

seafloor between Pinta and Marchena is cut by fractures and fissures parallel to the WDL, and a major submarine ridge extends NE from fissures that cross-cut Genovesa Island. Elongate volcanic structures are unusual in off-axis seamount provinces and indicate strong deviatoric stresses on a regional scale.

Individual volcanoes in the northern Galapagos generally exhibit homogeneous geochemical signatures, although this may be an artifact of sparse sampling (see Blair et al. abstract). Regionally, however, lavas range from plume-like enrichment (Pinta) to MORB-like depletion (Genovesa, S. WDL), with many volcanoes of intermediate composition (Darwin, Marchena). The WDL volcanoes define two distinct chemical groups; lavas erupted south of Wolf Island are similar to those from the GSC west of 93°W, while the northern WDL resembles lavas from the GSC segment directly to their north. This distribution implies that the WDL is supplied by the same type of plume-affected mantle as the GSC segment that produced the lithosphere underlying the volcanoes.

We propose that the WDL and perhaps other northern volcanoes are primarily the result of tensional stresses emanating from the inside corner of the GSC transform fault at 91°W. The oblique orientation of the fault with respect to the Nazca plate spreading direction may further enhance regional tensional forces. The area is magmatic owing to the overlapping effects of the ridge and the plume. The volcanoes simply tap hybrid products of mixing at the margins of the sub-ridge convection system and the periphery of the plume, resulting in locally homogeneous but regionally variable lava compositions. Essentially, the stress field around the transform fault, normally not observable in a typical mid-ocean ridge setting, is illuminated by the presence of melt from the adjacent hotspot.

V61A-1358 0830h POSTER

The Role of Plume-Ridge Interaction in Magma Genesis II: Wolf Island, Galapagos

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Wolf Island is one of two isolated volcanoes in the NW Galapagos Archipelago. Along with Darwin Island and several seamounts, Wolf is part of an intriguingly linear bathymetric feature (Wolf-Darwin Lineament, WDL) that trends 140° between the Galapagos Spreading Center (GSC) and the main archipelago. Because Wolf is located only 60 km south of the GSC and <200 km north of Fernandina, the most active volcano in the region, Wolf is effectively upstream of the plume center relative to plate motion and not easily explained in the context of a traditional plume model. Most recently, the WDL has been proposed to be the result of tensional stresses caused by the transform fault at 91°W, allowing underlying magmatic material to erupt along these zones of weakness.

Despite its small sub-aerial extent (<5 km²), Wolf has a complex volcanic history, including at least two major eruptive phases. First, the southern part of the island is constructed of horizontal, 1-2 m thick basalt flows. Next, thicker (2-8 m), flat-lying flows erupted after a significant hiatus in activity. Their eruption resulted in a caldera, now eroded to form a bay. Wolf has produced plagioclase ultraphyric basalts throughout its history, with up to 60% plagioclase and crystals nearly 4 cm long. Such basalts are typical of islands from the northern Galapagos and are rarely observed elsewhere. Unlike the other northern islands, however, ultraphyric flows constitute a major fraction of Wolfs sub-aerial volume. Megacrysts are segregated into bands within the thicker flows and are more abundant in the most recently erupted material.

Wolf lavas exhibit some of the most extreme compositional variations observed at a single volcano in the Galapagos, from slightly less enriched than Fernandina to MORB-like depletion. The enriched signatures confirm that plume material is a major component in the mantle underlying the northern Galapagos, likely the result of magmatic communication with the GSC. Early in Wolfs history, lavas peak in enrichment but become abruptly more depleted in later flows. The temporal variation indicates that the intensity of the plume supply may have varied over the lifetime of the volcano. If Wolf is the result of tension-induced volcanism, this further implies that the northern Galapagos mantle is a dynamic mixture of plume and upper mantle, capable of change over relatively short periods (1 m.y.).

V61A-1359 0830h POSTER

The Role of Plume-Ridge Interaction in Magma Genesis III: Darwin Island, Galapagos

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Located only 50 km south of the Galapagos Spreading Center, Darwin Island marks the northernmost extension of the Wolf-Darwin Lineament, a >50 km-long alignment of volcanoes and seamounts north of the main Galapagos Archipelago. Like neighboring Wolf Island, Darwin formed closer to the GSC than to the plume center and sits on younger lithosphere than the rest of the Galapagos volcanoes.

A small (1.5 km²), largely inaccessible island, Darwin has experienced at least two explosive episodes during its history. The base consists of a 20 m-thick tuff layer covered by over 40 meters of predominantly plagioclase ultraphyric basalt flows. The lavas are generally of uniform thickness (1-2 m), but can reach up to 8 m near the top of the sequence. A second tuff layer caps the lava flows, evidence of a later explosive phase. Although sub-aerially Darwin appears to be volumetrically insignificant, bathymetric and field evidence suggest that what is currently visible is merely the eroded remnant of a much larger volcano with an elongate footprint parallel to the WDL. Morphological evidence indicates that Darwin is significantly younger than Wolf Island, which is confirmed by previous age determinations (White et al., 1993).

Darwin lava flows are compositionally homogeneous, in stark contrast to the wide variation observed at Wolf Island, possibly the result of Darwins younger age. Darwin lavas exhibit moderately enriched signatures similar to those erupted along the adjacent GSC, indication that the Galapagos plume is a significant component of Darwins mantle source. The wide range and erratic distribution of compositions along the WDL further suggest each volcano is tapping mantle that is a spatially variable mixture of depleted and plume material, rather than a sub-lithospheric pipeline transporting plume material to the ridge. We propose that Darwin, along with the rest of the WDL, is the surface manifestation of tensional volcanism induced by ridge-transform stresses along the GSC. Migration of magma to the surface is controlled by regional stress fields, resulting in constructional lineaments such as the WDL.

V61B MCC: Hall C Saturday 0830h

Hydrothermal and Geothermal Posters

Presiding: D R Janecky, Los Alamos National Laboratory

V61B-1360 0830h POSTER

Low Temperature Alteration of Basalts During the Last 9 Ma at 14°15'S on the South East Pacific Rise

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Little is known about the influence of low temperature alteration on the mineralogical and chemical composition of the oceanic crust once it leaves the spreading axis. Yet this crust is one of the major inputs to subduction zones, its composition is therefore highly relevant for the evolution of mantle, crust and biosphere. In addition, any secondary minerals contain a large amount of H₂O (i.e. clays), in consequence they play an important role as a water depot and therefore affect the dehydration reactions during subduction. For a better comprehension of the alteration effects it is important to understand the effects of the initial low temperature alteration. To determine these features, electron microprobe, X-ray diffraction and ICP-MS analyses have been carried out on basalts from the eastern

flank of the East Pacific Rise at 14°15'S. The investigation concentrates on the products of a single spreading segment in a corridor perpendicular to the SEPR over a period from 0 to 9 Ma. Fresh rocks were sampled at the ridge axis (0-0.015 Ma), whereas off-axis basalts contain features of seawater generated alteration, which increases in intensity with time. Celadonite is the main alteration component in 0.12-4.6 Ma old rocks, whereas phillipsite is more abundant in rocks older than 4.6 Ma. The secondary minerals show evidence for a slight change in redox condition with time, from oxidizing, water-dominated to more reducing, rock-dominated environment. Iron-oxyhydroxide and celadonite are the first alteration products filling voids and veins and replacing olivine, partly replaced by saponite under more reducing conditions. The Fe necessary for the formation of these minerals is furnished by the dissolution of glass and the breakdown of olivine. Phillipsite is present in fractures and veins in rocks older than 1 Ma. Analyses also indicate an illite-smectite mixed layer which is believed to be an intermediate between saponite and celadonite and small amounts of a chlorite/smectite mixed layer. The presence of calcite is due to contamination with foraminifera and/or sediment. All samples are characterized by the lack of hydrothermal related minerals. We conclude that the alteration took place under seawater-dominated conditions at low temperature.

A comparison of ICP-MS and XRF analyses from altered whole rock samples and their attendant fresh glass chips provide a record of element flow during alteration. Off-axis basalts show a significant increase of Rb, Cs and Ba which are supplied by seawater and incorporated in or on secondary minerals. The enrichment of U is connected to the oxidative conditions. K₂O is also gained in all altered off-axis basalts, which is believed to be the result of the formation of celadonite.

V61B-1361 0830h POSTER

Hydrothermal Activity on the Southern Mid-Atlantic Ridge

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We present evidence for high-temperature hydrothermal venting along the southern Mid-Atlantic Ridge (MAR) 2-14S. The MAR south of the equator has been identified as a key target for hydrothermal exploration because the large-offset Romanche and Chain fracture zones may act as important barriers to biological communication along the ridge-axis (Van Dover et al., Science, 2002). During RRS James Clark Ross cruise JR65 (Sept-Oct. 2001) we occupied a series of 13 CTD hydrocast stations, one each at the centre of a series of 2nd-order ridge-segments, close to and away from the influence of the Ascension Island "hotspot". Post-cruise laboratory analyses have revealed TDMn anomalies of >2nmol/litre (background = 0.5 nmol/litre) at stations within each of four segments located between the Chain and Ascension Fracture Zones (away from the "hotspot") and in the two northernmost "hot-spot influenced" segments to the south, between the Ascension and Boca Verde Fracture Zones.

Strongest anomalies were observed in the segment closest to Ascension Island itself, where TDMn anomalies measured in bottle-samples coincided with optical back-scatter anomalies measured in situ using a SeaTech LSS light scattering sensor. A weaker TDMn anomaly was also observed adjacent to the Boca Verde Fracture Zone and coincident with a WOCE section which has previously reported evidence for primordial 3He release from the MAR-crest (Ruth et al., Deep Sea Res., 2000). Our survey covered a large section of ridge-crest, comparable to that investigated by Klinkhammer et al. (Nature, 1985) on the northern MAR. Multiple offset segments have been investigated and the data support the presence of multiple discrete hydrothermal sources. To-date, the best positional information we have for any one vent-site is in the segment immediately south of the Ascension Fracture Zone. Water depth in this segment is >3000m yet it is situated <100km from the port of Georgetown, Ascension. We believe this station to be close to a vent-site because this plume is particle laden as well as containing significant TDMn anomalies. Equivalent signals from the Broken Spur or SnakePit hydrothermal plumes (29N and 23N, MAR respectively) are only observed within 2-5km of those active vent-sites (German et al., Deep Sea Res. 1999).

V61B-1362 0830h POSTER

Geochemical and microbial export from the Rainbow vent-site, 36N Mid-Atlantic Ridge.

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We present results from a detailed investigation of the physical, chemical and microbial fluxes away from the Rainbow hydrothermal field 36N, Mid-Atlantic Ridge. Physical oceanographic studies (Thurnherr & Richards, JGR, 2001; Thurnherr et al. JPO, 2002) have used in situ CTD and optical back-scatter data, combined with lowered-ADCP measurements and long-term current meter records to investigate circulation through this section of the MAR rift-valley and to determine fluxes of plume particulate material away from the Rainbow vent-site. Using the continuous optical back-scatter data-set from a SeaTech LSS light scattering sensor mounted on our BRIDGET deep-tow vehicle and combining that data with analyses for (e.g.) TDMn and CH4 in discrete water-bottle samples collected during the BRIDGET tow-yos we can now construct integrated geochemical fluxes through the Rainbow hydrothermal plume.

From the integrated LSS-anomaly flux across the sill NE of the Rainbow vent-site we estimate total Mn and methane fluxes which approach 1 mol/second being discharged through the non-buoyant hydrothermal plume. The fluxes calculated by this approach require discharge of the well-characterised Rainbow end-member fluids (Douville et al., Chem Geol., 2002) at a rate of >400 Litres per second. In addition to dissolved chemical export fluxes, particulate Fe and associated trace metal fluxes can also be calculated. Further, the Rainbow plume is characterised by high microbial concentrations (3 x background) the majority of which are also particle-attached. Molecular microbial analyses of samples of these particle-attached microbes have revealed that the majority of clones produced through PCR are archaeal in nature (bacteria typically dominate in the open ocean). In particular, group II marine archaea (euryarchaeota) are especially abundant, notably methanogens, consistent with the high dissolved methane fluxes associated with the Rainbow hydrothermal plume.

V61B-1363 0830h POSTER

Geochemical Evidence for Seawater and Sediment Input in the Conical Seamount Hydrothermal System

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Conical Seamount is located on the flanks of Lihir Island, part of Tabar-Lihir-Tanga-Feni island chain in SW Pacific. Lihir Island is the host of the giant Ladolam epithermal gold deposit and polymetallic epithermal-style gold mineralization was discovered at the Conical Seamount in 1998 during the RV SONNE cruise "SO-133". The seamount is a submarine volcanic cone composed of trachybasalts to tephrites underlain by a thick (5 km) sedimentary layer composed of mudstone, limestone, and intermixed calcareous and volcanoclastic sediments. Sr isotopic compositions in altered and mineralized volcanic samples range from 0.7042 to 0.7086, distinctly more radiogenic than the fresh lavas (0.7038). The elevated 87Sr/86Sr ratios suggest mixing in the seamount's hydrothermal system between more radiogenic Sr, derived from either seawater or the thick layer of mainly calcareous sediments in the area and less radiogenic Sr derived from the host volcanics. Most of the hydrothermally altered samples show a decrease in Sr concentration with an increase in 87Sr/86Sr, similar to trends observed in seawater-driven MOR hydrothermal systems, thus suggesting that the hydrothermal fluid in the Conical Seamount system was modified seawater. Some of the altered samples however, show an increase in Sr with increased 87Sr/86Sr indicative of involvement of fluids with high Sr content. Circulating hot, acid hydrothermal fluid through the sediments beneath the seamount could easily acquire elevated Sr content due

to the mainly calcareous character of the sediments. Pb isotopic compositions of altered rocks that contain relatively low Pb concentrations are very similar to the host volcanics implying that Pb was not significantly disturbed during hydrothermal alteration. Seawater contains insignificant amounts of Pb and therefore will not significantly affect the Pb isotopic compositions of the altered and mineralized samples. However, mineralized samples containing 2-3% Pb have more radiogenic Pb isotopic compositions than the unaltered volcanics suggesting that part of the Pb was derived from a different source. Pb isotopic compositions of sedimentary xenoliths contained in some fresh lavas from nearby TUBAF Seamount have Pb isotopic values similar to the mineralized samples suggesting that part of the Pb and presumably other ore metals sharing similar geochemical behavior (e.g. Zn, Cu, Ag) were derived from the thick layer of sediments underlying Conical Seamount.

The polymetallic (Pb-Zn-Cu-As-Sb-Ag-Au) mineralization on Conical Seamount is distinct from the relatively simple Fe-Cu +/-Zn, Pb mineralization observed in seafloor hydrothermal systems, but is similar to the polymetallic mineralization discovered in Izu-Bonin Arc seamounts. However, the mineralization in the Izu-Bonin Arc is associated with felsic (andesitic to rhyolitic) volcanism. The Ladolam gold deposit on Lihir Island is associated with monzonite porphyry, also suggesting that polymetallic mineralization requires more evolved magmatic rocks. Sr and Pb isotopic data from Conical Seamount provide evidence that some of the ore metals in the hydrothermal system are derived from the sediments in the area. Our results suggest that the existence of submarine polymetallic mineralization requires an enriched source that can be either evolved magmatic rocks or sedimentary sequences.

V61B-1364 0830h POSTER

The Behaviour of Uranium in a Ridge Flank Setting

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The magnitude and locus of hydrothermal circulation remains one of the largest uncertainties in global geochemical budgets. In particular, a large and poorly constrained chemical flux may be associated with low temperature fluid flow through the mid-ocean ridge flanks. Uranium is potentially a valuable tracer of this low temperature hydrothermal exchange as removal of U during high temperature on-axis hydrothermal circulation is quantitative and appears to be virtually complete in warm spring fluids of 62-64°C.

The exchange of U across a young thinly sedimented ridge flank has been examined along a transect across the eastern flank of the East Pacific Rise at 14°S. Sediment cores were collected and pore fluids extracted during the EXCOII cruise from locations overlying oceanic crust with estimated ages of 0.3, 1.5 and 4.0 Ma. Upwelling of basement fluids was observed in some cores collected from each site. A number of these cores reached basement, providing a good measure of sediment thickness and allowing the composition of basement fluids to be inferred. The maximum ΔT in the EXCO study area was ~2°C, thus these samples represent very low temperature hydrothermal fluids.

Two distinct basement fluids were identified from pore fluid measurements. A reducing fluid with U concentrations indicating removal of ~60% seawater U, and a less altered fluid suggesting removal of ~10-20% seawater U. A large diagenetic signal, with significant release of U at ~150 cm depth, was observed in regions of no flow at the 0.3 Ma site. The systematic deviations of pore fluid U concentration from the background diagenetic profile have been used to estimate basement fluid upwelling velocities at this site in the range of a few mm to cm per year through the application of a simple advection-diffusion model.

Incorporating these new data into a simple fluid flow model based on geophysical and geochemical budget constraints suggests that the hydrothermal U sink is on the order of ~10 Mmol yr⁻¹. This estimate agrees reasonably well with the sink of 5.5±3.3 Mmol yr⁻¹ estimated from MORE alteration data and suggests that low-temperature crustal alteration is one of the major sinks of U from the ocean.

V61B-1365 0830h POSTER

Chemical Evolution of Hydrothermal Fluids From EPR 21°N: 23 Years Later in a Phase Separating World

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AdVenture 9 Science Party

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The first active black smoker vents were discovered on the East Pacific Rise at 21°N in 1979, and were most recently sampled in January 2002. In contrast to much of the data from 1979 vs 1981 vs 1985, distinct chemical changes are now observed in most of the vent fluids. At the NGS site, where two vents were sampled in 1979, but only one in 1981 and 1985, two extinct sulfide edifices were located at the same relative locations to the OBS vent as in 1979. Single high temperature vents were found and sampled at both the OBS and HG sites, as in the past. At the SW (or Clam Acres) site, an abundance of active black smokers were found and six were sampled, in contrast to the single chimney sampled in 1985 and five smokers in 1981. As no markers were deployed at the SW site in previous years, direct comparison of vent fluids at this site will remain slightly ambiguous. All of the vents sampled in 2002 had fluids containing less than seawater chloride contents. In the past, NGS had issued high chloride fluids, but these vents are now extinct. When earlier data sets were published, phase separation was not the accepted paradigm. One amazing observation is that only the vapor phase is now issuing at this site, providing yet another site with a mass balance problem for Cl (as at 9°N EPR). Visually, the sites are remarkably unchanged from previous pictures, so there is no evidence for new eruptive events. The Cl in the fluids from the HG site, which was low in 1981 when first sampled, has continued to increase but remains below the seawater concentration. In contrast, vent fluids from the OBS and SW sites appear to have decreased in Cl content since 1985, and the Si and H₂S have also decreased. Fe and Li concentrations have decreased in all of the vent fluids from this site compared to 1985. Measured temperatures ranged from 280-366°C, in some cases slightly higher than previously reported. Deployment of Hobo recording temperature probes for several days showed no temperature variations. The data will be discussed and interpreted in the context of phase separation, possible causes of temporal variation, and water-rock reaction.

V61B-1366 0830h POSTER

Evidence of Volcanism and Extensive Low-Temperature Off-Axis Hydrothermal Venting along the Cleft Segment of the Southern Juan de Fuca Ridge (JdFR)

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Systematic geological observations and off-axis sampling of the Cleft Segment of the southern JdFR made with the MBARI ROV Tiburon provide a unique perspective on the crustal evolution along this typical moderate spreading-rate ridge. The rift valley walls are comprised of a series of major bounding faults, separated by blocks of oceanic crust that exhibit little or no deformation. Unlike the present axis that is dominated by sheet and lobate flows, these blocks are almost entirely comprised of unfaulked, constructional pillow ridges, mounds and hornitos some of which formed along off-axis eruptive fissures and from point-sources that appear related to the formation of rift-bounding faults. Other volcanic constructs seem to be related to the formation of the first series of abyssal hills, consistent with "volcanic growth faults" draped with syntectonic lava flows. Observations with Tiburon combined

with high-resolution Simrad EM300 bathymetry suggests that the inflated flank topography that characterizes the Cleft Segment was created by extensive constructional volcanism that formed pillowed flow fronts tens to hundreds of meters high.

Approximately three kilometers east and west of the axis, a contact between the massive pillowed units and older sheet flows is clearly delineated both by increased sediment cover and by the change in lava flow morphology. Close to this contact on the east side of the ridge flank, a linear mound of altered and fractured sheet flows coated with flocculent precipitates was observed with curtains of shimmering fluid emanating from its porous interior. Several more ridges 6-8 m tall, discovered and sampled in 2002 extend over a few hundred meters and are actively venting low-temperature fluids. The venting at the "Flyer Field" is characterized by ubiquitous amorphous Fe-rich precipitates and by weakly diffuse fluid flow with temperatures 3-20 degrees C above ambient. Microbial mats are conspicuous and intermixed with green precipitates composed of amorphous Fe and Si with abundant bacterial filaments. In 2002 a second Fe-Mn mound was discovered 4 km off-axis on the west side of the spreading axis. Push cores reveal dramatic chemical gradients with a 4 cm red Fe-oxide crust over a dark green interior. Similar to the eastern ridges, the mound precipitates include abundant fragments of altered basalt.

Both sites of off-axis venting thus appear to be related to active ridge-parallel faults with fragmental basaltic debris embedded in hydrothermal precipitates. Some hydrothermal/pelagic crusts could be also related to late tectonic volcanism. We suggest such low-temperature venting is a common phenomenon of the faulted oceanic crust outside of the axial ridge and may represent important foci of biogeochemical exchanges. On going analyses of precipitates, fluids and low temperature vent microbiota will be used to identify possible microbial signatures associated with the extensive rock alteration, and their relationship to the fluid and particulate chemistry.

URL: <http://www.mbari.org/education/cruises/index.htm>

V61B-1367 0830h POSTER

$\delta^{37}\text{Cl}$ of Mid-Ocean Ridge Vent Fluids Determined by a new SIMS Method for Stable Chlorine Isotope Ratio Measurements

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A method has been developed for the direct determination of $\delta^{37}\text{Cl}$ in natural fluid samples or rock leachates (pyrohydrolysis products) using Secondary Ion Mass Spectrometry (SIMS). Samples as small as 1 μl (<2 μg Cl) are simply dried by evaporation and the residual salts are then admixed with 1 mg of graphite powder and pressed into a small (1mm diameter) pellet amenable to SIMS analysis. Analyses are performed with a large format high-transmission, high-resolution ion microprobe - the IMS 1270. Mass resolving powers of greater than 5000 are used to exclude isobaric interferences on ^{35}Cl and ^{37}Cl , producing an accurate and reproducible measurement of $\delta^{37}\text{Cl}$. Nine analyses of NIST Cl isotope standard 975a yield an external reproducibility of 0.5 ‰ (2 σ). Repeat analyses of samples are reproducible within 1 ‰.

First $\delta^{37}\text{Cl}$ data for mid-ocean ridge hydrothermal vent fluids from three sites at EPR 9°N and the Logatchev site (MAR 15°N) have been collected. End member $\delta^{37}\text{Cl}$ compositions for the EPR fluids are between +6.5 and +7.1 ‰, whereas that of the Logatchev fluid is +4.6 ‰. Together with pore waters from accretionary prisms, which are depleted in ^{37}Cl (-2.0 to -7.7 ‰; Ransom et al., Geology, 23, 715-718, 1995), seawater-derived fluids in the marine environment span range in $\delta^{37}\text{Cl}$ of 15 ‰. This variability is remarkably large when compared to >100 analyses of continental waters (formation and oil-field waters, fresh waters, brines, etc.) that cluster around 0 ‰ with a maximum variation of only 5 ‰.

Two observations suggest that the ^{37}Cl enriched nature of the vent fluids is not related to phase separation. (1) Laboratory experiments indicate that the $\Delta^{37}\text{Cl}$ (vapor-brine) associated with super-critical phase separation of seawater between 420 and 450°C is small (-0.6 to 0.2 ‰; Magenheim, PhD Thesis, UCSD, 1995). (2) Conjugate vapor-brine pairs of boiling sampled in 1991 and 1994 at F vent (Von Damm et al. EPFL, 149, 101-111, 1997) have basically identical $\delta^{37}\text{Cl}$ values indicating that phase separation (sub- or super-critical) does not significantly fractionate chlorine isotopes. We suggest, therefore, that the heavy Cl

isotope signature of the fluids is a result of seawater-rock interaction and/or mineral precipitation rather than phase separation of seawater. However, the specific mechanisms responsible for this enrichment are not yet understood. The Cl isotope signatures of hydrothermally altered gabbros and sheeted dike rocks ($\delta^{37}\text{Cl}$: 0.4-3.4 ‰) tend to be heavier than seawater and it has been suggested that this indicates preferential uptake of ^{37}Cl by amphibole (Magenheim et al., EPFL 131, 427-432, 1995). Amphibolitization can therefore not account for the development of the ^{37}Cl enrichment of the fluids. Although the exact mechanisms of Cl isotope fractionation are not yet defined, our data suggest that Cl may not be a strictly conservative component in MOR hydrothermal systems.

V61B-1368 0830h POSTER

Multiphase Fluid Equilibria between Supercritical Carbon Dioxide and Brine: Potential for Widespread Relevance in Geochemical Systems

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The potential significance of two fluid phases (excluding air and hydrocarbons) has been established for a limited number of geochemical processes. Of note are phase equilibria in metacarbonate rocks for low to moderate prograde metamorphism, flow and transport in metamorphic rocks, and fluid inclusions. However, the reactive properties of a supercritical carbon dioxide phase that may coexist at relatively low temperatures and pressures with brine has implications not evaluated or appreciated in the a broad range of geologic systems. Flexible cell hydrothermal experiments are being used to evaluate reactions with supercritical carbon dioxide and 5.5 molal NaCl brine during hydrothermal alteration of sandstone and shale. Experimental brine-aquifer-aquitarid systems approach steady state (32 to 59 days) before injection of carbon dioxide and continued reaction (45 to 80 days). Separate experiments without injection of carbon dioxide provide baseline reactions and kinetics.

Concentrations of Na in the brine decrease, and Si, Mg, Fe and Mn increase, following injection of carbon dioxide. Carbon dioxide concentration in the brine increases from 5 to about 270 millimole/Kg following injection to supersaturation at 200C and 200bars. Silicate minerals (quartz, oligoclase, microcline and biotite) display textures (etch pits, mineralization) indicating significant reaction. Pressure decrease (about 30 bars over 72 hours) following injection of carbon dioxide is indicative of a decrease in the volume of the system due to the phase change of supercritical carbon dioxide to dissolved carbonate, and finally to mineral carbonate. Development of approaches to calculate reaction paths, including phase equilibria of immiscible carbon dioxide and water allows exploration of reaction processes and insight into influence of two fluid phases on mineral equilibria. Using EQ3/6, brine chemistry of degassed samples at STP (pH 6.5) has been evaluated for carbon dioxide-saturated conditions at 200C (pH 3.5). Brine samples from experiments with low carbon dioxide concentrations do not exhibit such large pH swings between STP and in-situ conditions. Our results bear on the developing issues of sequestration of anthropogenic carbon dioxide and classic questions of the origin and distribution of carbonate cements and veins in sedimentary basin sandstones.

V61B-1369 0830h POSTER

The Systematics of Strontium and Chlorine Isotopes in Hot Springs and Mud Volcano Fluids in Taiwan Accretionary Wedge

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Taiwan is located at the plate boundary between the Philippine Sea Plate and the Asia Continental Plate and has an extensive distribution of hot springs and mud volcanoes. In this study, we have selected fluids from various geological settings and analyzed for major and trace chemical constituents, as well as Sr and Cl isotopes. The isotopic compositions of fluids were determined by a thermal ionization mass spectrometer (Triton TI) installed at NCKU. These chemical and isotopic results provide important information of fluid sources and hydro-geochemical processes in an accretionary wedge.

Chlorine isotopes are useful tracers for studying groundwater circulation and hydrothermal alteration at mid-ocean ridges. Our results show large Cl isotope variations, in a range of V8.5 to 6.9 permils. The mud volcano fluids display rather light isotopic compositions of V8 permils which is consistent with porewaters recovered at ODP Leg 131, Nankai trough, where the décollement was penetrated at 1000 mbsf. The observed light Cl isotopes, as well as O and C isotopes, suggest deep source origin of these fluids. Hot springs from various localities are enriched in heavy Cl isotope (up to 6.9 permils), possibly associated with volcanic degassing of HCl.

Strontium isotopes in hot springs and mud volcano fluids are sensitive to several factors, including Sr sources, water/rock interactions and ambient rock types. Close relationships between lithology and $^{87}\text{Sr}/^{86}\text{Sr}$ were observed in hot springs. Low $^{87}\text{Sr}/^{86}\text{Sr}$ (0.70511-0.70512) and low Sr contents (29-47ppb) are typical characteristics of springs in igneous region. Springs from metamorphic and sedimentary areas are high in Sr (69-447ppb) but the former appear to be more radiogenic (0.71359-0.71610). The $^{87}\text{Sr}/^{86}\text{Sr}$ vs. 1/Sr plot suggests possible mixing between the hot springs and meteoric waters. The Sr isotope compositions of mud volcano fluids fall in a small range between 0.71129 and 0.71175, suggesting intense interaction with clays at depth.

V61B-1370 0830h POSTER

Active and Fossil Geothermal Activity at Lake Chapala, Mexico

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Geothermal systems are very abundant in the tectonically active zones of the earths crust and the Citala rift, where Lake Chapala is located, is not the exception. The Lake Chapala basin is characterized by its paleo- and actual geothermal activity that includes: thermal springs, fossil sinter deposits and hydrothermal petroleum manifestations.

Thermal springs occur both inside and outside the lake. The spring water in out-shore thermal springs around Lake Chapala is carbonate (Medina-Heredia A, 1986). To the NE area is San Luis Agua Caliente (69°C; ~ 240mgL₋₁ [HCO3]₁) in the NW at Jocotepac (36°C; ~ 263mgL₋₁ [HCO3]₋); in the South we find Tuxcueca and Tizapn El Alto (30°C; 193 mg L₋₁ [HCO3]₋). However, there is an exception, the spring water at the San Juan Cosal sector (North), which is sulfate (64-83°C; ~ 479mgL₋₁, [SO4]₋₂). Examples of in-shore thermal springs are Los Gorgos (near South shore) and El Fuerte (near East shore and temporary "out-shore" because of actual severe drought); the characterisation of water of this in-shore sites is in progress.

On the SE shore and five km NW from Regules village, outcrops a carbonate deposit named La Calera. This carbonate fossil sinter outcrops 2 km in E-W direction and 600 m in N-S direction and overlies andesitic rock. With a thickness of approximately 5m and a roughly horizontal attitude, the carbonated sinter material is characterized by both massive and banded structure. When massive, it is colored in yellow brownish and grey and elsewhere it shows a pseudo-brecciated structure and when banded, alternated of yellow and dark millimetre bands can be seen; is characterized by vuggy porosity and silica (quartz and chalcedony) veinlets. Under microscope a pseudo-micritic texture is observed; vugs coated by iron oxides, are filled with calcite, and/or quartz, chalcedony and clay minerals. Six samples of carbonate of La Calera deposit were analysed for their stable isotopes (LODC-UParis VI). From $\delta^{13}\text{C}_{\text{PDB}}$ values we have two set of data: one near zero (-8.03 to -8.69 ‰) that means a no contribution of organic carbon and other with low values (-0.35 to -0.75 ‰) meaning an important contribution of organic carbon; from very low $\delta^{18}\text{O}_{\text{PDB}}$ values (-8.5 to -0.27 ‰) we deduced a precipitation in meteoric water with a temperature deposition higher than the surface that matches with an hydrothermal origin. Mineralogy was confirmed by XRD diffractometry.

Near the sub-lacustrine spring Los Gorgos there are some small land spots which look like islands (< 3 - 4 m²) made of solid bitumen and which are linked to the bottom of the lake. Because of these hydrocarbon manifestations the company Petróleos Mexicanos drilled (2,348 m deep), without success, an oil exploration well (Lpez-Ramos, 1979). The characterisation of this solid bitumen is in progress.

V61B-1371 0830h POSTER

Magmatic Chimney Beneath Telaga Bodas Revealed by Magnetotellurics Profiling: A Case Study at the Karaha Bodas Geothermal System, Indonesia

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Karaha-Telaga Bodas is a partially vapor-dominated geothermal system located on the flanks of Galunggung Volcano in Java, Indonesia. Fumaroles, hot springs and a shallow acid lake occur at the southern (Telaga Bodas) end of the geothermal area. Enrichments in chloride, fluoride, and sulfur in the lake water and the presence of tourmaline, fluorite, and native sulfur at depth are related to the flux of magmatic gases. Here, temperatures as high as 350 degree C are found at depths of about 2 km. A magnetotellurics profile crossing the Telaga Bodas area is used to test for presence of a magmatic chimney, which is believed to be the source of the magmatic components. The profile was modeled on a grid having 248x48 cells with 46 closely spaced stations aligned along NW-SE direction. The TM mode and vertical H-field data were rotated to strike of 10 degree east and inverted with a 2-D algorithm which damps model departures from an a-priori 1-D structure. The dataset consists of 25 periods running from 0.01024 to 1024 seconds yielding an RMS of 2.3. Five distinctive resistivity features are recognized: (1) resistive thin layer at the surface (about 1.5 km asl); (2) conductive layers sloping to the NW and SE; (3) a slightly resistive region in the center encapsulated by the conductive layers; (4) a vertical conductive structure inside the slightly resistive region; and (5) a resistive basement starting from 2 km below sea level. The sloping conductive layers (< 10 Ohm.m) are interpreted as representing clay-rich and/or weathered layers that exist for cap rock over the geothermal system whereas the slightly resistive region in the center corresponds to altered volcanic rocks and the underlying intrusives. The width of these volcanic rocks varies from about 2 km at their top to about 5 km at their base. The chimney is represented by a vertical conductive structure (< 10 ohm-m) inside this slightly resistive region. The size of the chimney is about 1 km wide and 2.5 km high. The low resistivities are interpreted as representing the presence of advanced argillic alteration assemblages formed by interactions between magmatic sulfur dioxide and the surrounding geothermal waters. The profile suggests that the gases migrate upwards through a vapor-dominated magmatic chimney overlying a cooling intrusion.

V61B-1372 0830h POSTER

Possible earthquake-generated wave deposits near Yellowstone Lake: Clues into triggering mechanisms of a large hydrothermal explosion crater

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Yellowstone National Park has experienced numerous hydrothermal explosions in the past and there is no reason to suggest that such activity will diminish in the future. Craters and associated breccia deposits created from hydrothermal explosions are mapped as Holocene units throughout the Park, primarily within the 0.64-Ma Yellowstone caldera. The largest hydrothermal explosion crater in Yellowstone, referred herein as the Mary Bay explosion crater complex, has a diameter of 2 km by 1 km and is nested in Mary Bay in the northern basin of Yellowstone Lake, an area where extremely high heat flow values are measured. Formation of hydrothermal features in Yellowstone is related to convective meteoric hydrothermal fluid circulation above a magma chamber. Hydrothermal explosions result from accumulation and release of steam generated during

hydrothermal fluid ascent, possibly reflecting changes in confining pressure that accompany and may accelerate failure and fragmentation of overlying lithologies. Sealing of surficial discharge conduits due to hydrothermal mineral precipitation contributes to overpressuring and catastrophic failure.

Exposed in wave-cut cliffs along Mary Bay north of Yellowstone Lake is a sedimentary sequence, which gives insight into the history of the Mary Bay hydrothermal explosion event. A sequence of lake sediments overlain by the Mary Bay hydrothermal explosion deposit is separated locally by an unusual dark, well sorted, cross-bedded, fine-grained sand layer. This unit is 1.5 to > 2 meters thick and contains numerous small en echelon faults. We conclude that this sand represents a deposit from an earthquake-generated tsunami-like wave, which in turn triggered the explosion of the Mary Bay crater complex. The potential of an event like this occurring today is currently under evaluation.

V61B-1373 0830h POSTER

Hydrothermal Vents in Yellowstone Lake: Chemical Fluxes, Siliceous Deposits, and Collapse Structures

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The geochemistry of Yellowstone Lake is strongly influenced by sublacustrine hydrothermal vent activity. The hydrothermal source fluid is identified using Cl and dD data on water column and sublacustrine hydrothermal vent fluid samples.

Silica-rich hydrothermal deposits occur on the lake bottom near active and presently inactive hydrothermal vents. Pipe- and flange-like deposits contain cemented and recrystallized diatoms and represent pathways for hydrothermal fluid migration. Another major type of hydrothermal deposit comprises hard, porous siliceous spires up to 7 m tall that occur in 15 m of water in Bridge Bay. Bridge Bay spires are hydrothermal silica deposits formed in place by growth of chimney-like features from lake-bottom hydrothermal vents.

The Cl concentrations indicate that Yellowstone Lake water is about 1 percent hydrothermal source fluid and 99 percent inflowing stream water and that the flux is about 10 percent of the total hydrothermal water flux in Yellowstone National Park. With recent swath-sonar mapping studies that show numerous new hydrothermal features, Yellowstone Lake should now be considered one of the most significant hydrothermal basins in the Park. Many lake-bottom hydrothermal vents occur in small depressions that are clearly imaged on multi-beam sonar, some of which are interpreted as collapse structures based on seismic reflection data. Sediments collected from such vents show chemical evidence of leaching of 60-70 wt. percent SiO₂, which may result in volume reductions up to 80 percent and provides a mechanism for vent structure formation.

V61B-1374 0830h POSTER

Equilibrium Distribution of Common Geologic Fluids in Anhydrite Aggregates

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Anhydrite rocks are commonly associated with salt domes where they are believed to form an impermeable caprock that arrests or traps migrating hydrocarbons. In addition, salt domes have been proposed as potential repositories for nuclear and toxic chemical wastes. In both settings, the most important consideration is the relative mobility of common geologic fluids within and through the anhydrite rocks.

The relative mobility of fluids in unfractured rock is directly related to the equilibrium distribution of the fluid, as predicted by the solid-fluid dihedral angle (Θ). In this study, anhydrite-fluid dihedral angles were measured for a series of anhydrite aggregate samples experimentally equilibrated with common geologic fluids. The starting material was a natural anhydrite aggregate (Wandflue) that was pre-annealed at

500°C and 100 MPa for 7 days to ensure an equilibrium texture and to remove unwanted volatile components (especially H₂S). The samples were then loaded with ~5 wt% of either water, 6M NaCl brine, or CO₂ (as silver oxalate powder) and run at 300°C to 600°C and 100 MPa for 1 day (brine, 600°C) to 2 weeks (CO₂). The anhydrite-fluid dihedral angles were measured from SEM images using NIH Image software and standard protocols.

The preliminary results indicate that in anhydrite aggregates under the conditions of our experiments, CO₂ fluids are unlikely to be interconnected ($\Theta > 60^\circ$), pure water may show some degree of interconnectedness ($\Theta \sim 60^\circ$), and brines are likely to be interconnected along three-grain channels ($\Theta < 60^\circ$), especially at lower temperature (300°C to 400°C). Additional experiments using mixed water-CO₂ and brine-CO₂ fluids are underway. However, the results to date clearly raise important questions as to the suitability of anhydrite rocks for retention of waste materials in a salt dome environment.

V61C MCC: 122 Saturday 0830h

Applications of Synchrotron Radiation in Low-Temperature Geochemistry and Environmental Science II (joint with H)

Presiding: P Fenter, Argonne National Laboratory; M Rivers, University of Chicago; N Sturchio, University of Illinois, Chicago; S Sutton, University of Chicago

V61C-01 0830h INVITED

Quantitative analyses of pore-scale multi-phase flow processes: An application of synchrotron-based micro-imaging in the environmental sciences

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Our current understanding of groundwater flow and contaminant transport in the subsurface is, to a large degree, limited by existing measurement techniques. To correctly describe transport of contaminant species, it is essential to understand the interplay of advection, mechanical dispersion, and diffusion and their dependency on soil water distribution, degree of saturation, as well as gas-liquid phase contact characteristics. However, these pore-scale mechanisms cannot be measured with traditional experimental techniques. X-ray computerized microtomography provides non-invasive pore-scale observation of variables such as changing fluid phase content and distribution, as well as interfacial area and curvatures. We present results obtained at the microtomography facility at GSECARS (sector 13) at the Advanced Photon Source, Argonne National Laboratory. Samples of 6-7 mm diameter sand or glass bead packs were scanned at different stages of drainage and imbibition and with varying boundary conditions. We observed significant differences in fluid saturation and phase distribution for different boundary conditions, clearly showing preferential flow and a dependence on the applied flow rate. Individual pores, water/air interfaces and their curvatures as a function of pore-water pressure were resolved and the interfacial areas quantified using image analysis techniques. We plan to use this detailed information to verify existing pore-scale numerical models and to aid development of new modeling approaches dealing with contaminant flow and transport in the subsurface.