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What triggered the early-to-mid Pleistocene tectonic transition across the entire eastern Mediterranean?

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ABSTRACT

Subduction plays a fundamental role in plate tectonics and when interrupted it may trigger a series of geodynamic and sedimentary responses. Synchronous structural modifications recorded across the entire eastern Mediterranean region are dated to a relatively short period — early-to-mid Pleistocene. These deformations are documented within plates (e.g., Arabian, Sinai and African plates), along plate boundaries (e.g., Dead Sea and North Anatolian faults and Cyprus Arc), and in the Mediterranean basin. During the same period the northward subduction of the Sinai plate was interrupted when the Eratosthenes Seamount–Cyprus Arc collision initiated. Subduction–collision processes of the eastern Mediterranean serve as a unique modern analogue for similar settings worldwide. Understanding their association with accompanying neo-tectonic processes is therefore predominantly important. By fostering a detailed and comprehensive approach this research provides a coherent tectonic picture for the eastern Mediterranean early-to-mid Pleistocene tectonic transition in order to explore its triggering mechanisms. Since the Neogene convergence across the eastern Mediterranean was accompanied by Eurasian indentation by Arabia northward motion, westwards Anatolia escape and southwards Aegean propagation. This semi counterclockwise plate motion was temporarily interrupted by the incipient Seamount–Arc collision which is suggested here as a trigger of the early-to-mid Pleistocene tectonic transition.

1. Background

The eastern Mediterranean basin is a fossil remnant of the Meso and Neo-Tethys oceans (Fig. 1). The basin started to develop during the late Paleozoic when Eratosthenes block, amongst other platelets, drifted away from the Gondwana super-continent (Garfunkel, 1998; Schattner and Ben-Avraham, 2007). During the Paleogene–Neogene, fore-arc extension and subduction hinge rollback of the northern Afro-Arabian plate dominated the development of the eastern Mediterranean basin (Robertson, 1998). Towards the terminal stages of the Neo-Tethys, during the Oligocene to the present, the entire northern flank of the Afro-Arabian plate progressively subducted northward beneath Eurasia.

Until early–middle Eocene a single active subduction zone occupied the northern margin of the eastern Mediterranean basin, in southeastern Turkey, where arc volcanism continued into the early Neogene (Robertson, 1998). From the Neogene, the northwards subduction and hinge rollback continued with varying rates across the Alpine–Himalayan orogen (Ben-Avraham and Nur, 1976; Faccenna et al., 2006). While much of the subducted slab was consumed, some seafloor features were accreted onto the overriding plate (Şengör et al., 2003). During the Miocene the subduction front jumped to its present location south of Cyprus (Kempler and Ben-Avraham, 1987; Robertson, 1998).

At the forefront of subduction, slab break-off developed along the northern underthrusting edge of the Arabian plate (Faccenna et al., 2006). The break-off was suggested to propagate from the Owen fracture zone westward towards the northern edge of the Dead Sea fault, concurrent with increasing northwards indentation of Eurasia by Arabia (Fig. 1). The remaining of Arabian oceanic crust gradually collided and accreted to form the Bitlis–Zagros suture by the late Miocene to early Pliocene (Robertson, 1998; Faccenna et al., 2006).

In contrast, west of the Dead Sea fault, subduction of the eastern Mediterranean basin under the Cyprus Arc persisted without prominent interruptions until the early Pleistocene (Kempler, 1998; Robertson, 1998). Increased slab-pull towards the north resulted in accelerated slab retreat and arc propagation southwards (Faccenna et al., 2006). Further to the south the continental margins of the Sinai and African plates remained passive throughout the Neogene.

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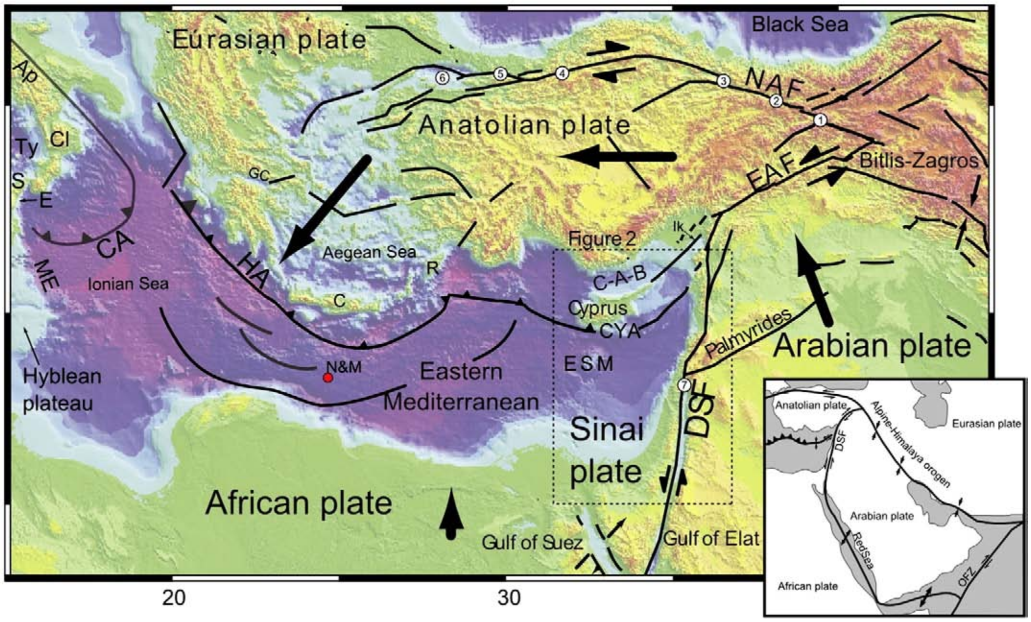

Fig. 1. Geodynamic settings of the eastern Mediterranean basin showing the differential convergence (subduction/collision) between Africa–Sinai–Arabia and Eurasia–Anatolia. Large arrows indicate general plate motion, small arrows represent relative motion. Abbreviatios: S — Sicily; E — Etna volcano; Ty — Tyrrhenian Sea; Cl — Calabria; Ap — Apennine mountains; CA — Calabrian arc; ME — Malta escarpment; HA — Hellenic arc; GC — Gulf of Corinth; C — Crete; R — Rhode; N&M — Napoli and Milano mud volcanoes; C-A-B — Cilicia–Adana basins; ESM — Eratosthenes Seamount; CYA — Cyprus Arc; IK — Iskanderun bay; NAF — North Anatolian fault; EAF — East Anatolian fault; DSF — Dead Sea fault. Numbers along the NAF and DSF represent the following basins that developed as pull-aparts and were crossed by a diagonal through-going fault: (1) Erzincan, (2) Suşehri–Gölova, (3) Erbaa–Niksar, (4) Bolu–Yeniçağa, (5) Izmit–Sapanca, (6) Marmara Sea and (7) Hula. Inset: regional tectonic settings. DSF — Dead Sea fault; OFZ — Owen fracture zone.

The current work pieces together a wealth of accumulated knowledge published in the literature into a coherent tectonic reconstruction of the eastern Mediterranean convergence system during the beginning of the Pleistocene. Results indicate that the most severe interruption in the convergence between the African–Sinai–Arabian and the Eurasian–Anatolian plates initiated with the arrival of Eratosthenes Seamount to collide with the Cyprus Arc during the beginning of the Pleistocene. Hence, the reconstruction brings forward the early-to-mid Pleistocene tectonic transition in order to identify its triggering mechanism.

2. Early-to-mid Pleistocene tectonic transition across the eastern Mediterranean

A major kinematic transition occurred across the eastern Mediterranean region during the early Pleistocene, termed here the early-to-mid Pleistocene tectonic transition. Approximately synchronous structural modifications which are recorded along plate boundaries as well as within the plates are integrated below and in Fig. 2 for the first time to give a full tectonic picture of the region.

2.1. Arabian plate and the Dead Sea fault

Eurasia indentation by the underthrusting northern Arabia resulted in the uplift of the Zagros belt (McQuarrie et al., 2003; Faccenna et al., 2006; Reilinger et al., 2006) and activation of the East Anatolian fault since the Pliocene (Fig. 1; Westaway and Arger, 2001). Along the River Euphrates in southeast Turkey, northern Syria and western Iraq uplift of terrace deposits increased in the late early Pleistocene (Demir et al., 2007). Further south, branches of the Dead Sea fault ruptured the Palmyrides and the stable part of the Arabian plate from the early Pleistocene (Rukieh et al., 2005). The regional stress field shifted from N to NW striking compression as evident by structural variations along the northern border of Arabia during the early Pleistocene (Zanchi et al., 2002).

Increasing convergence between the Sinai and Arabian plates along the central and northern segments of the Dead Sea fault (Gomez et al., 2007) during the early Pleistocene, resulted in synchronous structural modifications along the Dead Sea fault axis. Along the northern Dead Sea fault (Fig. 3), the Ghab basin subsided continuously during the Plio-Pleistocene (Brew, 2001). During the late early Pleistocene the Jisr ash Shugshur basalts (1.3–1.1 Ma; Sharkov et al., 1994) flowed to the northern part of the basin, covering a possible northern transverse faulting (Kopp et al., 1999). A notable phase of transpressive motion, folding and uplift deformed the Syrian coastal ranges (Gomez et al., 2006) and uplifted of the Nahr El-Kabir at the Mediterranean shore of NW Syria during the Pleistocene (Hardenberg and Robertson, 2007); uplifted the Lebanese restraining bend (Dubertret, 1955; Butler et al., 1998; Walley, 1998; Griffiths et al., 2000; Tapponnier et al., 2004; Elias, 2006); and branching developed along the Dead Sea fault Yammunneh main fault (Gomez et al., 2007). However, timing of initiation of the transpressive phase in Lebanon and Syria is often reported to the entire Pliocene–Pleistocene period.

Further south, basaltic units dated from the early Pleistocene onwards are found exclusively east of the Dead Sea fault axis (Weinstein et al., 2006). One of these units, the 1.5–0.5 Ma old Hazbani basalt (Sneh and Weinberger, 2003) flowed southward from its source in southern Lebanon along the Dead Sea fault axis towards the subsiding Hula basin (Heimann, 1990). Similar to the 1.3–1.1 Ma Jisr ash Shugshur basalts, the Hazbani basalt also covered the northern part of the basin, precluding a possible transverse fault from being identified at the surface (Sneh and Weinberger, 2006). At that time the Hula basin ceased to develop as a pull-apart, when a diagonal through-going strike-slip fault propagated between its SE and NW corners. The trajectory of this fault was found to be parallel to the present-day motion along the Dead Sea fault (Schattner and Weinberger, 2008). In temporal and structural coincidence with the development of the Hula diagonal fault, block rotation initiated along the Korazim block (Heimann and Ron, 1993); rapid subsidence of the Sea of Galilee basin was accompanied by depocenter migration to the northeast (Hurwitz et al., 2002); two NE-striking anticlines developed immediately south of the Sea of Galilee (Rotstein et al., 1992; Zurieli, 2002); subsidence of two basins in the southern Jordan valley was accompanied by bending of overlaying monoclines (Lazar et al.,