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Salt tectonics and mud volcanism in the Latakia and Cyprus Basins, eastern Mediterranean

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ABSTRACT

Salt tectonics and mud volcanism in the Latakia and Cyprus Basin, eastern Mediterranean, is investigated by means of swath sounding, reflection seismics and side-scan data as well as by camera and video sledge observations. Both basins are located east of Cyprus and are associated with the collision front between the African and Anatolian plate. The Pliocene–Quaternary sediment succession is underlain by up to 1 km thick Messinian evaporites. Both thick-skinned plate tectonic and thin-skinned salt tectonic control fluid dynamics and associated mud volcanism in the Latakia and Cyprus Basin as well as at the Troodos Latacia Culmination, which separates both basins. An end-member model is proposed which explains the presence of elongated topographic highs and trenches along the Troodos Larnaca Culmination and south of it by gravity gliding of the Messinian evaporites and associated fluid migration. Thin-skinned extension in the Troodos Larnaca Culmination and boudinage, respectively, facilitate fluid flow through and out of the evaporites. The fluid or mud flow dissolutes the salt layer and creates elongated trenches. Mud intrudes into the Pliocene–Quaternary sediments above the trenches. Consequently, the overburden is thickened and forms morphological ridges. South of the culmination the evaporites and overburden are folded due to thin-skinned shortening of the evaporites. In one instance fluid extrusion out of the evaporites is inferred from seismic data interpretation. The outflow caused a volume reduction and collapse of the evaporites. Mud volcanoes and fold anticlines align above deep-rooted transpressional fault systems which are associated with the African–Anatolian collision zone. The faults may act as conduits for rising fluids. In the western part of the survey area, where the Cyprus Arc strikes almost West–East and the collision occurred more frontal and stress was highest, mud volcanoes emerged. Further to the east, where the Cyprus Arc runs SW–NE and sinistral strike-slip has been proposed, fold anticlines evolved. Particular mud volcanoes and folds emerged prior to the deposition of the Messinian evaporites. The undisturbed upper Pleistocene sequences as well as the absence of significant mud outflow on the seafloor strongly suggest that the main fluid dynamic ceased.

1. Introduction

Fluid flow and associated mud volcanism have an important impact on the gas budget as well as geochemical and nutrient cycles in marine basins (e.g., Kopf et al., 2001; Dimitrov, 2002). Many publications deal with mud volcanism in the eastern Mediterranean (Fig. 1), in particular at the Mediterranean Ridge (Cita et al., 1981; Cita and Camerlenghi, 1990; Cita et al., 1995; Robertson and Kopf, 1998; Huguen et al., 2004; Zitter et al., 2005), the Anaximander Mountains and Florence Rise (Woodside et al., 1998, 2002), or the Nile Fan (Loncke and Mascle, 2004). Yet, the role of the widespread Messinian evaporites in the formation and evolution of mud volcanoes in the eastern Mediterranean has been rarely discussed. Evaporites are generally considered to be effective seals in terms of seal capacity and resistance to fracturing (Downey, 1984). Loncke and Mascle (2004) suggested that the fluid reservoirs of mud volcanoes, gas chimneys, hydrothermal pockmarks or hydrocarbon seeps at the Nile Fan are located within the sub-salt strata and that the conduits are restricted to salt welds where the evaporites have vanished due to lateral gliding (thin-skinned tectonic). However, recent publications showed upward directed fluid pathways through or even out of Messinian evaporites (Gradmann et al., 2005; Bertoni and Cartwright, 2005; Netzeband et al., 2006a).

The Cyprus Arc in the eastern Mediterranean and the adjacent basins like the Cyprus and Latakia Basins are part of the collision zone between the African and Anatolian plate (e.g. Robertson, 1998; Aksu et al., 2005). Previous seismic studies revealed a complex fault pattern

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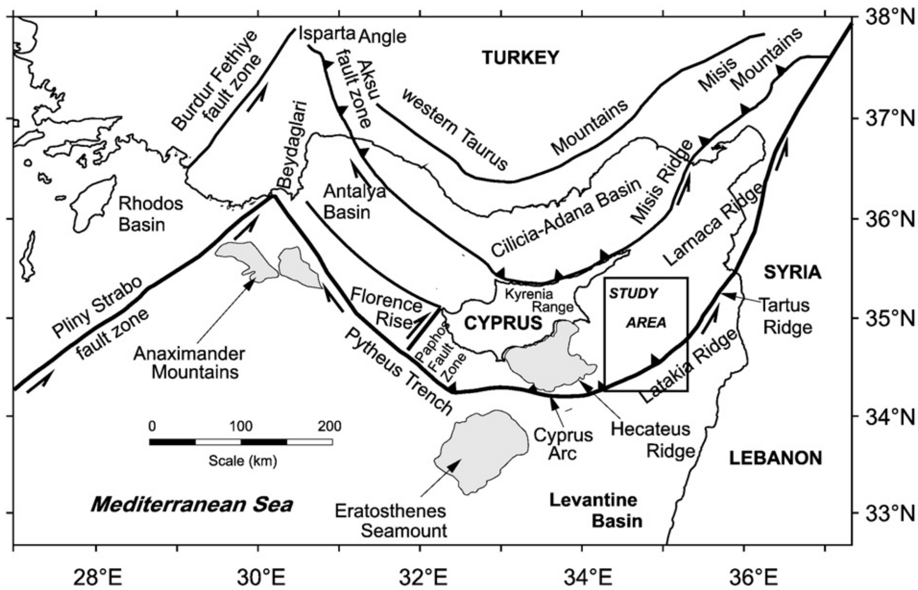

Fig. 1. Overall map of the eastern Mediterranean (Courtesy: J. Hall). The study area of the eastern Cyprus Arc is marked by a rectangle.

that result from the "thick-skinned" plate-tectonic evolution of this intricate realm (Calon et al., 2005). Bathymetric and high-resolution reflection seismic data collected at the eastern Cyprus Arc with *RV LeSuroit* in 2003 (BLAC project; Benkhelil et al., 2005) revealed a complex topography of the Cyprus and Latakia Basins including surficial folds, graben and mud volcanoes suggesting additional processes. In this paper we present new data from a subsequent seismic studies in 2004 with *RV Pelagia* (SAGA project) carried out to better image the Messinian evaporites and the Pliocene–Quaternary overburden. The discussion aims on an advanced understanding of the interaction between thin-skinned salt tectonic, mud volcanism and plate tectonics in these evaporite floored basins.

2. Geological setting

The eastern Mediterranean consists of several larger (Eurasian, African and Arabian Plate) and smaller (Apulian, Aegean, Anatolian and Sinai Plate) lithospheric plates (Fig. 1). Tectonic processes and plate boundaries are still a matter of debate (e.g., Woodside, 1976, 1977; Nur and Ben-Avraham, 1978; Riad et al., 1981; Rotstein and Kafka, 1982; Rotstein and Ben-Avraham, 1985; Kempler and Garfunkel, 1994; Ben-Avraham et al., 1988; Robertson et al., 1990, 1994, 1995; Ben-Avraham et al., 1995; Robertson, 1998; Anastasakis and Kelling, 1991; Woodside, 1991; Ambraseys and Adams, 1993; Oral et al., 1995). Excellent reviews of this topic can be found by Robertson (1998) and Aksu et al. (2005). It is consensus that the Levantine Basin (Figs. 1, 2b) evolved during the Late Triassic. The convergence between the African and Eurasian plates started in the Early Cretaceous simultaneously to the opening of the South-Atlantic. Subsequently, an intra-oceanic subduction zone developed in the Neo-Tethys. The plate-kinematic setting of the eastern Mediterranean changed significantly in the Late Miocene (e.g., Bosworth et al., 2005; Hall et al., 2005) when the Eratosthenes Seamount collided with the Cyprus Arc (Galindo-Zaldivar et al., 2001) and the Arabian Microplate collided with the Eurasian Plate along the Bitlis–Zagros fold-thrust belt. The Anatolian plate started to move westwards along the North- and East Anatolian Transform Faults (Sengör et al., 1985; Dewey et al., 1986). Consequently, the compressional regime along the Cyprus Arc changed into a sinistral, partly transpressional regime (Hall et al., 2005). Sage and Letouzey (1990), Vidal et al. (2000a,b) and Kläschen et al. (2005) showed that the Levantine Basin terminates against the southern flank of the Cyprus Arc. The Levantine Basin of today is floored by highly stretched continental crust (Hirsch et al., 1995; Netzeband et al., 2006b).

During the Messinian Salinity Crisis the Mediterranean was cut off from the water exchange with the Atlantic. Sea-level dropped dramatically due to evaporation and tabular evaporites were deposited in the Mediterranean sub-basins (Hsü et al., 1977; Cita, 1982). In the Levantine Basin the Messinian evaporites reach thicknesses of almost 2 km (Netzeband et al., 2006a). The evaporites reveal a complex internal reflection pattern (Gradmann et al., 2005; Netzeband et al., 2006a; Bertoni and Cartwright, 2006; Hübscher and Netzeband, 2007). Intra-salinar reflections offshore Israel have been previously interpreted as embeddings of over-pressurized clastic sediments between evaporites by Garfunkel and Almagor (1984) and Garfunkel (1984). Gradmann et al. (2005) observed mud flows on the seafloor and above a strong reflection that cuts through the evaporites. Netzeband et al. (2006a) interpreted cone-like features atop the evaporites and an overlying mud volcano at the seafloor as results of fluid outflow from the Messinian evaporites.

The survey area covers the western part of the eastern Cyprus Arc and includes the southward shallowing and 1000 m deep Latakia Basin, the 1500–1600 m deep Cyprus Basin, and the 2000 m deep northernmost Levantine Basin (Fig. 2). The Troodos Larnaca Culmination includes the southern and shallowest part of the Latakia Basin as well as the southern slope which links Latakia and Cyprus Basin. The Cyprus Arc marks the boundary between the Levantine and Cyprus Basin.

Several elongated topographic highs align SW–NE along the Troodos Larnaca Culmination. They are 1–2 km wide and up to 80 m high (Fig. 2). The ridges at the lower slope of the Troodos Larnaca Culmination are more continuous. Several round shaped or elongated topographic highs are present in the Cyprus Basin. They partly align along a bended morphological step of some 10 m height. Compressional folds in the northern most Levantine Basin have been discussed by Netzeband et al. (2006a) and result from the northern creep of the Messinian evaporites caused by the sediment load of the Nile cone. These folds are not discussed in this study.

3. Methods

Bathymetric data from the eastern Cyprus Arc have been gained using the hull-mounted EM300 multi-beam swath sounder system