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$^{87}Sr/^{86}Sr$ and $^{18}O/^{16}O$ ratios of clays from a hydrothermal area near the Galapagos rift as records of origin, crystallization temperature and fluid composition

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ABSTRACT

Strontium and O isotope compositions of green clay minerals from sediment cores of three boreholes drilled into (sites 424A and 509B) and close to a hydrothermal mound (site 424B) near the Galapagos Spreading Center (DSDP Legs 54 and 70) were determined. The green clays consist mostly of a transition from Fe-smectite (nontronite) to glauconite.

$^{87}Sr/^{86}Sr$ ratios were measured on clay size-fractions after gentle acid leaching and on the recovered leachates from different samples. The $^{87}Sr/^{86}Sr$ ratios of the clay residues from both the 424A and B sites are well below the modern seawater value, which points consistently to precipitation from hydrothermal fluids that contained variable amounts of seawater, even away from mound. However, most of the clay residues from mound site 509B have $^{87}Sr/^{86}Sr$ ratios significantly above the seawater value, suggesting the occurrence of a detrital component together with the new authigenic particles. The clay minerals of the hydrothermal mound are mixed with detrital components, and that of the sample taken outside but near the mound as a reference for the surrounding oceanic environment, yields a hydrothermal signature.

Crystallization temperatures of the clays range from 32 to 63 °C assuming a $\delta^{18}O$ value of +2.2‰ for the mineralizing fluids. Hydrothermal fluids generated in the underlying oceanic crust, mixed in varied proportions with ambient seawater and migrated into beds of the mound in a sequence of recurrent processes that ultimately resulted in the formation of the observed clay minerals. No significant temperature differences were detected for crystallization of the K-rich glauconite and K-depleted nontronite. The $^{87}Sr/^{86}Sr$ ratios of the Sr leached off the clay particles are near the value of modern seawater, inferring a progressive replacement of the hydrothermal fluids by seawater in the pore space of the mound sediments.

1. Introduction

Contribution of hydrothermal fluids from ocean ridges to the chemical budget of the world ocean was first postulated by Skornyakova (1964) on the basis of abnormally high elemental concentrations in sediments from the flank of the East Pacific Rise. Elderfield and Gieskes (1982) also suggested that advective fluxes of hydrothermal fluids out of sediments from an off-axis location had a significant impact on the chemical budget of seawater, especially for Sr. In order to balance combined chemical supplies from ocean ridges and continental rivers, Palmer and Edmond (1989) used higher on-axis fluxes than suggested before to account for Sr in the ocean budget. Alternatively, Hess et al. (1991) postulated that evidence for advective hydrothermal fluids was very tenuous, especially at the Galapagos Spreading Center (GSC). Subsequently, Wheat et al. (1997), Mottl et al. (1998), Elderfield et al. (1999), and Butterfield et al. (2001) questioned the assumption that interstitial brines were representative of hydrothermal fluids reacting with basalts at elevated temperature. Knowing how fluids evolve at and near a ridge-axis recharge zone remains a basic question in the global interpretation of the surface and subsurface evolution of spreading centers at and near ridge axes.

The GSC being one of the most studied ocean-rift zones in the world, it appeared as an appropriate object to complement with an isotopic study what is known of the green clays from the mounds discovered next to the spreading center by observations from a submersible (Lonsdale, 1977; Corliss et al., 1978; Williams et al., 1979). These mounds were sampled by drilling during DSDP Leg 54 (e.g., Donnelly, 1980; Dymond et al., 1980), revisited 2 years later and drilled again during DSDP Leg 70. They supposedly represent visible features of the local hydrothermal activity, consisting of green, clay-rich units sandwiched between pelagic siliceous globigerina oozes that are all capped by Fe–Mn oxy-hydroxide crusts (Honnorez et al., 1983). About 20–30 m high above the surrounding seafloor, the mounds are located in larger areas of high heat flow (8–10 HFU), often

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on top of vertical faults in the basaltic basement (Williams et al., 1974). The texture of the green clays in the mounds resulted from replacement of previously existing sediment and open space filling (Schrader et al., 1980).

Clays from greenish layers of these mounds consist of nontronite and celadonite/glauconite (Hoffert et al., 1980; Honnorez et al., 1981a, 1981b; Varentsov et al., 1983). A mineralogical and crystallographic study of those from the mound drilled during DSDP Leg 70 allowed Buatier et al. (1989) to distinguish curled veil-like Fe-smectite from rigid lath-like glauconite particles, on the basis of particle morphology, K content and layer stacking mode. High-resolution transmission electron microscopic observations did not show lattice fringes between veil-like Fe-smectite and lath-like glauconite, so that the chemical transition from former to latter was considered to only proceed by a dissolution/precipitation.

To enhance our knowledge of clay crystallization in various marine environments, we geared an isotopic approach used previously for reconstruction of the genesis of authigenic glauconite from smectite off the African west coast (Stille and Clauer, 1994) to identify the crystallization conditions of the same types of clay minerals during the discharge of hydrothermal fluids into sediments. The challenge was the combined application of the Sr and O isotope tracers to GSC clays that crystallized from fluids expected to vary in composition and temperature. Sr isotope chemistry was used to track indirectly specific aspects of the chemical composition of the fluids interacting with the clay particles, and O isotope analysis to estimate the crystallization temperatures of the authigenic clays.

2. Geologic setting and sampling

DSDP Leg 70 was designed to extend the sample and data acquisition obtained 2 years earlier during DSDP Leg 54 in a region characterized by hydrothermal mounds that were discovered during observation of local ocean-spreading activity (Honnorez et al., 1983). The relatively high temperatures of 12–20 °C measured in the sediment cover of the ridge suggested that the green clays precipitated from mixtures of seawater and hydrothermal fluids (Corliss et al., 1978). The drill-holes were located on the southern flank of the GSC (~1° N, 86° W), about 22 km from main spreading center (Fig. 1). On the basis of magnetic determinations, the age of basement rocks in the area was estimated to be about 0.60 to 0.63 Ma using a half-spreading rate of 35 cm/year (Klitgord and Mudie, 1974), while measurements of U isotope disequilibria provided significantly younger ages of 90,000 to 300,000 years for clay minerals from mounds (Lalou et al., 1983).

The sediment cover of the drilled mound consisted of two facies: a lower unit of pelagic oozes (from top of the basaltic basement at 33.4 m to 16 m below sea floor in Hole 509B) and an upper unit containing greenish clay layers interbedded with pelagic oozes (from 16 to 3 m deep in Hole 509B). Fragments of Mn-oxide were found in the uppermost 4.3 m of the core. Calcite was dominant in the pelagic oozes, as expected, whereas Mn-oxide crusts that cap the sediment sequence were mainly todorokite (e.g., Honnorez et al., 1981a, 1981b, 1983). The green, clay-rich layers consisted of irregular and friable grains mainly containing nontronite, also called Fe-smectite in the present study (e.g., Hoffert et al., 1980; Schrader and Stow, 1983). Pore waters from GSC sediments were enriched in Ca and depleted in Mg due to mixing with hydrothermal fluids that ascended through the pelagic oozes before precipitating the green minerals (Bender, 1983).

Sediment samples that were previously studied for their mineralogical and chemical characteristics as well as for the morphologic shapes of the clay material by Buatier et al. (1989) were selected from three drill holes: Hole 509B completed in 1979 and penetrating 33.4 m of sediment before encountering the basement, and nearby Holes 424A and 424B that were completed in 1977 into 34.0 and 46.5 m of sediments, respectively. Holes 424A and 509B targeted the same hydrothermal mound, whereas Hole 424B was drilled off the mound specifically for recovery of sediment unaffected by visible hydrothermal activity. To comply with strict constraints on sample requests, eleven small samples from green clay units of Holes 509B, 424A and 424B were analyzed. They are reported in Table 1 with

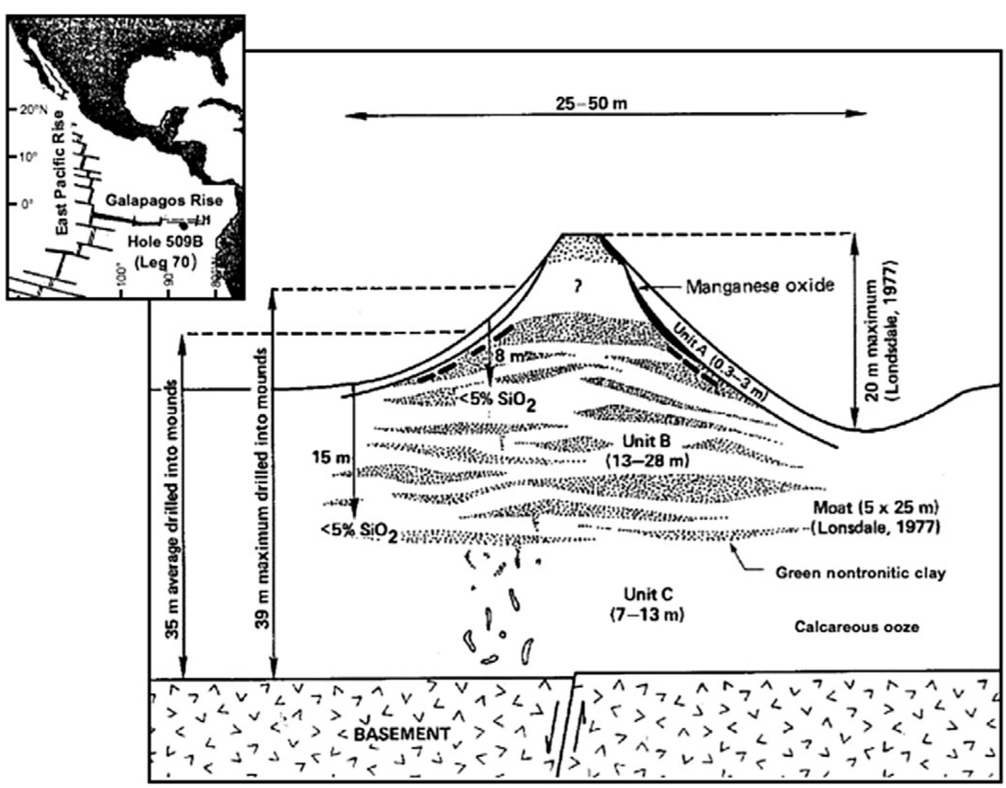

Fig. 1. Sketch of a hydrothermal mound in the Galapagos area with a general map of the southern Pacific and the location of the drill holes south off the Galapagos Spreading Center.