Sr, Pb isotopes and *REE* analyses of five cores of the Red Sea: An insight into hydrothermal input

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The formation of the Red Sea was initiated by the separation of the Arabian and Nubian plates and is generally considered to be an embryonic ocean which offers the opportunities to study the transition from a continental to an oceanic rift. Between 16 and 20°N, the oceanic crust is continuous, further to the North the axial trough becomes discontinuous and only some isolated deeps contain metalliferous sediments. Hydrothermal fluids flow and could react with the important Miocene evaporite deposits, the recent sediment deposits and the young oceanic crust. The resulting fluids overflow in the deeps and allow the formation of hot, salty, concentrated and reducing brine pools. Sr, Pb isotopic compositions and *REE* patterns have been determined on sediments and interstitial waters from five cores of the Red Sea sampled during the RedSed cruise in september 1992. Four of these cores were retrived from four deeps located on the axial graben (Atlantis II, Thetis, Port-Soudan and Suakin), and one at 10 km from the axial trough. This study yields new constraints on the contribution of the different end-members (biogenic, detritic, basaltic and evaporitic), on the formation of the metalliferous sediments, and on the impact and magnitude of hydrothermalism in these various deeps.

The strontium isotopic results of sediment interstitial waters show values similar to those deep water of each site. They are equilibrated with the present brines or with the overlying water for the deep without brines. This argues for water circulation towards the sedimentary column. These waters do not give the Sr isotopic signature corresponding to that present at the time of the deposit. The results obtained on the salt-free sediments trace various sources. Atlantis II deep contains the most metalliferous muds with individualization of sulphide and oxide layers. The sediments of Atlantis II deep present the lowest Sr isotopic composition ($0.70702 < {}^{87}Sr/{}^{86}Sr < 0.70817$; Fig. 1), a major positive Eu anomaly (Eu/Eu* max = 19.25) and high *LREE* enrichments (La/Yb max = 1.89). The highest Eu/Eu* ratios are generally related to low $^{87}Sr/^{86}Sr$ ratios (Fig. 1). However, it is not the case for the basaltic sample located at the bottom of the Atlantis II core and the two upper core sediments depositing in less reductive conditions. These results emphasize a basaltic contribution and a hydrothermal origin for the Atlantis II sediments. Conversely, the 'out deep' core shows other signatures, typically biodetrital with low positive Eu anomaly (1.2<Eu/Eu*<1.36), slight negative Ce anomaly (between 0.88 and 0.96), La/Yb ratios between 0.52 and 0.66 and the more radiogenic lead isotopic composition. The 'out deep' core $^{87}Sr/^{86}Sr$ ratios are lower than Red Sea water (Fig. 1) and show an important participation of the aeolian continental detritus related to the proximity of the coast. The Port-Soudan and Suakin deep sediments consist of biodetrital and chemical sediments; the more mineralized levels are characterized by a lower Sr isotopic composition which suggests an increase of the hydrothermal activity. For example, in the Suakin deep sedimentary column, the more mineralized sediment containing up to 15% of pyrite has the lower $^{87}Sr/^{86}Sr$ *ratio* equal to 0.707809. In the case of the Port-Soudan study, Fig. 1 clearly shows an increase of the Eu/Eu* ratios together with a decrease of the $^{87}Sr/^{86}Sr$ ratios. This indicates a hydrothermal influence, although the impact of the basaltic source is less important than in the Atlantis II deep sediments. The Thetis deep is the only deep without brines, although its sediments consist of ferriferous (goethite, hematite, lepidocrosite) and manganiferous (manganite) oxyde zone, reaching up 100% in some layers. The Thetis deep is the most mineralized deep (highest metal contents) of the Red Sea graben after the Atlantis II deep. The occurrence of such mineralized sediments requires a hydrothermal activity that is proven by the high positive anomalies obtained (Eu/Eu* maximum = 7.8). The Sr isotopic compositions ($^{87}Sr/^{86}Sr$: 0.70903 to 0.70914)

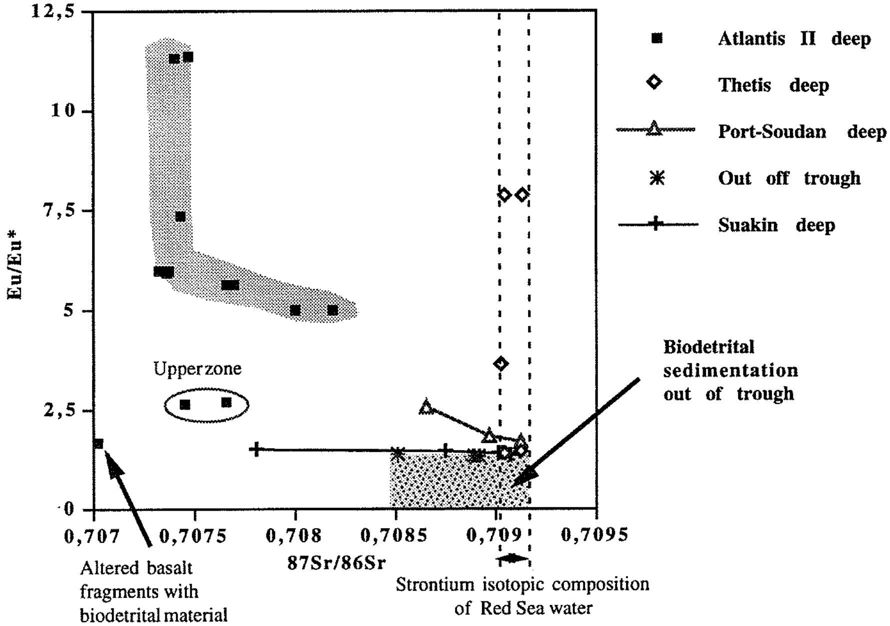

FIG. 1. Variation of the Eu/Eu* ratios *vs.* $^{87}Sr/^{86}Sr$ ratios of sediments from five Red Sea cores.

of the Thetis deep sediments are in equilibrium with the Red Sea bottom water (Fig. 1) due to the lack of brine filling the deep. The lead isotopic compositions of the Atlantis II and Thetis deeps support an important participation of the basaltic source. Interestingly, the fields defined for the Thétis and Atlantis II deeps are close to the hydrothermal metalliferous sediments of the Mid Atlantic Ridge. The Miocene evaporites also appear as a main end-member for the source of lead measured on the brines and sediments. The leaching of the thick evaporite layers by intensive circulation of fluids induces the increase of salinity of the hydrothermal solutions (from 144‰ in Suakin brines to 270‰ in Atlantis II brines). The other Pb possible sources are: sea water, biogenic particules and detrital materials. The Suakin and Port-Soudan deep sediments can be interpreted as a result of a mixing between these various end-members including a lower participation of the basalt compared with the Atlantis II and Thetis deeps. The involvement of the evaporites is well expressed in the Suakin deep sediments and the detrital end-member is predominant for the Port-Soudan sediments.

This study reveals the occurrence of intensive hydrothermal circulations taking place along the rift and it underlines the crucial impact of the interactions between the hydrothermal fluids and the basalts partly controlled by the temperature parameter. The Miocene evaporites constitute important supplies which contribute efficiently to chemical sedimentation. The Atlantis II and Thetis deep sediments have the most basaltic imprint in comparison with the other deep sediments which result from a higher biodetrital sedimentation. These hydrothermal manifestations differ from the more active oceanic ridge.