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High Temperature Mid-ocean Ridge Hydrothermal Flux Estimates from Sr-transport Modeling of Fluid-rock Exchange in Hole 504b

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Hydrothermal exchange between seawater and the oceanic basement has profound influences on the composition of the oceans, the thermal and tectonic structure of the ocean crust and through subduction the heterogeneity of the mantle. Estimates of thermal, fluid and chemical fluxes vary by at least an order of magnitude, with the greatest error being the relative influence of high temperature axial systems versus the low temperature exchange on the ridge flanks. Flux estimates based on discharge fluid chemistry are compromised by the uncertainties arising from the possible range in vent temperatures, the intermittent nature of the spectacular near-critical point black smoker systems observed at the ridge crests and the significance of the chemical transport by low temperature fluid circulation off-axis. The alteration state of oceanic crust in the diffuse recharge zones provides an integrated record of the fluid flow history and here we report estimates of the time-integrated recharge flux based on $^{87}Sr/^{86}Sr$ profiles and sulphate contents. Hole 504B, in 6 Ma-old crust in the eastern equatorial Pacific is the only penetration of oceanic basement to sample a complete section of extrusive lavas, the lava-dike transition zone and ~1 km of sheeted dikes. Importantly, it is the only Hole to recover anhydrite - a critical phase in oceanic hydrothermal systems due to its retrograde solubility, and the abundance of sulfate in seawater. Anhydrite is present throughout the Hole 504B core, from mid-levels in the pillow lavas to the lowermost dikes. Analyses of anhydrite from Hole 504B provide unique constraints on the chemical and isotopic evolution of fluids during hydrothermal recharge [1]. Sr-isotopic measurements show little departure from seawater values in the lava sequences but change rapidly with depth in the upper-sheeted dikes such that the composition of anhydrite in the lower dikes is indistinguishable from basement fluids responsible for the precipitation of amphibole and epidote. The anhydrite profile, is mimicked by the $^{87}Sr/^{86}Sr$ ratios of whole rock samples which show only minor exchange throughout the pillow lavas, reflecting the replacement of glass and mesostasis by clay minerals, but greater exchange with fluids in the uppermost sheeted dikes. This increase in exchange coincides with a significant step in the geothermal gradient in Hole 504B as well as the increased replacement of igneous plagioclase by albite. Anhydrite compositions in the lavas provide little information on fluid fluxes but the rapid change in recharge fluid (anhydrite) $^{87}Sr/^{86}Sr$ ratio with depth within the sheeted dikes can be modeled using simple tracer transport theory [2] to estimate time integrated fluid fluxes. Using appropriate fluid and rock Sr contents and a linear kinetic exchange model, these mass balance calculations suggest that the Sr exchange recorded by the whole rock and anhydrite compositions can be accounted for by a fluid flux of $\sim 1.7 \pm 0.2 \times 10^6$ kg/m^2. This fluid flux is a factor of 3 to 20 smaller than estimates from thermal or chemical budget calculations ($\sim$5-35 x 10^6 kg/m^2; [1, 3, 4]), but reconciles a number of key observations regarding the thermal structure of young ocean crust. These larger fluid volumes result in strong cooling of the lavas and dikes to near seawater temperatures and elevated temperatures will occur in only a narrow thermal boundary layer directly above the heat source [5]. However, oxygen isotope analyses and the alteration assemblages recorded by the sheeted dikes of Hole 504B suggest that the sheeted dikes have never been to low temperatures (<100 ºC), and thermal models are required that keep this portion of the crust at moderate temperatures (200-350 ºC). Estimates of the amount of seawater-derived sulfur now present in the Hole 504B crust as both anhydrite and secondary sulfide require a seawater flux of similar size to that suggested by the transport modeling ($\sim$1.4 x 10^6 kg/m^2; [1]). If this estimate of fluid flux from Hole 504B is correct, this suggests that global high temperature hydrothermal fluxes are significantly lower than previous estimates requiring oceanic chemical budgets to be adjusted to reflect the lesser influence of these systems. Alternatively Hole 504B may not be representative of the average oceanic crust or there may be significant channeling of hydrothermal recharge. However, until further drilling of *in situ* oceanic crust is attempted, Hole 504B will remain a solitary reference section for the uppermost ocean basement.

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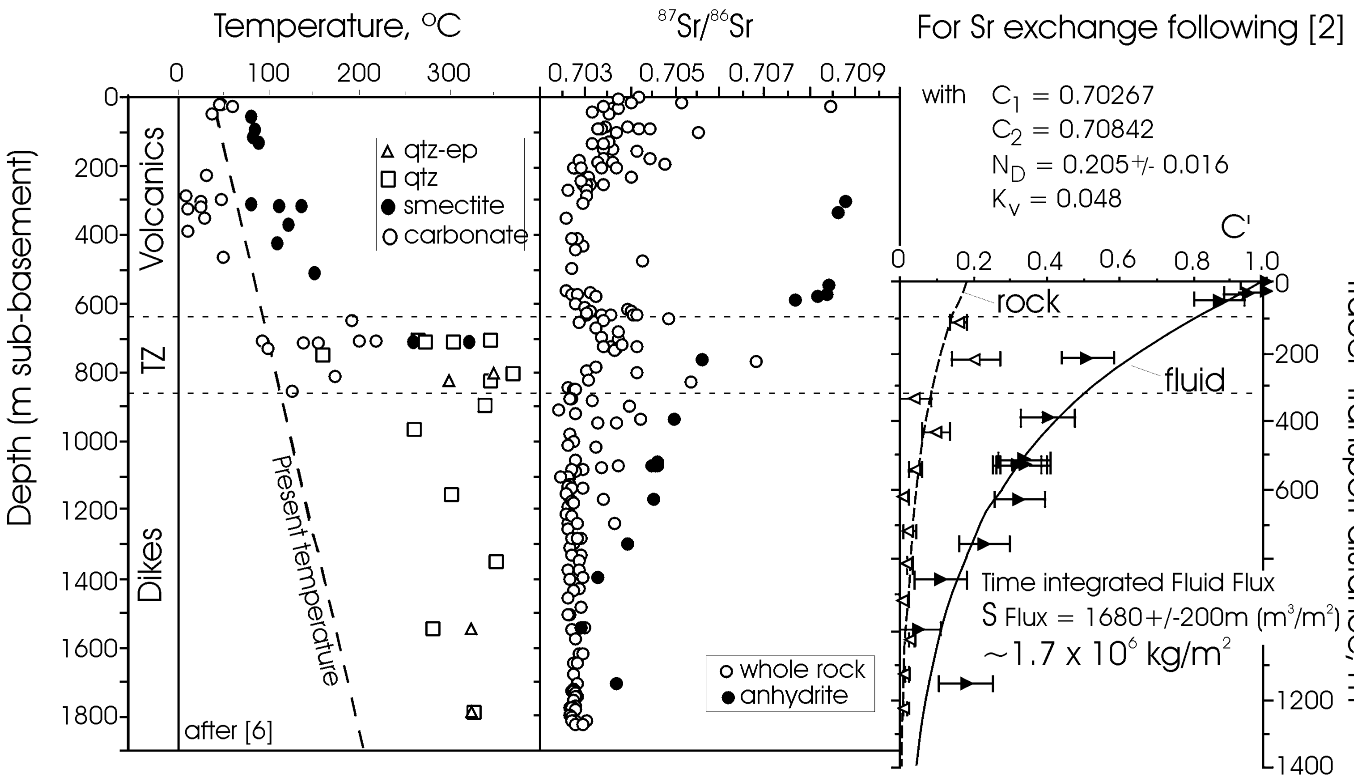

Figure 1: Temperature [6] and Sr-isotopic [1] variation with depth in Hole 504B compared to tracer exchange model following [2].

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