



Strontium isotope constraints on fluid flow in the upper oceanic crust at the East Pacific Rise

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Abstract

Strontium isotopes are useful tracers of fluid–rock interaction in marine hydrothermal systems and provide a potential way to quantify the amount of seawater that passes through these systems. We have determined the whole-rock Sr-isotopic compositions of a section of upper oceanic crust that formed at the fast-spreading East Pacific Rise, now exposed at Hess Deep. This dataset provides the first detailed comparison for the much-studied Ocean Drilling Program (ODP) drill core from Site 504B. Whole-rock and mineral Sr concentrations indicate that Sr-exchange between hydrothermal fluids and the oceanic crust is complex, being dependent on the mineralogical reactions occurring; in particular, epidote formation takes up Sr from the fluid increasing the $^{87}\text{Sr}/^{86}\text{Sr}$ of the bulk-rock. Calculating the fluid-flux required to shift the Sr-isotopic composition of the Hess Deep sheeted-dike complex, using the approach of Bickle and Teagle [1] [M.J. Bickle, D.A.H. Teagle, Strontium alteration in the Troodos ophiolite: implications for fluid fluxes and geochemical transport in mid-ocean ridge hydrothermal systems. *Earth Planet. Sci. Lett.* 113 (1992) 219–237] gives a fluid-flux similar to that determined for ODP Hole 504B. This suggests that the level of isotopic exchange observed in these two regions is probably typical for modern oceanic crust. Unfortunately, uncertainties in the modeling approach do not allow us to determine a fluid-flux that is directly comparable to fluxes calculated by other methods.

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1. Introduction

One of the largest chemical cycles in the Earth throughout most of geological time involves the creation, alteration and recycling of the oceanic crust. This cycle brings mantle components into the ocean crust and exosphere at mid-ocean ridges (MORs), and

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seawater components into the mantle through subduction. Coupled fluid flow and chemical exchange, operative throughout the life cycle of an ocean plate, acts to cool the oceanic lithosphere and modulate the chemistry of the crust and oceans. Contrasting thermal structures at MORs and in ridge flanks result in distinctive fluid and chemical fluxes and alteration patterns [2–4]. Although a significantly larger volume of seawater passes through the crust in the flank environment, axial chemical fluxes are comparable to those in the flanks due to significantly higher temperature fluid–rock interactions (~ 350 °C at MORs, <25 °C in flanks) [3].

Vent fluid chemistry, in combination with physical measurements of fluid flow rate and/or heat flow, yield an instantaneous, point source determination of axial chemical fluxes integrated along the entire reaction pathway. Hydrothermally altered rocks provide a time-integrated view of chemical flux, with explicit information about the controlling reactions in specific parts of the reaction pathway (see [5] for review). The link between chemical and fluid fluxes can be directly examined in active systems, although with significant uncertainties [4]. It is more challenging to make this link for ancient systems as only chemical fluxes derived from altered rocks are available and we have no direct view of the subsurface until tectonic activity serendipitously exposes ocean crust at the seafloor or on land, or crust is recovered by deep drilling. If the fluid flow pathways and fluid–rock reaction mechanisms are known, then the magnitude of chemical fluxes can theoretically be translated into fluid and heat fluxes by modeling geochemical tracers that are sensitive to the magnitude of hydrothermal exchange, such as Sr- and O-isotopes (e.g., [1,6,7]) and Mg [8].

To fully understand mid-ocean ridge hydrothermal systems, it is necessary to integrate knowledge gained from the instantaneous views of hot smoker chemistry, axial heat flow measurements and geophysical images of the subsurface with the record of fluid–rock interactions preserved in crustal sections. Where and to what degree heat and chemical exchange occurs must be known in order to accurately model the cooling rate of the lower crust and hence crustal accretion models (e.g., [9,10]), rheological behaviour of the lithosphere (e.g., [11,12]) and global scale geochemical fluxes (e.g., [13]).

In this contribution, we present whole-rock Sr-isotopic and Sr data for an upper crustal section that formed at the fast-spreading East Pacific Rise (EPR) [14]. Exposures at Hess Deep provide our most detailed view of the spatial variability of hydrothermal alteration in modern ocean crust [15–17] and provide an essential comparison to, and extension of, studies of the only other well characterized upper crustal section, Ocean Drilling Program (ODP) Hole 504B. We focus on the sheeted dike complex because the most significant chemical exchange is thought to occur within this portion of the axial hydrothermal system. We demonstrate that the extent of isotopic exchange and time-integrated fluid fluxes were similar to that at Hole 504B. In order to evaluate the accuracy of flux calculations, we then examine the mineralogical controls on Sr-exchange and Sr-mobility. We conclude that the models commonly used to determine fluid flux are useful for general comparisons between locations, but that there is considerable uncertainty in the accuracy of the calculated fluxes. Hence, we caution against comparisons of fluxes derived from Sr-isotopic data with those derived from independent constraints such as heat fluxes.

2. Geological background

Hess Deep is the deepest part of a rift valley that formed by the propagation of the Cocos-Nazca spreading center into the eastern side of the Galapagos microplate, rifting young (0.5–1.2 Ma) crust that formed at the fast spreading (130 mm/yr) EPR [18]. The focus of this paper is a 4-km wide area along the northern scarp of the Hess Deep rift valley where crustal sections that formed at the East Pacific Rise are well exposed (see Fig. 1 [17] for map). The volcanic sequence, sheeted dike complex and uppermost gabbros, which record $\sim 60,000$ yr of spreading history, were mapped and sampled during two *Alvin* dive programs (P. Lonsdale, unpubl. data, 1992, [14,19]). Previous study of the sheeted dike complex has documented the spatial distribution of key alteration features, including the extent of replacement of primary phases, hydrothermal mineral assemblages and whole-rock O-isotopic compositions [16,17]. These data show that hydrothermal alteration patterns are spatially complex and are not solely related to depth.

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