

## Energy for chemoautotrophs in mid-ocean ridge flanks

W. BACH

Department of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution, 360 Woods Hole Road, Woods Hole, MA 02543, USA, wbach@whoi.edu

The alteration chemistry of basalts from the upper ocean crust provides a means of estimating the potential for chemoautotrophic primary production in ridge flank hydrothermal systems.  $\text{Fe}_2\text{O}_3$ ,  $\text{FeO}$ , and S concentrations of DSDP/ODP drill core samples from upper basaltic ocean crust suggest that oxidation is rapid in young crust. A trend of  $\text{Fe}^{3+}/\Sigma\text{Fe}$  increasing from around 0.18 to 0.40 within the first 10 Myrs of crustal evolution can be discerned.  $\text{Fe}^{3+}/\Sigma\text{Fe}$  remains fairly constant in crust that is older than 10 Myrs. This relationship implies that oxidation proceeds for 10 Myrs at a rate of  $2.2 \times 10^{-8} \text{ yr}^{-1}$ . If the depth extent of oxidative alteration is 500 m,  $4.8 \times 10^{15} \text{ g}$  of fresh basalt with an average of 10.4 wt.%  $\text{FeO}^{\text{total}}$  is exposed to oxidative alteration per year. At steady state,  $1.1 \times 10^{14} \text{ g FeO}$  ( $1.5 \times 10^{12} \text{ mol FeO}$ ) are oxidized per year. A similar estimate based on sulfur contents of drill core suggests a sulfur loss of 60% and a sulfur oxidation rate of  $1.2 \times 10^{11} \text{ mol S/yr}$ . The potential for hydrogen-based subsurface microbial ecosystems in ridge flanks has also been explored. If it is assumed that oxidation of iron and sulfide through consumption of dissolved oxygen proceed at the same rate, 40% of the ferrous iron oxidation may be attributed to hydrogen reduction. This would produce  $3 \times 10^{11} \text{ mol H}_2/\text{yr}$ . Heat flow measurements indicate that on the order of  $5 \times 10^{15} \text{ kg}$  of seawater circulate annually through young ridge flanks. Hence, the average  $\text{H}_2$  concentrations of ridge flank fluids is  $\sim 60 \mu\text{mol/kg}$  -- more than three orders of magnitude higher than in basalt-hosted continental groundwater systems that are believed to harbor hydrogen-based autotrophic primary production. This analysis suggests that hydrogen-based microbial ecosystems may be found in ridge flanks.

Free energy calculations indicate that sulfate reducers might be expected where sulfate is high, but significant sulfate removal may favor methanogens that appear to dominate in continental basalt-groundwater systems. Estimates of primary biomass production by chemoautotrophs indicate that on the order of  $10^{12} \text{ g}$  biomass dry weight may be produced by iron and sulfide oxidation. The biomass that may be produced by hydrogen-based microbial ecosystems in mid-ocean ridge flanks is probably one order of magnitude smaller. Biomass production within the basaltic crust may be similar to that fueled by anaerobic sulfate reduction in deep-seated heterotrophic systems. Because a larger biomass may be supported by oxygen-consuming reactions than by hydrogen consumption, microbial abundances may be greater in young ridge flanks (<10 Ma) or generally in areas of seawater recharge.

## Anatomy of a dacite-hosted submarine hydrothermal system – results from drilling at PACMANUS

W. BACH<sup>1</sup>, F. BARRIGA<sup>2</sup>, R. BINNS<sup>3</sup>, S. ROBERTS<sup>4</sup>, S. SCOTT<sup>5</sup>, D. VANKO<sup>6</sup>, C. YEATS<sup>3</sup>, LEG 193 SHIPBOARD SCIENCE PARTY

<sup>1</sup>Woods Hole Oceanographic Institution, Woods Hole MA02543, USA (wbach@whoi.edu)

<sup>2</sup>Dept of Geology, Universidade de Lisboa, Lisboa 1749-016, Portugal

<sup>3</sup>CSIRO Exploration and Mining, POBox 136, North Ryde, NSW 1670, Australia

<sup>4</sup>Southampton Oceanography Centre, University of Southampton, Southampton SO14 3ZH, UK

<sup>5</sup>Dept of Geology, University of Toronto, Toronto, 22 Russell St., ON M5S 3B1, Canada

<sup>6</sup>Dept. of Physics, Astronomy & Geosciences, Towson University, 8000 York Rd., Towson, MD 21252, USA

Ocean Drilling Program (ODP) Leg 193 successfully drilled four deep holes (126 to 386 m) into basement underlying the active dacite-hosted PACMANUS hydrothermal field in the eastern Manus Basin, north of Papua New Guinea. The PACMANUS basement consists of pervasively altered vesicular lava flows, autoclastic breccias, and rare volcanoclastic sediments; massive sulfides are not abundant. Inter-borehole differences in the depths of cristobalite-quartz transition and zones of prevailing alteration styles suggest strong lateral heterogeneity in basement alteration at PACMANUS. Anhydrite is abundant in the seafloor at PACMANUS, filling veins and vesicles, cementing breccias at upper levels, and, occasionally, replacing altered igneous rock. Contrasting styles of acid-sulfate and argillaceous alteration in the PACMANUS basement suggest that fluid pH was highly variable. Fluid inclusions indicate that fluids of highly variable salinities were trapped in different episodes. Variable oxide-sulfide assemblages furthermore suggest that oxygen fugacity was fluctuating. Oxygen fugacities may vary as a consequence of the chemical evolution of the fluid-rock system to more oxidizing conditions or may reflect episodic influx of oxidizing seawater or magmatic  $\text{SO}_2$ . A magmatic fluid component that is rich in  $\text{SO}_2$  and HF may also account for the development of acid-sulfate alteration. The variable alteration styles might then simply reflect the transient nature of episodic influx of magmatic volatiles. REE data from anhydrite veins also suggest that input of magmatic fluoride and sulfate as complexing agents might have played a role. Furthermore, high HF activities can be inferred from the presence of fluoroapatite in some anhydrite veins. Finally,  $\delta^{34}\text{S}$  values of anhydrite can be as low as 18.4‰ ( $\delta^{34}\text{S}$  of seawater is 21‰), which is likely due to influx of magmatic  $\text{SO}_2$ . On the other hand, pervasive chloritic alteration and Sr isotopes of anhydrite indicate a proportionately large flux of seawater.