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Research paper

Seismo-stratigraphic evidences for deep base level control on middle to late Pleistocene drift evolution and mass wasting along southern Levant continental slope (Eastern Mediterranean)

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A B S T R A C T

Since early Pliocene, a counterclockwise surface gyre transported Nile derived silt and clay northeastwards along the Levant coast, where a basinward prograding plastered drift emerged. Based on high-resolution seismic reflection data we develop a middle to late Pleistocene sequence stratigraphic scheme for this plastered drift. For creating stacked sections of the seismic data we used the common reflection surface (CRS) stack technology which enhanced lateral reflection continuity and visibility of deep reflections. The shelf comprises stratigraphic sequences which show classical, systems tract like stacking patterns of sea level controlled sequences such as offlapping forced regression deposits or diachronous ravinement surfaces which formed during base level rise. On the slope, base level was periodically located well below the wave base and thus rather controlled by hydrodynamics, presumably by high-velocity contour currents. Hence, the term '*deep base level*' is introduced. The deep base level controlled especially down and backstepping slope deposits. This example shows that care has to be taken when interpreting subsurface data containing typical systems tract like seismic sequences, since such geometries do not necessarily imply shallow water deposition of the sediments. A chronostratigraphic analysis based on the seismic stratigraphy indicates that base level fluctuations were related to eccentricity driven glacio-eustatic fluctuations. Periodic mass wasting, facilitated by foreset oversteepening and possibly triggered by salt tectonics or erosion by the contour current occurred during late base level fall or early base level rise.

1. Introduction

'Base level' is a fundamental conceptual surface in sequence stratigraphy which delineates a dynamic surface of balance between erosion and deposition (Jervey, 1988; Swift and Thorne, 1991; Cross and Lessenger, 1998; Catuneanu et al., 2009). A rise in base level creates accommodation, a fall destroys it. Base level is commonly controlled by two factors, which are relative sea level and hydrodynamics (Cross and Lessenger, 1998; Catuneanu et al., 2009 and references there in). Mechanisms such as tectonism and eustatic change combine to influence relative sea level and are considered as the primary mechanisms that control base level changes over geological time scales. The relationship between stratal stacking patterns and cyclic changes in base level is the fundamental theme of sequence stratigraphy (see Catuneanu et al., 2009, and references there in). Hydrodynamics related base levels in the shallow marine realm are governed, e.g., by the position of tide levels or the storm wave base and are therefore related to sea level. A consistent base level concept for continental slopes and the deep sea has not been developed yet. As discussed by Nielsen et al. (2008), conventional concepts of seismic sequence stratigraphy are not fully applicable to the stratigraphy of contourite drifts, since their internal stratigraphy is generally controlled by bottom or contour currents which are usually not related to shallow base levels.

The Nile Cone is the largest deep-sea fan in the Mediterranean

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Sea (Sestini, 1989) which started to evolve in the early Pliocene. It represents a mud-rich deep-sea fan and is more than 600 km wide and 300 km long (Loncke et al., 2002; Ducassou et al., 2009) (Fig. 1). Since the early Pliocene, a counterclockwise surface gyre transported Nile derived silt and clay northeastwards along the Levant coast (Fig. 2), where a basinward prograding contourite drift, also called Eastern Nile Fan, emerged (Emery and Neev, 1962; Gvirtzman and Buchbinder, 1978; Coutellier and Stanley, 1987; Stanley and Warne, 1998). The complex slope morphology of the southern Levant slope reflects frequent mass wasting (Fig. 2). In the past, trigger mechanisms were mainly attributed to subsurface salt

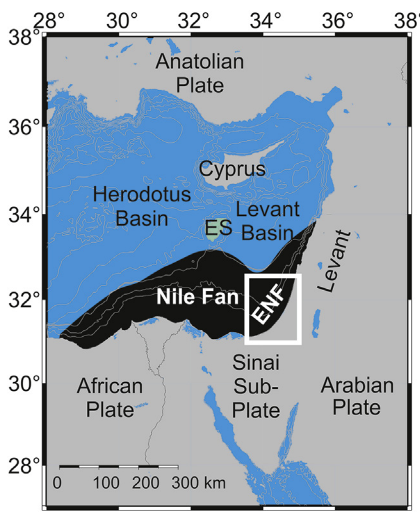

Fig. 1. Eastern Mediterranean with study area (white rectangle). ENF: Eastern Nile Fan. ES: Eratosthenes Seamount.

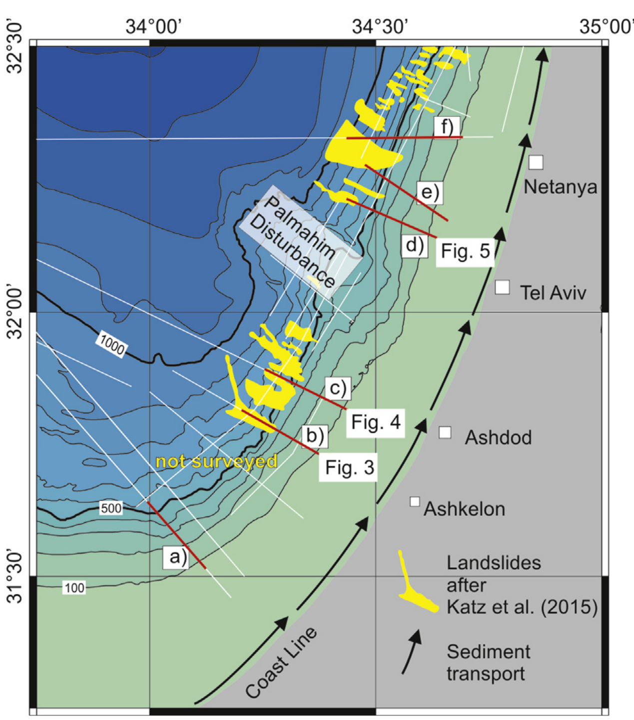

Fig. 2. Survey area with M52/2 seismic profiles (white lines). Red lines mark locations of Figs. 3–6. Labels a)-f) relate to line drawings shown in Fig. 6. Landslides mapped by Katz et al. (2015) are shown in yellow. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

tectonics related to the buried Messinian salt layer (Garfunkel, 1984; Gradmann et al., 2005; Baudon and Cartwright, 2008; Gvirtzman et al., 2015). Katz et al. (2015) analyzed 447 small to medium submarine landslides and suggested additional trigger mechanisms such as over-steepening, which means that the slope exceeds a critical angle which is observed to be 4°–5°.

In this study we develop a middle to late Pleistocene sequence stratigraphic scheme for the contourite drift along the southern Levant slope (Fig. 2) by means of high-resolution seismic reflection data interpretation. An estimated base level curve is used as a chronological tool for relating base level to glacio-eustatic variations. We will show that the prograding pattern along the upper slope is controlled by a "deep base level" and that abundant mass wasting occurred during the turnaround from deep base level fall to base level rise.

2. Setting

2.1. Geology

The continental Levant Basin (Fig. 1) evolved during several rifting phases starting in the Permian (Freund et al., 1975; Ben-Avraham, 1989; Garfunkel, 2004; Netzeband et al., 2006a). During the Messinian Salinity Crisis (Hsü et al., 1973; Ryan et al., 1973) an up to 2 km thick salt layer accumulated in the deep basin (Ryan and Cita, 1978; Mart and Ben-Gai, 1982; Gradmann et al., 2005; Bertoni and Cartwright, 2006, 2007; Netzeband et al., 2006b; Gvirtzman et al., 2013). Salt deformation is primarily related to gravitational forces, either causing salt to flow in response to differential sediment loading (spreading) or as a consequence of basement tilt (gliding) (Cartwright and Jackson, 2008; Clark and Cartwright, 2009; Cartwright et al., 2012; Reiche et al., 2014; Gvirtzman et al., 2015). This flowage resulted in huge rotational slumping along curved failure planes that extend from the sea floor to the top of the evaporites. Faults in the overburden propagate upwards and pierce the sea floor, proving present day salt movement (Garfunkel et al., 1979; Almagor and Garfunkel, 1979; Almagor, 1984; Garfunkel, 1984; Hübscher and Netzeband, 2007).

According to numerical studies of Ben-Gai et al. (2005), aggradation offshore Israel dominated the landward areas during the Pliocene, turning into basinward progradation since the Pleistocene. Nowadays, the shelf-break is about 20–30 km basinwards of its early Pliocene position (Gvirtzman and Buchbinder, 1978; Buchbinder and Zilberman, 1997; Gvirtzman et al., 2011). For the most complete and recent review of previous work in the study area we refer to Gvirtzmann et al. (2015).

The present day southern Levant shelf is up to 200 m deep, up to 20 km wide and narrows northwards (Fig. 2). Slope gradients on the shelf do not exceed 2°. The continental slope dips 4° or more between 200 m and 1000 m water depth. The complex slope morphology of the southern Levant slope reflects frequent mass wasting (Fig. 2). Salt tectonics has been identified as the main trigger mechanism (Garfunkel, 1984; Gradmann et al., 2005; Baudon and Cartwright, 2008; Gvirtzman et al., 2015; Katz et al., 2015). Two different types of mass movements have been described. The first type comprises over 1 km thick slumps with their primary detachment surface located within the Messinian evaporites (Almagor and Garfunkel, 1979; Almagor, 1984; Hall, 2005; Cartwright and Jackson, 2008). The Palmahim-Disturbance represents the largest slump of this kind (Fig. 2). Another example is the Dor Disturbance which is north of the study area (Garfunkel et al., 1979; Almagor and Garfunkel, 1979). The second type of submarine mass movements comprises small to medium landslides with surface areas $<10^{-2}$ - 10^{1} km^2 (Almagor and Garfunkel, 1979; Frey-Martinez et al., 2005). The 10–80 m high