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The Dead Sea Rift as a natural laboratory for earthquake behavior: prehistorical, historical and recent seismicity

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Introduction - The Dead Sea Fault

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The Dead Sea Fault (DSF) accommodates sinistral motion between the Arabia plate and the Sinai subplate since the Middle Miocene, ~20 Ma. The interpretation of 107 km left-lateral slip along the DSF is based on observations from four independent sources: regional plate tectonics, local geology, seismology, and geodesy. The regional tectonics shows that the Red Sea is an incipient ocean, where the Arabian plate has been breaking away from Africa since Late Oligocene-Early Miocene. This motion is transferred to the collision with Eurasia via sinistral shear along the DSF (Courtillot et al., 1987; Freund, 1965; Garfunkel, 1981; Joffe and Garfunkel, 1987; Quennell, 1956). Local geology shows systematic offset of numerous pre-Miocene geologic features by a total of ~107 km (Bartov et al., 1980; Freund, 1965; Quennell, 1956) and fault geometry that indicates left-lateral motion (Garfunkel, 1981). Paleoseismic and archaeoseismic studies show sub-recent activity as sinistral offsets of natural and of manmade structures (e.g., Amit et al., 2002; Ellenblum et al., 1998; Klinger et al., 2000; Meghraoui et al., 2003; Niemi et al., 2001). Focal mechanisms of moderate-to-large earthquakes show sinistral motion along the DSF and generally are in agreement with the location of the active faults, based on geological data (Baer et al., 1999; Hofstetter et al., 2007; Klinger et al., 1999; Salamon et al., 1996). And finally, geodetic measurements are consistent and confirm the left-lateral slip as well as the slip rate from other palaeoseismic evidence of 4±1 mm/yr (Le Beon et al., 2006; Le Beon et al., 2008; McClusky et al., 2003; Reilinger et al., 2006; Wdowinski et al., 2004). This rate, as well as uniform Gutenberg-Richter frequency-magnitude relation, indicate stable tectonic regime in the last 60 ka (Begin et al., 2005; Hamiel et al., 2008).

The complex geometry of the fault is apparent in pull-apart grabens, which are associated with releasing bends, and pressure ridges that formed where restraining bends occur. Garfunkel (1981) maintains that the pull-apart basins are all shorter the total lateral offset because they began to form at a later stage, after some motion had already accrued. This view is supported by seismic surveys that reveal earlier buried basins, which are no longer active (Frieslander, 2000).

The pull-apart basins have acted like sediment traps. Studies of the Miocene to Recent clastic and evaporitic sediments as well as some magmatic sequences that accumulated in the basins have yielded a wealth of information and insight on the history of sedimentological conditions and processes (e.g., Bookman et al., 2004; Frostick and Reid, 1989; Klinger et al., 2003; Sneh, 1981, 1982; Tsatskin and Nadel, 2003), climate (e.g., Bartov et al., 2003; Begin et al., 1974; Frumkin et al., 1991; Stein, 2001), geomagnetic secular variation (Marco et al., 1998), seismicity and deformation (e.g., Agnon et al., 2006; Bartov and Sagy, 2004; El-Isa and Mustafa, 1986; Heifetz et al., 2005; Ken-Tor et al., 2001; Marco et al., 1996; Migowski et al., 2004), fauna and flora (Kislev et al., 1992), humans, and environment (e.g., Braun et al., 1991; Goren-Inbar and Belitzky, 1989; Goren-Inbar et al., 2000; Ron and Levi, 2001).

Several authors noted that the detailed shape of the DSF had changed through time (Garfunkel, 1981; Heimann and Ron, 1987, 1993; Marco, 2007; Rotstein et al., 1992; Shamir et al., 2005; ten Brink et al., 1999; ten-Brink and Ben-Avraham, 1989). The widest zone of about 50 km of distributed faulting is found in the Galilee, where the early-stage (Miocene) faults were associated with formation of basins (Freund et al., 1970; Shaliv, 1991) and with rotation of rigid blocks about sub-vertical axes (Ron et al., 1984). Subsequent post-Miocene deformation took place mostly in the form of normal faulting on E-W trending faults and the transform movement is currently localized in a very narrow zone. The deformation in the south was characterized initially by a 20-30-km-wide zone with primarily strike-slip and some normal slip on faults trending sub-parallel to the main transform fault. It later became localized in the Arava, where a single narrow fault zone offsets the youngest alluvium. In the earliest phase, young faults became active in the Negev, some 20 km west of the Arava (Avni et al., 2000), perhaps indicating another widening phase of the DSF zone (Marco, 2007).

Table 1. Various estimates of the Dead Sea Fault slip rate

Period	Rate mm/y	Data	Reference
Late Pleistocene-Recent	10	Geological	(Freund et al., 1968)
Last 1000 yr	0.8-1.7	Historical	(Garfunkel et al., 1981)

Plio-Pleistocene	7-10	Geological	(Garfunkel et al., 1981)
Last 4500 yr	2.2	Seismicity	(Ben-Menahem, 1981)
Late Pleistocene	6.4±0.4	Seismicity	(El-Isa and Mustafa, 1986)
Plio-Pleistocene	6 (0.283°/ma)	Plate kinematics	(Joffe and Garfunkel, 1987)
Holocene	9	Geological	(Reches and Hoexter, 1981)
Plio-Pleistocene	20	Geological	(Steinitz and Bartov, 1986)
Holocene	>0.7	Geological	(Gardosh et al., 1990)
Plio-Pleistocene	5.4-6.1	Geological	(Heimann, 1990)
Plio-Pleistocene	3-7	Drainage systems, Arava Fault	(Ginat et al., 1998)
Pleistocene	2-6, prefer 4	Alluvial fans, N. Arava	(Klinger et al., 2000)
Pleistocene	4.7±1.3	Alluvial fans, Arava	(Niemi et al., 2001)
Last 2000 yrs	6.9±0.1	Paleo and Archaeoseismology, Missyaf (DSF in Syria)	(Meghraoui et al., 2003)
1996-1999	2.6±1	Geodesy, GPS	(Pe'eri et al., 2002)
1996-2003	3.3±0.4	Geodesy, GPS	(Wdowinski et al., 2004)
25 ka	3.8–6.4	Geological, Lebanon	(Daëron et al., 2004)
Last 5000 yrs	≥3	Stream channel, Jordan Gorge	(Marco et al., 2005)
Survey-Mode GPS	5.6 to 7.5	(from south to north)	(McClusky et al., 2003)
1999-2005	4.9±1.4	GPS	(Le Beon et al., 2008) and thesis
Last 47.5 kyrs	4.7 to 5.1 mm/yr	Offset channels, Jordan	(Ferry et al., 2007) Comment/Reply: (Ferry and Meghraoui, 2008; Klein, 2008)

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