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Formation of Thetis Deep metal-rich sediments in the absence of brines, Red Sea

M.C. Pierret [a], N. Clauer [a,*], D. Bosch [b], G. Blanc [c]

[a] Laboratoire d'Hydrologie et de Géochimie de Strasbourg (CNRS/UdS),1 rue Blessig, 67084 Strasbourg Cedex, France
[b] Laboratoire de Tectonophysique, Place E. Bataillon, 34095 Montpellier Cedex, France
[c] Département de Géologie et d'Océanographie, Avenue des facultés, 33405 Talence, France

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ABSTRACT

Almost all Red Sea deeps contain metal-rich sediments covered by brine pools. It is generally agreed that these metal-rich deposits precipitated from overlying metal-rich brines that originated from migrating hydrothermal fluids. No brine pool has ever been reported in Thetis Deep, inciting us to evaluate if such a brine layer ever occurred in the deep during the past. In order to address that questioning, a study combining mineralogical, geochemical (major-, minor-, rare-earth elements) and isotopic (Sr, Nd, Pb) approaches was completed on cored sediments and extracted interstitial waters from inside and outside the deep.

The sediments have an overall hydrothermal origin, as shown by the REE concentrations and patterns, metal contents, and Pb–Nd isotopic data, all pointing to a mantle signature. The intensity of the hydrothermal activity varied with time in the deep; the most intense episode resulting in an almost pure Fe-oxi-hydroxide layer. Varied chemical arguments, especially the Zr and REE data of the sediments, favor the fact that the whole sedimentation in Thetis Deep occurred in the absence of a stable, salt-rich and mineralized brine pool, and that no brine layer ever existed. This conclusion is supported by the constant Sr isotope composition of the sediment and its interstitial waters that are almost identical to that of the Red Sea seawater. The study also suggests that hydrothermal activity monitored fluid supplies that interacted differently with seawater in the different Red Sea deeps, resulting in an overall formation of metal-rich sediments, but along varied local conditions.

1. Introduction

The 2000-km long Red Sea is a narrow ocean between the African and Arabic plates characterized by an heterogeneous spreading history along the axis that started with an Oligocene rifting phase (about 28–32 Ma ago) followed by an intense magmatic activity. Sea-floor spreading and formation of oceanic crust lasted at least during the last 7 millions of years (Bohannon and Eitreim, 1991) with a mean spreading rate of about 2 cm/yr. During Miocene, high evaporation induced deposition of a thick evaporate unit that contributed to the formation of continental brines in the Gulf of Suez (Issar et al., 1971; Rosenthal et al., 1998) and of brine layers in most Red-Sea depressions (Zierenberg and Shanks, 1986). The oceanic crust of the Red Sea that has been extensively studied appears to be continuous in the southern deeps of the sea, between 16° and 20°N, and discontinuous to the North. In fact, only several insolated deeps have a typical basaltic floor (Bonatti, 1985; Le Quentrec and Sichler, 1991), as metal-rich sediments associated with hot brines were observed in most depressions (Miller et al., 1966; Degens and Ross, 1969; Bäcker and Schoell, 1972; Schoell and Hartmann, 1973; Bäcker and Richter, 1973; Deleveaux and Doe, 1974; Pottorf and Barnes, 1983; Nawab, 1984; Mustafa et al., 1984; Baumann, 1994; Anschutz and Blanc, 1995a,b), suggesting an abundant and almost permanent hydrothermal activity. Among the different depressions, Atlantis II is generally considered to be the reference location for the warmest and saltiest brines, as well as for the most metal-rich sediments (Fig. 1). The evolutionary models elaborated for the different deeps are, therefore, largely based on that of Atlantis II, where the metal-rich sediments have formed by chemical precipitation from overlying, mineralized, salt-rich hydrothermal brines (e.g., Hartmann, 1985; Jedwab et al., 1989).

In the Red Sea, the hydrothermal fluids related to sea-floor activity are thought to have interacted with oceanic basalts during migration, as well as with nearby sedimentary deposits such as the thick Miocene evaporates, which explains their mixed chemical signature of a saline and a mantle origin. Sixteen deeps were identified along the central graben of the rift system (Bäcker, 1976), to the North and South of Thetis Deep (Fig. 1a) and all contain presently hot and salty brine pools except the Thetis and Gypsum Deeps. It seems therefore reasonable to assume that all fluids emerging in any deep interacted with the several km thick Miocene evaporites occurring nearby. In fact, hydrothermal fluids were never directly sampled in the Red Sea, but studies of fluid inclusions of Atlantis II deposits point to salty high-temperature hydrothermal solutions (maximum temperatures and salinities of 400 °C and 33‰, respectively; Ramboz et al., 1988). The resulting brine-type solutions are

* Corresponding author. Laboratoire d'Hydrologie et de Géochimie de Strasbourg (CNRS/UdS), 1 rue Blessig, 67084 Strasbourg, France. Tel.: +33 390 02 40 43 (office), +33 680 01 80 49 (mobile); fax: +33 390 24 04 02.
E-mail address: nclauer@illite.u-strasbg.fr (N. Clauer).

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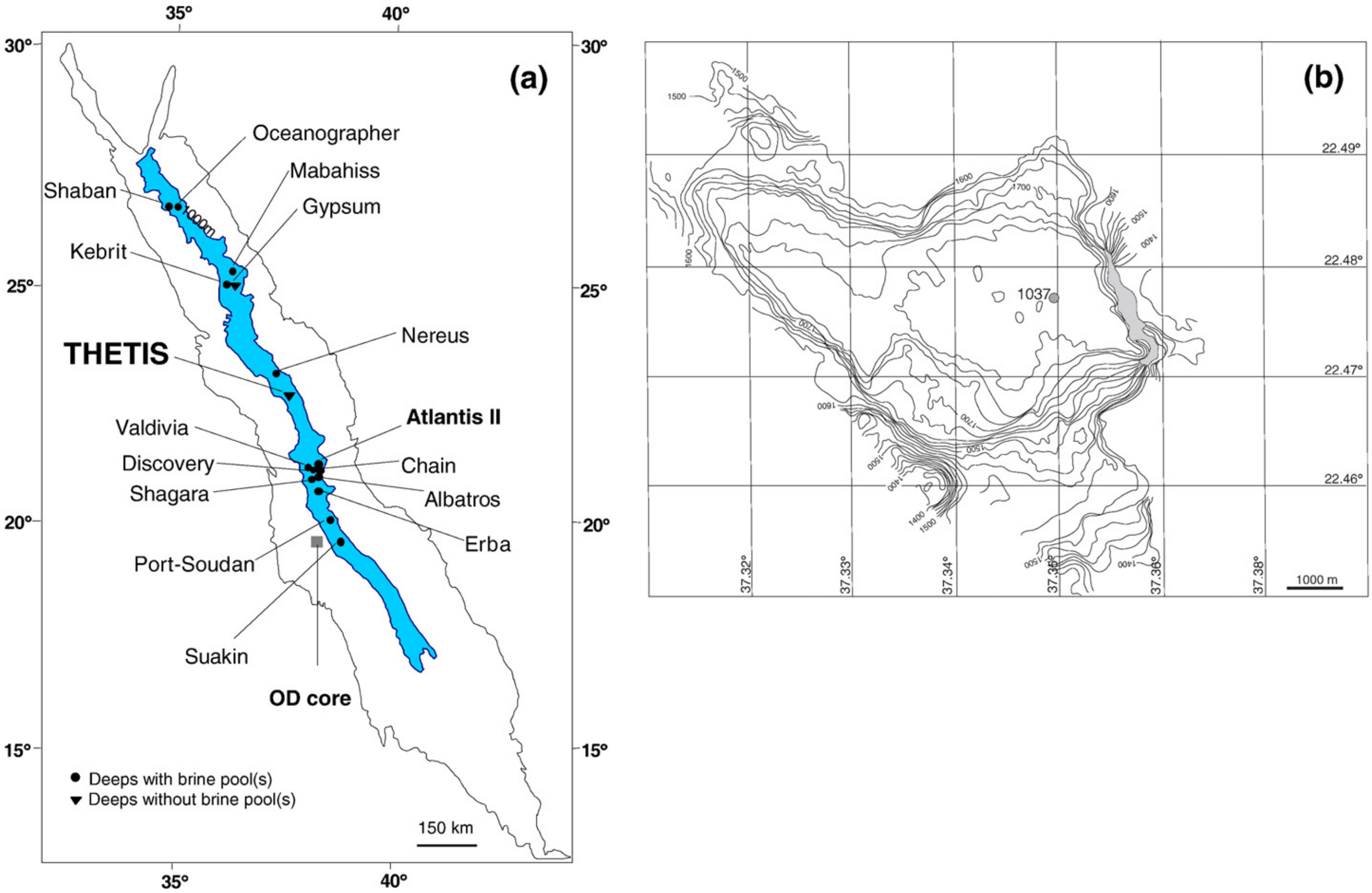

Fig. 1. (a) Map of the Red Sea with locations of Thetis Deep core 1037 and the outside deep core 1016 (labeled OD core), and (b) detailed bathymetric map of Thetis Deep. The grey part is deeper than 1000 m.

warmer, saltier and denser than seawater and fill most bathymetric depressions, allowing formation of brine pools separated from overlying deep seawater by temperature and salinity gradients (Shanks and Bischoff, 1980; Danielsson et al., 1980; Anschutz et al., 1995; Anschutz and Blanc, 1996; Hartmann et al., 1998). Such pooled brine layers can last hundreds to thousands of years with no need of additional salt input. It has been shown that mineral precipitation from such acidic, reduced and metal-rich brines induced metal-rich deposits (e.g., Bischoff, 1969; Shanks and Bischoff, 1977; Shanks, 1984; Butuzova et al., 1990; Anschutz et al., 2000).

Alternately, hydrothermal fluids of mature oceanic ridges, such as the East Pacific Rise and the Mid-Atlantic Ridge, are known to yield wide ranges of chlorine contents, but never higher than 8%, and salinities often near that of seawater (Von Damm et al., 1985; Von Damm, 1995; Bonifacie et al., 2005; Valsami-Jones et al., 2005; Cruse and Seewald, 2006). In summary, the differences between oceanic hydrothermal deposits, such as sulfide chimneys and mounds, and those of Red-Sea deeps are largely due to trapping of hydrothermal fluids with high salinities in the bathymetric depressions as hot-brine pools, whereas the hydrothermal fluids are thoroughly mixed with seawater when arriving into the oceanic environment. In this respect, Thetis Deep represents a special case among the Red-Sea deeps, as it contains the second most metal-rich sediments after Atlantis II (Bäcker et al., 1975; Scholten et al., 1991), but it is not filled presently with brines. On the basis of mixed Fe–Mn oxi-hydroxide occurrences, Butuzova et al. (1990) concluded that the bottom waters of Thetis Deep were never stratified, whereas Scholten et al. (1991) suggested the presence of a temporary brine pool during deposition of the Fe-facies in the deposits.

As the occurrence of a past brine pool in Thetis Deep is still matter of discussion, we have completed a detailed mineralogical, geochemical and isotopic study on its sediments and their interstitial waters: (1) to identify the nature and origin of the sediment components, and (2) to search for potential records of past brines in the sediments and/or their interstitial waters. The ultimate goal is to provide additional information able to promote one of the two possible evolution models still under debate and which can be summarized as: (1) either a brine pool was temporarily present in the past, and in this case it would be of interest to describe why, how and when the brine pool disappeared, or (2) no brine pool ever developed in the deep. The first of these two models would generalize the evolutionary model of Atlantis II Deep as a rule for the whole Red Sea, while the second would point to changing evolution paths for the sedimentation, the accumulation of the salt-rich mineralized brines, and the intensity and impact of the hydrothermal activity in the Red-Sea deeps.

2. Geological setting and sampling strategy

Discovered in 1971, Thetis Deep (22.48°N of Latitude and 37.35°E of Longitude, Fig. 1) was further explored in 1984 and 1992; no brine having ever being reported. Located 160 km to the northwest of Atlantis II (Bäcker, 1976), it is divided into several sub-basins. Approximately 10 km long and 3 km wide with an average depth of 1780 m, the main basin is located to the northwest of the deep. During the 1984 scientific cruise, coring reached the basalt underneath 10 m of sediments. Radiocarbon dating of fossil-rich layers established the earliest sedimentation at about 23000 yr BP, giving sedimentation rates that ranged from 7 cm/kyr in the youngest layer to 65 cm/kyr in the Fe-rich facies just below (Scholten et al., 1991).

Brines and sediments were observed and sampled in seven Red-Sea deeps during the REDSED cruise in September 1992 aboard the R.V.