Movements of thick evaporites on the flanks of a mid-ocean ridge: the central Red Sea Miocene evaporites

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Abstract

Thick evaporites ("salt") were deposited in the South and North Atlantic, and Gulf of Mexico basins, in some parts deposited onto the flanks of nascent oceanic spreading centres. Unfortunately, knowledge of the history of evaporite movements is complicated in such places by their inaccessibility and subsequent diapirism. This is less of a problem in the Red Sea, a young rift basin that is transitioning to an ocean basin and where the evaporites are less affected by diapirism. In this study, we explore the vertical movements of the evaporite surface imaged with deep seismic profiling. The evaporites have moved towards the spreading axis of the basin during and after their deposition, which ended at the 5.3 Ma Miocene-Pliocene boundary. We quantify changes in the average elevation of the evaporite surface due to (1) deflation needed to balance the volume of evaporites overflowing oceanic crust of 5.3 Ma age, (2) thermal subsidence of the lithosphere and (3) loss of halite through pore water diffusion, allowing for isostatic effects. The reconstructed evaporite surface lies within the range of estimated global sea level towards the end of the Miocene. Therefore, the evaporites appear to have filled the basin almost completely at the end of the Miocene. Effects of shunting by terrigenous sediments and carbonates near the coast and contributions of hydrothermal salt are relatively small and unresolved by this reconstruction.

Introduction

The configuration of the evaporite surface at the end of its period of deposition in the Red Sea at around 5.3 Ma is interesting for knowing whether the basin became filled. Although interbedded clastics and evaporites found at the top of the Miocene (Zeit Formation) in commercial wells suggest shallow water or even sabkha conditions (Hughes and Beydoun 1992), we don't know if such shallow conditions were caused by basin filling or draw down of the level of the Red Sea.

This work draws on deep seismic reflection profiles of Izzeldin (1982), which cross the basin (Figure 1) and image basement (Figure 2). It also draws on recent work on the nature of the crust in the central Red Sea. Crustal type has been controversial because the publicly available data have tended to be ambiguous. However, seismic refraction data (Egloff et al. 1991; Tramontini and

Davies 1969), axis-parallel symmetrical magnetic anomalies (Izzeldin 1987), a basement high at the axis and behaviour of Bouguer anomalies (Shi et al. 2018) all suggest that oceanic crust lies at least to 60-80 km from the axis here. This crustal type allows us to use oceanic half-space models to correct the evaporite surface for thermal subsidence of the underlying lithosphere.

When we also adjust the evaporite surface for deflation caused by the flowage of evaporites over the 5.3 Ma crustal boundary, the loss of halite by pore-water diffusion and by dissolution and diffusion in the brine lakes, the reconstructed level is almost at modern sea-level, though below predictions of extreme sea-level elevation at the end of the Miocene (Figure 3).

Implications?

The reconstruction does not allow for shunting of the evaporites towards the axis by terrigenous sediments and carbonates deposited along the coasts (Mitchell et al. 2017), nor other sources of evaporites such as hydrothermal precipitation (Hovland et al. 2018). Because the evaporite elevation cannot have lain above global late-Miocene sea level, shunting and hydrothermal precipitation were both relatively insignificant within the uncertainties of our calculations. We estimate the sum of these two effects to have been < 6 km^2 in terms of average marginal cross-sectional area along these profiles.

In the Miocene, the solutes that formed the Red Sea evaporites were probably supplied by seawater from the Mediterranean (Bosworth et al. 2005; Coleman 1974; Hughes et al. 1992; Orszag-Sperber et al. 1998). Hughes and Beydoun (1992) interpreted shallow water conditions in the Zeit Formation forming the top-most Miocene in boreholes around the Red Sea margins, in keeping with our results. As the evaporite surface at the end of the Miocene lay near sea level (Figure 3), drawdown of the Mediterranean Sea level would have left the Red Sea evaporites exposed to erosion by waves during the drawdown and subaerial erosion subsequently. This would help to explain a widespread unconformity at the top of the evaporite sequence found across the central and parts of the northern Red Sea (Bunter and Abdel Magid 1989; Izzeldin 1987; Mitchell et al. 2017; Mitchell et al. 2019).

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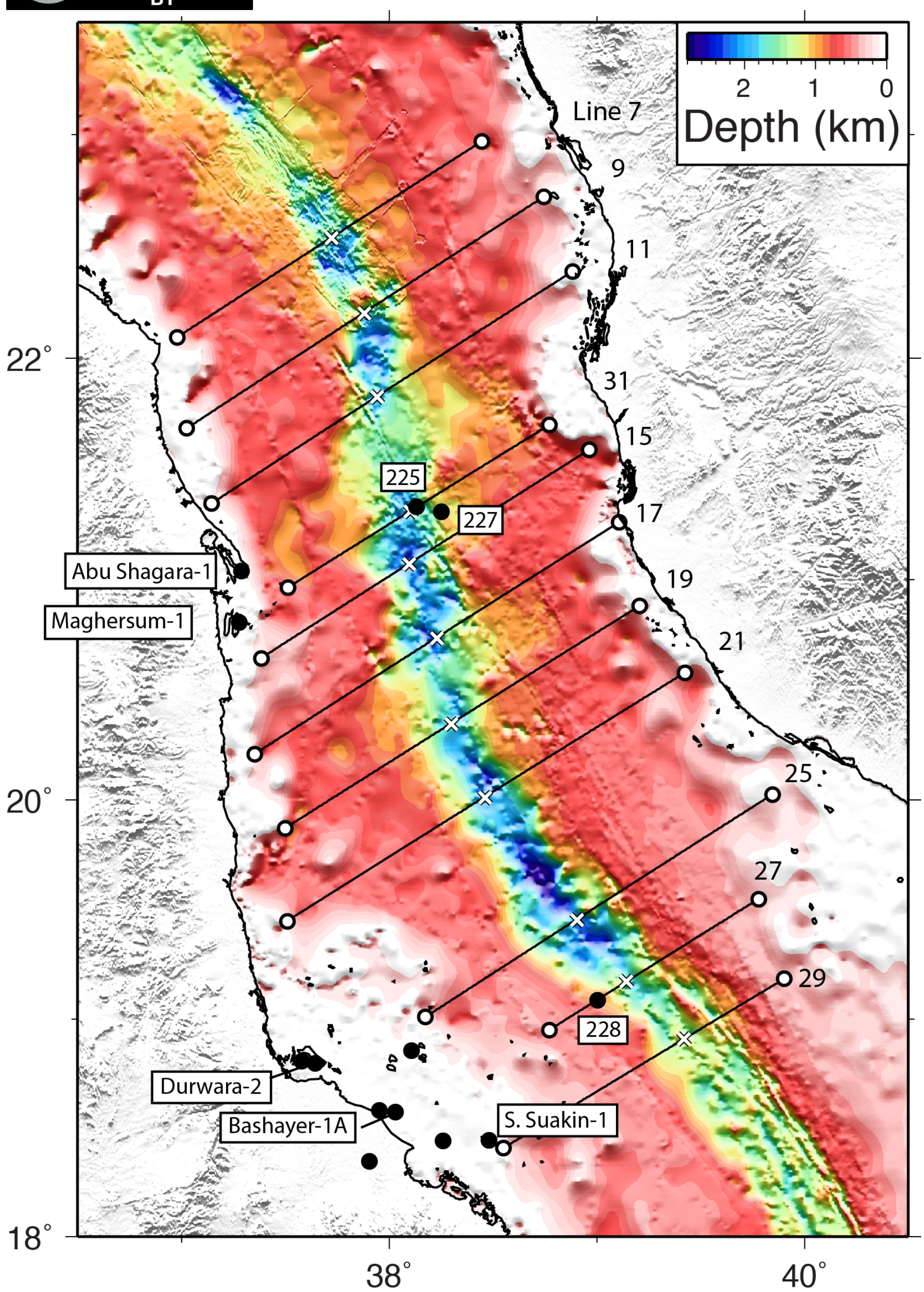

Figure 1: Bathymetry of the central Red Sea with the seismic lines of Izzeldin (1982) overlain. (Bathymetry data from the Global Multiresolution Synthesis (GMRT) grid (Ryan et al. 2009).)

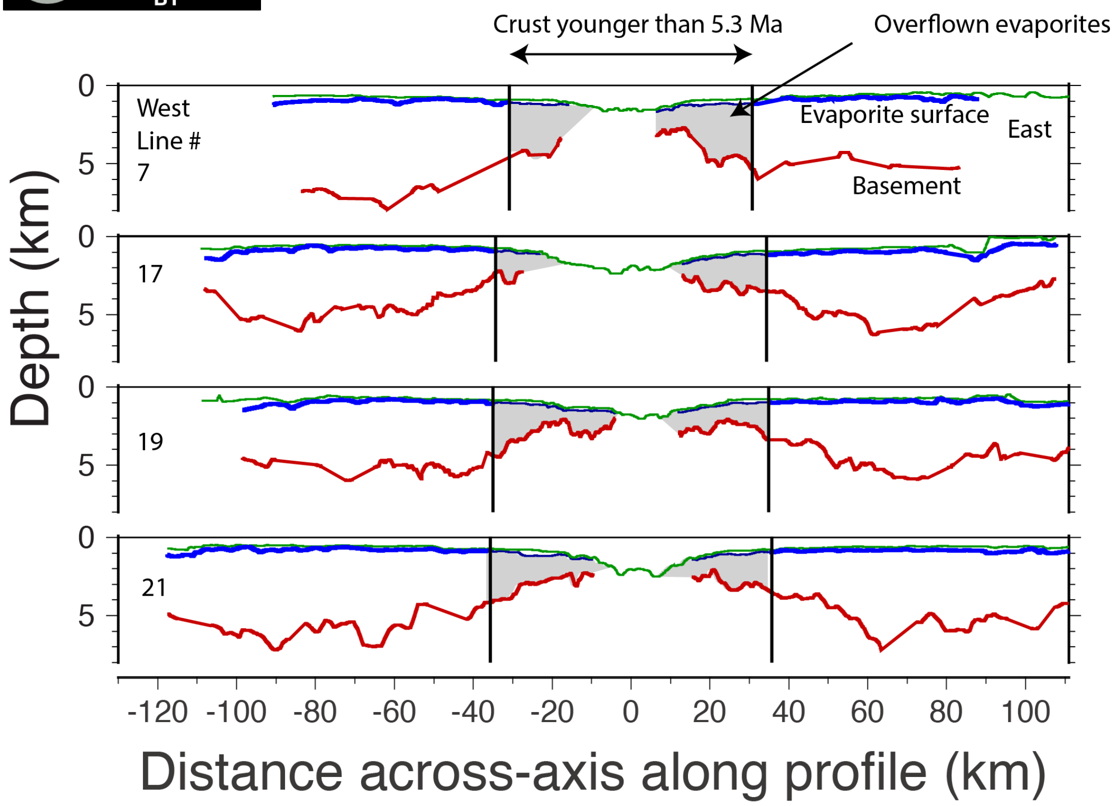

Figure 2: Selected profiles of seabed (green), top of the evaporites (blue) and basement (red) interpreted from the seismic data. Vertical bars mark estimated 5.3 Ma basement estimated from distance to the spreading axis and the Nubia-Arabia rotation poles of Chu and Gordon (1998). Evaporites that have overflown this boundary are highlighted in grey.

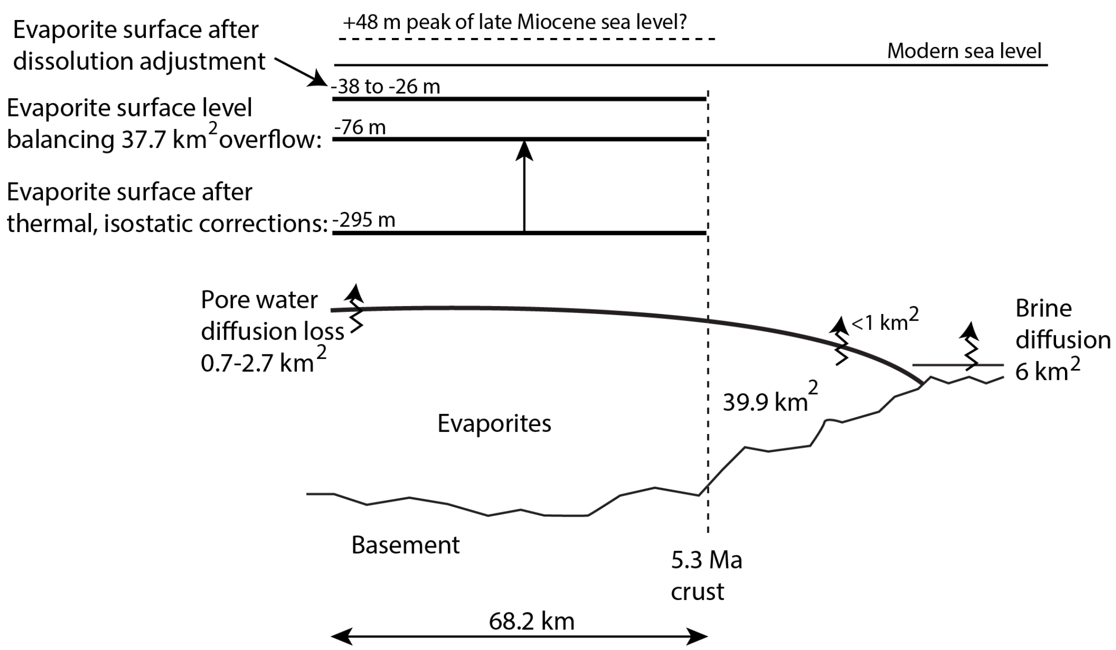

Figure 3: Summary of average cross-sectional areas, dimensions and evaporite surface level at the end of the Miocene in the central Red Sea (schematic only, not to scale).