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Crustal and uppermost mantle structure beneath the continental rifting area of the Gulf of Suez from earthquake tomography

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ABSTRACT

Suez rift is one of the active seismic zones in the northward continuation of the Red Sea, as indicated by recent earthquake records from the Egyptian National Seismological Network (ENSN). We present a new model of P and S wave velocities in the crust and uppermost mantle beneath the Gulf of Suez and surrounding areas, including the northern portion of the Red Sea. Using the records from 94 seismic stations, we analyzed ~66,000 P and ~17,000 S wave arrival times from 9700 events. The travel time tomography inversion was performed using the iterative LOTOS code. The spatial resolutions of the derived models were assessed using several synthetic tests. The most prominent anomaly is a sharp high-velocity anomaly beneath the Red Sea, which is observed in both the P and S models at all depth intervals. We interpret this anomaly to be oceanic crust that was formed through extension associated with a dispersed system of spreading centers. Beneath the Gulf of Suez, the upper and middle crusts appear to be strongly heterogeneous and are dominated by low-velocity anomalies, indicative of the continental nature of the crusts. In contrast, at a depth of 30 km, we observe a prominent high-velocity anomaly along Gulf of Suez, which is interpreted to be the result of crustal thinning associated with extension between the Sinai block and the African Plate. The thickness of the crust beneath the rift is estimated to be approximately 25 km, whereas that in the surrounding areas appears to be 30–35 km. In the northwestern part of the area, we observe a low-velocity zone in the middle and lower crusts that coincide with intense seismicity and a well-developed system of recent faults on the surface. This region may mark a possible area of northward propagation of the Suez Rift zone.

1. Introduction

The Gulf of Suez is located in a continental-type rift system at the northward continuation of the Red Sea, Egypt. It is approximately 350 km long and between 30 and 50 km wide. The Suez Rift valley is approximately twice as wide as the water-filled area of the Gulf itself. The rift is bounded by the Precambrian Sinai block and the Nubian plate (Fig. 1) and is cut by numerous extensional faults (red lines in Fig. 2, e.g., Darwish and El Araby, 1993; Bosworth and McClay, 2001). Reflection seismic studies have shown that the depth of the upper boundary of the basement in the rift valley is highly variable and can reach a depth of 8 km (e.g., Bosworth, 1994; Hurukawa et al., 2001). However, this valley is completely filled with recent sediment, making the bottom of the Gulf flat and shallow. This depositional pattern may indicate a relatively slow extension rate in the Suez rift, in which any subsidence of the basement is fully compensated by the sedimentary fill. For comparison, much smaller pull-apart basins in the Gulf of Aqaba and the Dead Sea are more clearly expressed in relief (Fig. 1) because of much faster subsidence rates (e.g., Ten Brink et al., 1993). The development of the Suez Rift is related to the ongoing opening of the Red Sea, especially the northern part of the Red Sea, and has been dated to the Oligocene (ca. 28 Ma) (Said, 1990). According to certain authors (e.g., Khalil and McClay, 2001), the Suez Rift ceased extension in the Miocene (ca. 5 Ma); however, according to other authors, it still remains active. The latter hypothesis is supported by the seismic activity present in the Gulf of Suez area (e.g., Ambraseys et al, 1994; El-Sayed et al., 1994; Al-Tarazi, 1999 and our results presented later) and GPS observations (e.g., McClusky et al., 2003; Mahmoud et al., 2005) that show present-day extension. Debates still exist regarding the northward continuation of the rift. Certain authors suggest that the seismically active fault system of the Cairo–Suez Relay in the direction of the Manzala Rift (at the Nile Delta) is a possible direction of the future

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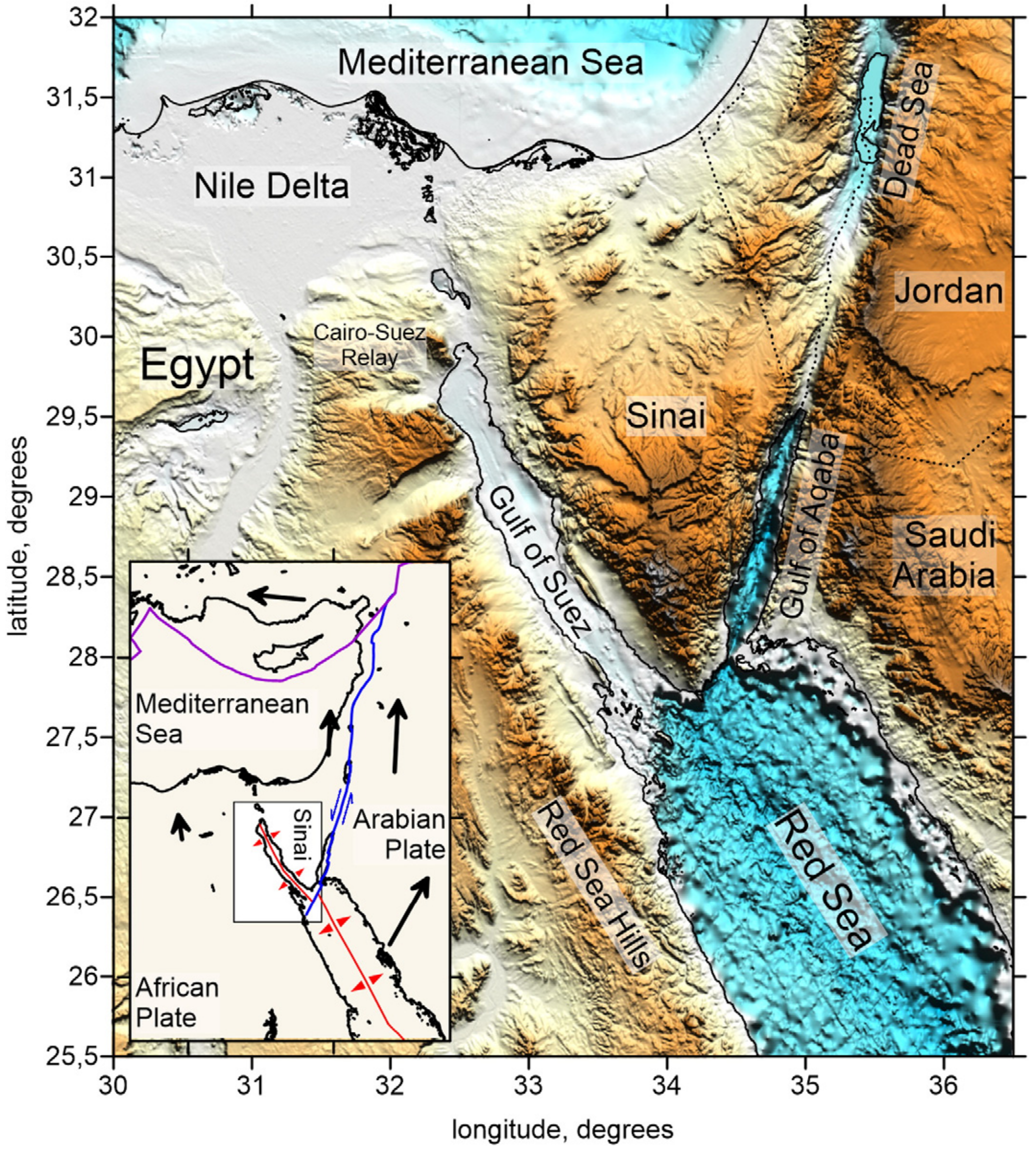

Fig. 1. Topography and the main geographic units in the study area. Inset is a simplified tectonic framework: black arrows schematically indicate the directions of the plate movements and their velocities (simplified after McClusky et al., 2003); blue line is transform fault; red lines are extensional boundaries; and violet line is a conversion border. White rectangle marks the study area.

opening of the rift (e.g., Bosworth, 1985) because this zone is presently one of the most seismically active areas in Egypt (e.g., Albert, 1987).

The origin of the Suez rifting is thought to be attributable to clockwise rotation of the Arabian Plate with respect to the African (Nubian) Plate (e.g., Richardson and Harrison, 1976; Le Pichon and Gaulier, 1988), as schematically shown in the inset in Fig. 1. Along the Eastern coast of the Red Sea, the Arabian Plate moves to the NNE, creating an extensional component in the Red Sea area. Further to the north, the orientation of the Arabian plate displacement changes to northward and becomes parallel to the Dead Sea Transform fault (DST). The western flank of the DST is also moving northward with respect to the African plate, but at a slower rate compared with the Arabian Plate. This difference in velocities leads to strike-slip displacements along the DST. Due to the existence of friction along the DST, the Arabian Plate accelerates the northward displacement of the Sinai block. In turn, the relatively faster northward movement of the Sinai block with respect to the African Plate leads to extension with a small strike-slip component in the Suez Rift valley (e.g., Francheteau and Le Pichon, 1972). According to this perspective, the extensional displacements in the Suez rift system are transmitted from the Arabian Plate through the DST.

On a local scale, complex tectonic processes are occurring within the Suez Rift valley and its surroundings. Based on the analysis of the basement shape and fault orientations, three separate zones with different strata dip directions have been identified (e.g., McClay et al., 1998; Bosworth and McClay, 2001). In Fig. 2, these zones are termed North, Middle and Southern Zones (NZ, MZ and SZ, respectively). In the literature, the NZ is also called the Darag Basin, the MZ is named the Belayim Province or October Basin, and the SZ is often identified as an entrance area to the Gulf of Suez. These basins are separated by the Zafarana and Morgan accommodation zones (ZAZ and MAZ, respectively), in which the orientations of the strata change abruptly to the opposite direction. The cause of this accommodation is actively debated and remains unclear.

The northern Red Sea region is characterized by extensive and continuous earthquake activity. The majority of the northern Red Sea seismicity is confined to the well-defined Sinai subplate boundaries (the Gulf of Suez, the Gulf of Aqaba and the axial rift of the Red Sea), as indicated by the recent catalogues of Egyptian National Seismological Network (ENSN) shown in Fig. 3. In the Gulf of Suez, earthquakes seem to be confined to the so-called axial trough and the shear zones along