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Fracturing patterns, stress fields and earthquakes in the Southern Dead Sea rift

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Abstract

Integrated investigations including the structural analysis of shear fractures and fault zones, the reconstruction of stress fields and the fractal analysis of the epicentral field of recent earthquakes have been pursued in the Dead Sea rift. The N–S and NW–SE trending faults are very extensive and they display large zones of crushed rock compared with faults of other orientations. According to the fractal analysis of the seismicity over the period of 1983–2002 and a review of historical destructive earthquakes associated with faulting of archaeological sites, large N–S and NW–SE fault zones traced in different sites are the major structures that control the seismic activity in the southern part of the rift. Many of the N–S trending faults are well pronounced within the basins but they are not as frequent in the inter-basin link zones. Meso-structural features document normal fault displacements along the major faults within basins. In the uplifted inter-basin links the kinematics varies from normal to strike-slip faulting along the same fault zones. The NW–SE faults are characterized by normal and oblique displacement, the E–W faults by strike-slip displacements and the NE–SW faults by composite strike-slip and normal displacement. The tectonic stress fields reconstructed from shear fractures orientations show that two main types of local stress tensors are associated with the structural development of the Dead Sea rift: (1) tension with E–W (mainly) and ENE–WSW trending σ_3 and (2) transcurrent with NE–SW (sometimes nearly E–W) trending σ_3 and NW–SE (sometimes nearly N–S) trending σ_1. The comparison between the obtained data and analog models of structural systems formed under variable loading conditions indicates that the observed features and the inferred stress fields in the Dead Sea rift are typical to oblique extension settings.

Keywords: Dead Sea rift; Fracturing; Faults; Stress fields; Fractal analysis; Earthquakes

1. Introduction

The Dead Sea rift extends for 1000 km from the northern Red Sea, to the south, to the East Anatolian Fault, to the north (Fig. 1). It consists of a series of basins bounded by steep-dipping faults with morphologically marked margins. The major basins in the south are the Gulf of Elat (Aqaba), the Dead Sea, the Lake Kinneret (Sea of Galilee) and the Hula Basin (Fig. 1). To the north of the Lebanese fault system are the basins of el-Gharb and Kara-Su. The basins are separated by threshold zones (inter-basin links) where the fault pattern is not evident in the morphology. Examples of the morphotectonic structures occurring within the investigated area are shown in Fig. 2.

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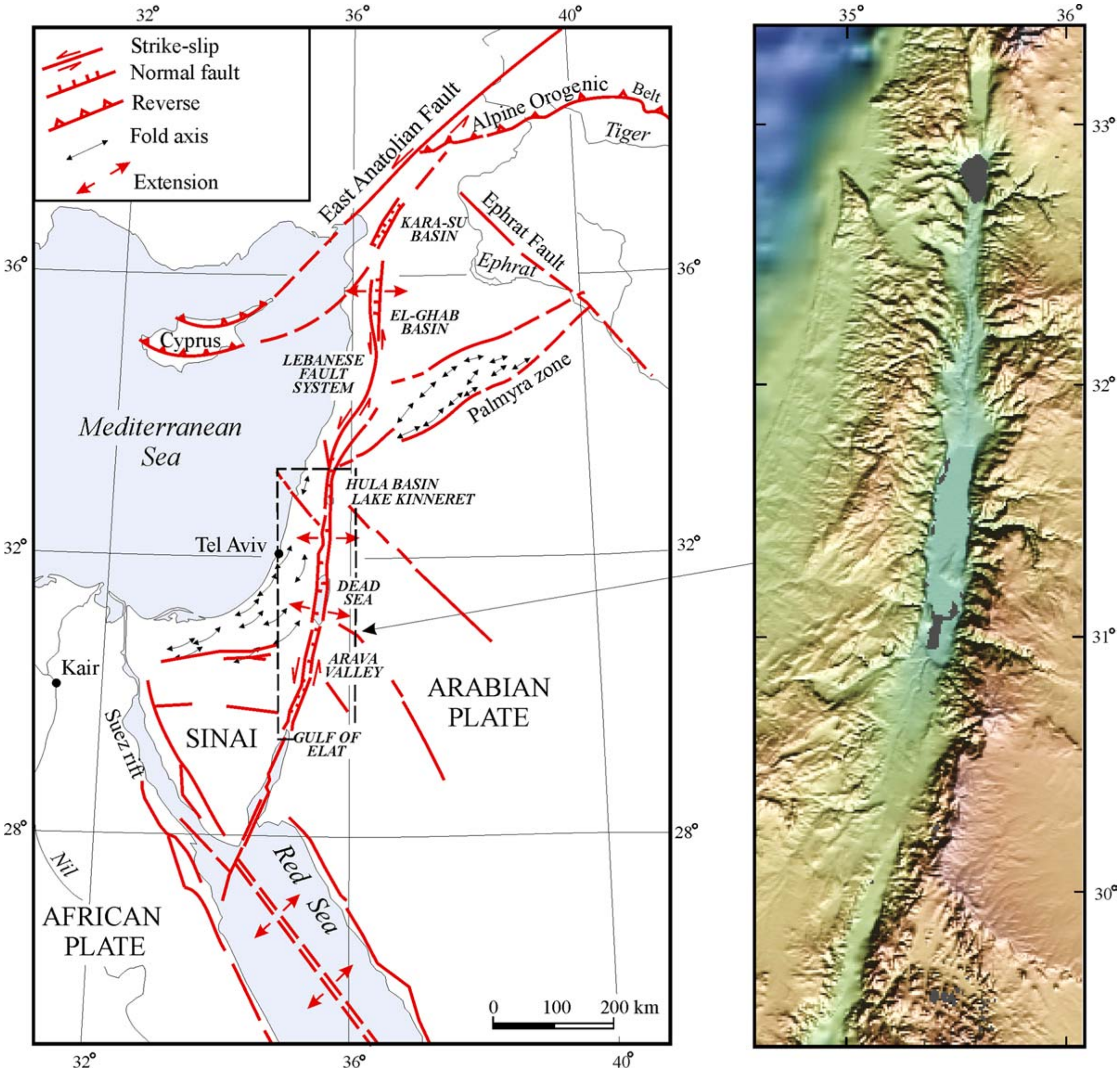

Fig. 1. Left: the tectonic framework of the Dead Sea rift and adjacent areas (after Darkal et al., 1990). The rectangle shows the investigated area. Right: digital shaded-relief map (from http://www.geomapapp.org).

The Dead Sea rift and the adjacent areas were the subject of many mapping campaigns, structural studies and the analyses of earthquakes focal mechanisms (Freund et al., 1970; Garfunkel, 1981; Kashai and Croker, 1987; Picard, 1987; Darkal et al., 1990; Van Eck and Hofstetter, 1990; Mart, 1994; Sneh, 1996; Shapira, 1997; Sagy and Reches, 2000; Horowitz, 2001; Mart et al., 2005 among others). Some of them were specifically dedicated to reconstruct the stress fields (Letouzey and Tremolieres, 1980; Eyal, 1996). Nevertheless, the development and geodynamics of the rift are a topic of intense discussion. The origin of the Dead Sea rift and its N–S orientation was attributed to: (1) E–W tension (Mart and Horowitz, 1981; Sagy and Reches, 2000; Horowitz, 2001); (2) NE–SW tension (Garfunkel, 1981); (3) N–S compression (Letouzey and Tremolieres, 1980) and (4) NNW–SSE compression and ENE–WSW tension (Eyal, 1996). The considerable variability of the local stress field is typical of the Dead Sea rift, which, like other fault patterns characterized by concurrent strike-slip and extensional tectonics, can lead researchers to different interpretations. In particular, according to Freund et al. (1970) and Garfunkel (1981), the Dead Sea rift is a transform fault, connecting the Red Sea oceanic spreading center with the East Anatolian Fault. Horowitz (2001) states that it is a “pure” rift, while Mart (1994) and Mart and Rabinowitz (1986) suggest that the Dead Sea rift is under the effects of both normal and left-lateral strike-slip displacements resulting from oblique extension. Tens of the contradictory