the overlying Great Valley series. There are two possibilities that can explain these dikes: back-arc basin spreading or collision of a spreading ridge. Propagation of a back-arc basin spreading center through the ophiolite in response to prolonged arc rifting could explain the shift in geochemistry from arc-like to MORB-like, but seems unlikely in a fore-arc setting. We suggest that collision with a spreading center circa 160 Ma can account for the shift observed in geochemistry and the termination of ophiolite-related igneous activity.

## V52A-1278 1330h POSTER

### Volcanism on the fossil Galapagos Rise spreading centre, SE Pacific

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A part of the fossil spreading centre of the Galapagos Rise at 10°S, 95°W in the SE Pacific Ocean was mapped and sampled. This spreading centre was active for about 12 Ma and was abandoned about 6.5 Ma ago when the spreading rate of the East Pacific Rise (EPR) increased. The aim of this study is to understand the tectonic and petrological implications of the ridge jump for the spreading centre and to gain insights into the processes in its melting column.

Bathymetric swath mapping of a part of the Galapagos Rise revealed an elongated structure with a NNE-SSW strike direction which is bounded by a large fracture zone in the north. The mapped area can be divided into three segments, each of about 50 km length. The northernmost segment consists of an 4400 m deep rift which shows similarities to a slow-spreading centre, e.g. the Mid-Atlantic Ridge. The southern two segments are volcanic ridges with numerous volcanic flank cones which reach water depths up to 490 m. This volcanic ridge is interpreted as the continuation of the fossil spreading axis. While the northernmost segment is magmatically starved, the volcanic ridges of the southern two segments apparently formed after cessation of spreading.

The rock samples from the rift flanks in the north are incompatible element-depleted (K/Ti 0.08-0.28) and plagioclase-phyric basalts resembling typical mid-ocean ridge basalts (MORB). In contrast, the lavas from the two volcanic ridge segments in the south are highly vesicular incompatible element-enriched alkali basalts with K/Ti of 0.65-1.4. The depleted rift basalts have Sr isotope ratios below 0.7027 while the alkali basalts from the ridge range between 0.7029 and 0.7031. The rift basalts have significantly lower sodium contents than the alkali basalts and thus the southern lavas are probably derived by smaller degrees of partial melting. The relatively low Si contents of the alkali basalts also indicates formation deeper in the melting column than the northern MORB-like samples. The mantle source of the alkali basalts is similar to the enriched source of off-axis seamounts along the EPR. Our preliminary data suggest that the northernmost segment formed by tectonic processes during a final slow-spreading phase of the Galapagos Rise while the southern two segments erupted alkaline lavas probably after spreading stopped.

## V52A-1279 1330h POSTER

### Sulfide Undersaturated Basalts from Mid-Ocean Ridges and Oceanic Plateaus; Implications for Mantle Melting and Heterogeneity

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Mid-ocean ridge basalts (MORB) almost always erupt saturated with sulfide melt, as shown by the immiscible sulfide blebs they contain and their linear trend on a plot of FeO versus S [1]. Submarine MORB glasses are better for judging S undersaturation because they are rapidly-quenched liquids that erupted under hydrostatic pressures sufficiently high to preserve magmatic S without degassing. Here, using FeO-versus S relationships and Cu contents in glasses, we show for the first time that certain MORB and oceanic plateau basalts were sulfide undersaturated when erupted. In some cases they may have exhausted mantle sulfide during melting. The S-undersaturated basalts are MORB from Kolbeinsey Ridge and Indian Ocean ridges and have low Na8.0. Also, low-Na tholeiites from Ontong Java Plateau (OJP) and environs. All have formed by large extents of melting. Additional S-undersaturated MORB from the Indian Ocean that have formed by smaller extents of melting suggest that the mantle source is regionally depleted in S compared to other areas. Sulfide undersaturation there might correlate with an Indian Ocean isotopic signature, pointing to a peculiar makeup of the source.

We consider the behavior of S, Cu and PGEs in terms of a column melting model [2] and the negative pressure dependence, the positive temperature (T) dependence and the compositional dependences of the S content at sulfide saturation (SCSS) [3,4]. Most magmas should reach crustal levels undersaturated with sulfide [3], but rapidly become saturated as T decreases and they evolve by olivine crystallization. Unlike [3] we feel that changes in T and composition are sufficient to bring about sulfide saturation: assimilation is not required. Differences in extent of melting should affect S saturation history. Average MORB that form by moderate extents of melting at relatively shallow depths will not be too far removed from sulfide saturation, and can rapidly attain saturation as T decreases and 10-20% olivine crystallizes, most likely in the lower crust and uppermost mantle. Basalts from OJP and Kolbeinsey that form by large extents of melting will reach the crust as picrites that are much farther from S saturation. They are more likely to erupt S-undersaturated, and able to "deliver" PGEs to shallower levels. Cumulates could have high PGE concentrations at the point of sulfide saturation. The residual mantle could be very heterogeneous with respect to S, Cu and PGEs. Uppermost mantle is likely to be highly melted and depleted in S and PGEs. Deeper levels should preserve more PGEs and S. Since sulfide should dissolve quickly into silicate liquid, ascending S-undersaturated magmas are likely to strip sulfide + PGEs from the uppermost mantle they pass through, even if they do not cause additional melting, re-equilibrate with REE.

1 Mathez, E.A., (1976) J. Geophys. Res. 81, 4269-4276. 2 Langmuir, C.H., Klein, E.M. and Plank, T. (1992), AGU Monograph 3 Mavrgenes J.A and O'Neill, H. St.C., (1999) Geochimica et Cosmochimica Acta 63, 1173-1180. 4 O'Neill, H. St.C. and Mavrgenes J.A., Jour. Petrol. (in press)

## V52A-1280 1330h POSTER

### Temporal Changes in Melting Beneath the Australian-Antarctic Discordance Since the Miocene

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The Ocean Drilling Programs (ODP) Leg 187 set out in November 1999 to trace the off axis configuration of the unique isotopic boundary between Indian and Pacific MORB mantle documented from analyses of 0-4 m.y. old ocean crust near the eastern boundary of the Australian-Antarctic Discordance (Klein et al., 1988, Pyle et al., 1992, Pyle et al., 1995). This boundary is currently centered beneath the eastern boundary of the Australian-Antarctic Discordance (AAD). The AAD is an anomalously deep, readily identifiable section in the global mid ocean ridge system with unusually low gravity signals, high upper mantle seismic velocities, rough topography, and long transform offsets. The trace of the depth anomaly is evident across the entire Southern Ocean basin indicating that this feature has been present for at least 96 Ma and possibly as long as 300 Ma (Veevers, 1982; Mutter et al., 1985). However, aeromagnetic data show that the present day crenulated geometry of the spreading axis and the rough topography has developed through asymmetric spreading and rift propagation over only the past 25 Ma (Vogt et al., 1984). ODP Leg 187 drilled 23 holes at 13 different sites (ODP 1152 to 1164) in crust ranging from ∼14 Ma to ∼28 Ma (Christie et al., 2000). Basaltic glasses recovered from each of these sites were analyzed for their major and trace element content. These new data show that the melting regime associated with the isotopically defined Indian and Pacific MORB mantle have changed significantly in the last 28 Ma. Near axis low degree melts derived from Indian MORB mantle have high K2O and Na2O contents. These characteristically AAD compositions were not sampled during Leg 187. The absence of small degree melts within the depth anomaly between 14 Ma and 28 Ma are inferred from the melting proxies Fe8 and Na8. Older Indian MORB are higher degree melts derived from greater depths then near axis (i.e. <4 m.y.) Indian MORB within the AAD. The absence of low degree melts on older Indian Ocean seafloor is further supported by trace element ratios of highly incompatible elements (Ba and Rb) to moderately incompatible (La) and more compatible (Zr) elements. The ODP Leg 187 data point to a significant cooling of the mantle beneath the AAD since Miocene time.

## V52A-1281 1330h POSTER

### Geochemistry of basalt from the Ayu Trough, equatorial western Pacific

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The Ayu Trough is a relatively short segment of divergent margin located in the equatorial western Pacific between Philippine Sea and Caroline plates, bounded to the north and south by subduction zones. Previous studies have suggested that the Ayu Trough is an ultra-slow spreading ridge (4-5 mm/yr) with its pole of opening located just south of Palau Island on the basis of sediment thickness. However, there is a great deal of uncertainty with this estimate and the seafloor age is largely unknown. According to recent detailed mapping of the region, the trough has opened in an oblique manner and the tectonic and morphologic variations can be divided into three sections: the north (4°-6°N), middle (1°30'-4°N) and south (0°-1°30'N). This study examines major and trace elements geochemistry of basalt rock samples collected at nine along-axis sites in 2001. The samples can generally be classified into three groups: N-MORB, E-MORB and T-MORB. N-MORB is mainly derived from the southern and middle sections, and E-MORB and T-MORB from the middle section. The ranges of incompatible element contents among samples are too large to be explained by melting alone. As a result, mantle heterogeneity is needed to explain the variability. Detailed examination reveals two types of heterogeneity. The first heterogeneity appears to be caused by mixing between depleted and enriched components, with most of incompatible elements lying within the range of global MORB array. One possible source of enriched components may be the recycled ancient oceanic crust on the basis of relatively higher enrichment of Nb and Ta compared to Th, Ba and La. The second heterogeneity is observed in four elements (Cs, U, Rb and K) which are offset from the global MORB array and affected by fluid. The source of the fluid may be an extinct subduction zone nearby. The degree of melting, together with morphological differences, suggests that the Ayu Trough has variable melting regime from north to south.

## V52A-1282 1330h POSTER

### Geomagnetic intensity of near axis flows on the East Pacific Rise, 9°30'-10°N: constraints on timing of eruptive activity

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Well located submersible and glass core samples from the 9°N segment of the fast-spreading East Pacific Rise (EPR) provide an excellent opportunity to use geomagnetic intensity fluctuations as a dating tool for near axis flows. Absolute paleointensity data from archeomagnetic and volcanic materials document substantially higher fields (50% above present) at ∼1-3 ka and much lower values (20% of present value) near 40 ka. We measured paleointensity using the Thellier double-heating method on ∼1000 glass specimens from ∼200 sites, distributed both along-axis and up to ∼4 km off-axis. We find that most axial samples (those from the axial summit collapse trough, ASCT) have paleointensity values consistent with the present field intensity at the site (35 $\mu$T). A few samples from within the ASCT have significantly higher values suggesting ages > 100 years, and several samples from the margins of the ASCT have values implying they are at least several hundred years old. These old ages are difficult to reconcile with eruptive frequencies of < 10 years that have been suggested for fast spreading ridges, unless eruptive volumes are small. Off-axis paleointensities generally follow a pattern with distance from the axis consistent with independent records of changes in intensity with time. For example, high values are common up to 2 km from the axis, with decreasing values farther away from the axis. This agrees well with other observations of young flows up to 2 km from the axis. Low paleointensities, presumably reflecting the dipole intensity minimum near 40 ka, are typically found 3-4 km from the axis but also occur as close as 2 km off axis (the nominal distance for 40 ka crust). If the latter samples also represent the same intensity low near 40 ka, this would suggest minimal off axis volcanism at this locality. The paleointensity data also provide a powerful age discriminant when used in conjunction with geochemical data. For example, we distinguish adjacent samples with identical chemistry but with distinct paleointensities that imply a time separation of hundreds or thousands of years. We also identify samples with substantially different geochemistry but with indistinguishable paleointensities, suggesting that they may have been erupted very close together in time.

### V52A-1283 1330h POSTER

### Possible Recent Volcanic Activity on the East Pacific Rise at 9° 32'N

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In 2001, the DSL-120A near-bottom mapping system was used to survey a 31.4 km by 6.8 km corridor of the East Pacific Rise crest between 9° 25'N and 9° 57'N. The mapping system included a 120 kHz sidescan and interferometric bathymetry sonar that was used to produce 2 meter-resolution sidescan images of the corridor. The sidescan data depict three scarps located approximately 3 km west of the ridge axis that are interpreted to have been volcanically overprinted between 9° 31'N and 9° 32'N on the basis of sharply lineated features that are interrupted along-strike. In transcripts, video, and 35 mm film footage of the same region collected during Alvin Dive 2490 in 1992, these same scarps are documented as two inward-facing and one outward-facing vertical walls that are 17-18 m high. Co-registration of the DSL-120A and Alvin 2490 datasets shows a strong correlation between other features that are depicted in both the acoustic and photographic data, but the appearance of the scarps changes markedly between 1992 and 2001.

In the DSL-120A sidescan data, amorphous-shaped regions of relatively high backscatter characterize the area where the scarps are thought to be volcanically overprinted. In some cases, these reflective patches appear to pond at the base of faults or to spill over the faults. To verify whether the morphology changes between 1992 and 2001 reflect recent volcanic activity on the flank of the ridge axis, we have located SeaMARC-II data for the same region collected in 1987. A cursory examination of the much lower-resolution SeaMARC-II sidescan images vaguely shows the presence of similarly-shaped reflective scarps in the approximate location of the new flow. We are presently reprocessing the SeaMARC-II data to improve the data resolution, making a map from the DSL-120A bathymetry data, and searching for additional datasets that may confirm the existence of a new off-axis flow. The results of our efforts will be reported in December.

### V52A-1284 1330h POSTER

### Depleted Peridotites of Macquarie Island, an Uplifted Section of In-situ Oceanic Crust

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Macquarie Island, located 1500 km southeast of southernmost Australia, is thought be the sole complete section of ocean crust uplifted in the ocean basin in which it formed. It is an exposure of the Macquarie Ridge complex, which marks the modern Australian-Pacific plate boundary. The oceanic crust of the island formed in the final stages of spreading, ~6 mya, as indicated by Ar-Ar plateau ages of basaltic glass. Geometries of marine faults on the island suggest that it formed near the intersection of a ridge and a transform. At this latitude, the plate boundary evolved from a spreading ridge to a transpressional boundary between ~33 and ~6 mya, thus the rocks of the island record an interesting tectonic history and may provide clues to the mantle process during a major plate motion re-organization. Residual, plagioclase-free mantle peridotite samples were collected along transects through all of the mantle sections on the island, with an average of 100 meter spacing between samples.

Orthopyroxenes, clinopyroxenes and chrome spinels were analysed by electron microprobe. Spinel chrome numbers (Cr-nr) ranged from 0.39 to 0.46 (n=23), which corresponds to 15-16% fractional melting applying the empirical melting equation of Hellebrand et al (2001). Their low Ti contents (0.02-0.07) attest to the residual nature of the Macquarie Island peridotites. Cpx is preserved in only 7 samples (alteration, depletion), and occurs mainly as small interstitial grains or as exsolved blebs in opx porphyroclasts. Cpx titanium (0.00 0.04 wt% TiO2) and sodium (0.00 0.05 wt% Na2O) contents are extremely low, confirming the high depletion and supporting highly efficient melt extraction. Opx porphyroclast cores have very high Mg-nr (0.92 on average).

Spreading rates at the time of formation of the Macquarie Island crust have been calculated to be 30mm/yr (full) which is considered slow. However, the levels of depletion indicated by the spinel Cr-nr and Ti and Na contents of cpx of the Macquarie Island peridotites are more similar to those seen at fast spreading centers or ophiolites. This depletion could be caused by the progressively changing spreading direction disrupts mixing in the mantle, causing repeated melting of the same mantle source or biased sampling in the existing abyssal peridotite database. Further analyses of peridotites and associated basalts will test which model is most likely.

Hellebrand et al., (2001) Nature 410, 677-681.

### V52A-1285 1330h POSTER

### Normal and Abnormal Major Element Variations in Lavas from Intermediate Spreading Centers: SEIR and Galapagos

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The Galapagos Spreading Center (GSC) and the Southeast Indian Ridge are major intermediate spreading centers that encompass significant gradients in depth and mantle temperature. Major elements contents of lavas sampled along these ridges, across the depth gradients vary in significantly different ways. With the exception of the hotspot-influenced Amsterdam-St Paul platform, the shallowest point (~2500 meters) on the SEIR is near 90°W while the deepest (>4500 m) region is between 115°W and 127°W, within The Australian Antarctic Discordance (AAD). Between these regions, a steady eastward depth increase in axial depth is accompanied by increasing Na8 and decreasing Fe8, consistent with the well-known global correlations of these parameters with axial depth. Along the Galapagos Spreading Center, the thermal influence of the nearby Galapagos hotspot causes axial depths to shoal by more than 1000 meters as the locus of maximum hotspot influence near 91°W is approached from both east and west. This effect is mirrored by regional increases in Sr and Nd isotopic ratios (Schilling et al., 1982, Verma et al., 1983). New analyses of basalt glasses collected from the GSC east of the hotspot during the MEGAPRINT expedition of R/V Sonne confirm the observation of Klein and Langmuir (1987) that values for GSC lavas do not conform to the global trend, as do recently published data from the G-Prime expedition to the western GSC (Detrick et al., 2002). Along-axis Na8 and Fe8 profiles east and west of 91°W are not, however, mirror images. For the eastern GSC, Na8 and Fe8 are positively correlated and cut at a high angle across the global trend. We can use this cross cutting trend, in combination with other geochemical and geophysical data to assess the combined effects of gradients in source composition, mantle temperature and magma system geometry on the compositions of erupted lavas. In recent years, a number studies of mid-ocean basalts have used Na8, Fe8 and other major element parameters to calculate pressures, temperatures and extents of melting. If we apply such calculations to eastern GSC lavas, the results are clearly in error because of the extreme effects of the along-axis gradients. In this poster, we use the magnitude of such errors to explore the variability of mantle source composition, properties and processes.

## V52B MCC: Hall C Friday 1330h

## Geochronology and Related Topics Posters

***Presiding:*** **T Torgersen,** University of Connecticut

### V52B-1286 1330h POSTER

### $^{40}Ar/^{39}Ar$ dating of the UG-2 Vein of the Bushveld Complex (South Africa): The diversity of spectra.

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The UG-2 vein (upper critical zone) is one of the prominent Pt-group enrichment zones in the Bushveld Complex (South Africa). Eleven individual phlogopite crystals were degassed incrementally with a CO2 laser in 30 to 40 steps each. The apparent age spectra display widely varying characteristics, ranging from essentially 100% concordant to strongly discordant (in some cases undulatory). All discordant spectra display common features; 1) apparent low age in the first 10 to 20% of the spectrum; 2) higher $^{37}Ar_{Ca}/^{39}Ar_K$ ratio (0.4 to 0.2). These spectra are good examples of the variable effects of $^{39}Ar$ recoil during irradiation in interlayer chlorite as observed in other studies of Fe-Mg micas (Lo and Onstott, 1989). In such spectra, plateau-like segments (more than 50% of the $^{39}Ar$ released) can be found even in highly discordant spectra and the more discordant spectra coincide with the oldest plateau "ages" (2106 +/- 12 Ma; analytical errors only). In such cases the integrated ages are better clustered than plateau ages. The least discordant spectra (90 to 100% of the $^{39}Ar$ released) yield integrated and plateau ages ranging between 2034 and 2047 Ma (based on Steiger and Jager (1977) decay constants and 28.02 Ma for the FCs standard; Renne et al., 1998), slightly younger than existing constraints from U/Pb dating (Ca. 2059 Ma, Buick et al., 2001). If the recently-inferred ca. 1% bias between currently used calibrations of the $^{40}Ar/^{39}Ar$ and U/Pb systems in valid, this implies a very rapid cooling rate for this part of the Bushveld Complex as proposed by Cawthorn and Walraven (1998). Nevertheless the possibility of subtle bias due to excess $^{40}Ar$ and unobviated recoil artifacts must be considered. In all cases, the heterogeneous age spectra reveal the likelihood for erroneous conclusions to be drawn from less complete data sets. The observed complexities also underscore the stringent requirements for data which can be used objectively to constrain the inter-system bias between U/Pb and $^{40}Ar/^{39}Ar$.

### V52B-1287 1330h POSTER

### Reconciling in situ Cosmogenic $^{36}Cl$ Production Rate Estimates

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The suitability of using cosmogenic nuclides for determining surface-exposure ages and rates of geomorphic processes depends upon the accuracy with which