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The crustal structure of Egypt and the northern Red Sea region

Ahmed Hosny [a,*], Andrew Nyblade [b,c]

[a] Seismology Dept., National Research Institute of Astronomy and Geophysics, (NRIAG), 11421 Helwan, Cairo, Egypt
[b] Department of Geosciences, Pennsylvania State University, University Park, PA 16802, United States
[c] School of Geosciences, The University of the Witwatersrand, Johannesburg, South Africa

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ABSTRACT

P-wave receiver functions from 26 stations in the Egyptian National Seismic Network (ENSN) have been modeled using the H-k stacking method and in a joint inversion method with Rayleigh wave group velocities to investigate crustal structure across Egypt and the northern Red Sea region. The new estimates of crustal structure, when combined with previous results, show that along the rifted margins of the Red Sea, Gulf of Suez and Gulf of Aqaba crustal thickness ranges from 25 to 30 km, the average crustal Vp/Vs ratio is 1.77, and the average crustal shear-wave velocity is 3.6 km/s. Beneath northern and central Egypt, including the Sinai Peninsula, crustal thickness ranges from 32 to 38 km, the average crustal Vp/Vs ratio is 1.79, and the average crustal shear-wave velocity is 3.5 km/s. Beneath southern Egypt, crustal thickness ranges from 35 to 40 km, the average crustal Vp/Vs ratio is 1.76, and the average crustal shear-wave velocity is 3.7 km/s. In southern Egypt, the crust is also characterized by a 10–20 km thick mafic lower crust. These findings indicate that crust along the rifted margins of the northern Red Sea, and Gulfs of Suez and Aqaba have been thinned by about 5 to 10 km. The thick mafic lower crust in southern Egypt can be attributed to suturing during the Neoproterozoic collision of east Gondwana against the Sahara metacraton. Overall, the structure of the crust in Egypt away from the northern Red Sea region is similar to the structure of Precambrian crust in many other parts of Africa.

1. Introduction

Compared to many parts of the African continent (i.e., eastern and southern Africa), little is known about crustal structure in the northeastern corner of the continent. In this paper, we address the lack of knowledge by modeling crustal structure beneath 26 stations in the Egyptian National Seismic Network (ENSN), and then combining our results with results from previous studies to characterize crustal structure across Egypt and the northern Red Sea region.

Over the past decade, many of the seismic stations in the ENSN have been upgraded with broadband sensors, while others are still equipped with three component short period seismometers. Here we use data from the broadband stations and the highest quality short-period stations to obtain 26 new point estimates of crustal thickness, Vp/Vs ratio, and crustal shear-wave velocity. These estimates are obtained by applying the H-k stacking method of Zhu and Kanamori (2000) to teleseismic P-wave receiver functions (PRFs), and by performing a joint inversion of the PRFs with Rayleigh wave group velocities (Julià et al., 2000, 2003).

While much information on African crustal structure has been obtained from modeling PRFs in the past 20 years (e.g., see Kachingwe et al., 2015 and Tugume et al., 2013 for reviews), and the modeling of PRFs from a small number of broadband stations in the ENSN already has been done by Hosny and Nyblade (2014), to date there has not been a comprehensive study of crustal structure in Egypt and the northern Red Sea region using seismic data from the ENSN. The results of this study elucidate the amount of crustal thinning beneath the rifted margins along the northern Red Sea, and Gulfs of Suez and Aqaba, reveal a region of thick mafic lower crust in southern Egypt, and otherwise show that the Precambrian crust underlying much of Egypt is similar to Precambrian crust in many other parts of Africa. New information on crustal structure provided by this study is also important for seismic hazard studies, particularly for improving seismic event locations in regions of Egypt prone to large earthquakes.

2. Geologic background

Fig. 1 shows a simplified geologic map of Egypt. Precambrian basement rocks are exposed primarily in the southern and southeastern parts of the country and within the Sinai Peninsula. Most of the Precambrian basement is part of the northernmost section of the Neoproterozoic Mozambique mobile belt that formed the core of the East African Orogen, as well as the Nubian-Arabian Shield (e.g., Stern and Johnson, 2010 and

* Corresponding author at: Seismology Dept., National Research Institute of Astronomy and Geophysics, (NRIAG), Helwan, Cairo, Egypt.
E-mail address: ahhosny2000@yahoo.com (A. Hosny).

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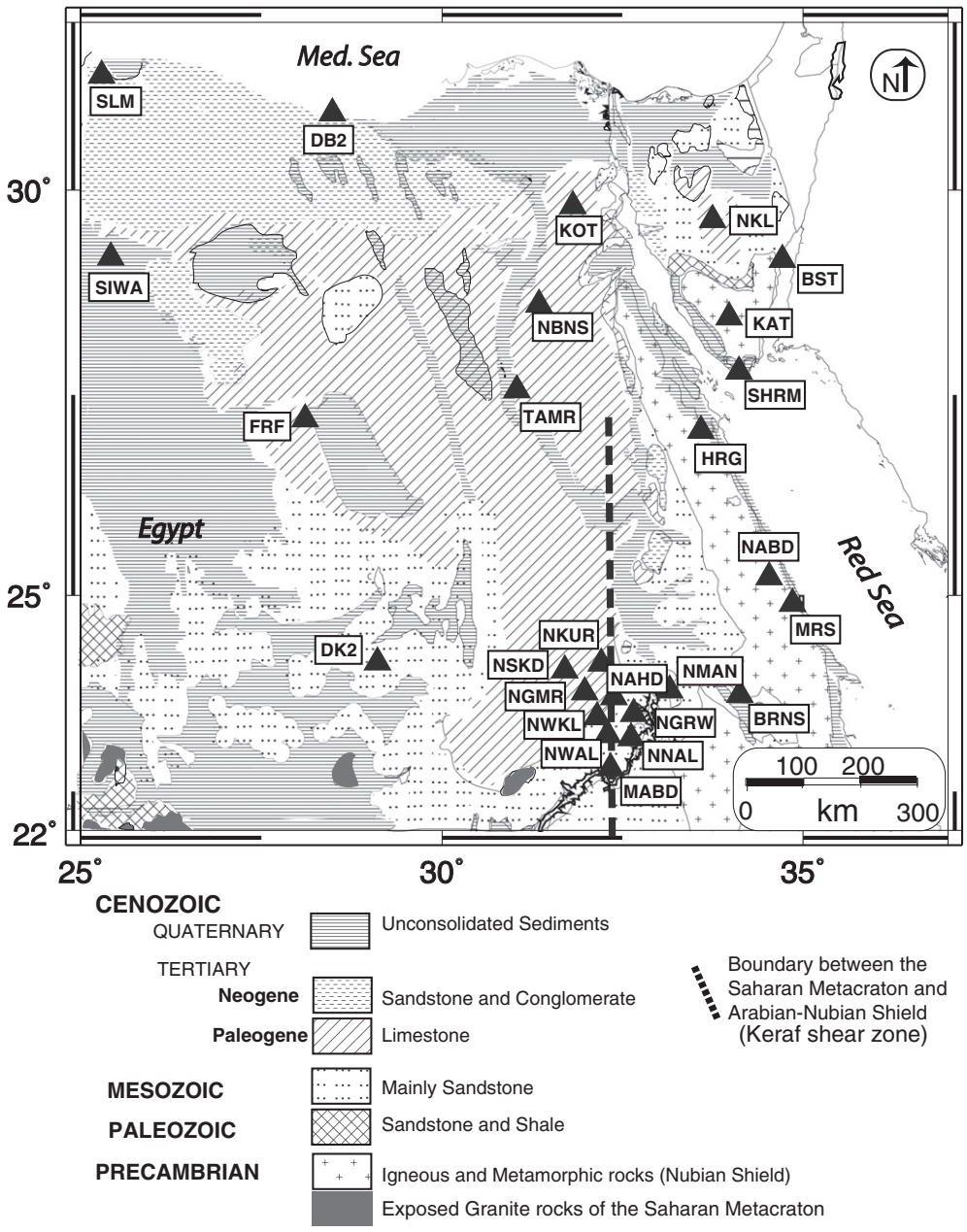

Fig. 1. Generalized geologic map of Egypt, redrawn after Egyptian Geological Survey and Mining Authority (1981). Black triangles show the locations the seismic stations used in this study. Stations DK2, MRS, KAT, and BST are short-period statins and the others are broadband stations.

references therein). However, in southern Egypt, a number of granitic outcrops have been interpreted to be part of the much older so-called Saharan metacraton. The suture between the Neoproterozoic terranes to the east and the metacraton to the west is marked by the Keraf shear zone, which can be traced from northeastern Sudan into southern Egypt (Abdelsalam and Stern, 1996a, 1996b; Abdelsalam et al., 1998) (Fig. 1). The Precambrian basement of the Nubian-Arabian Shield was disrupted along its eastern edge by the formation of the Red Sea in the Late Oligocene and the development of the Dead Sea/Gulf of Aqaba transform fault in the Middle Miocene.

Overlying the Precambrian basement across most of Egypt are Phanerozoic sedimentary rocks. Paleozoic sandstones and shales are found at the base of the sedimentary section, and in many places they are overlain by Mesozoic sandstones, Paleogene and Neogene limestones, sandstones, and conglomerates, and unconsolidated Quaternary sediments.

Crustal structure beneath Egypt has been investigated previously in a number of studies. Using seismic refraction, gravity measurements, and tomography, crustal thickness estimates of 24–27 km have been reported along the margins of the northern Red Sea and the Gulf of Suez (Makris et al., 1983; Marzouk, 1988; Gaulier et al., 1988; Rihm et al., 1991; Salah, 2011; and Abdelwahed et al., 2013). Also, Makris et al. (1983); Rihm et al. (1991); Gaulier et al. (1988), and Abdelwahed et al. (2013) reported crustal thicknesses of 31–38 km inboard of the Red Sea and Gulf of Suez coastlines in northern and central Egypt, while Makris et al. (1983); Dorre et al. (1997) and Abdelwahed et al. (2013) reported crustal thicknesses of 34–40 km in southern Egypt.

Modeling PRFs from data recorded on seven of the ENSN stations, Hosny and Nyblade (2014) reported crustal thicknesses of 35–38 km around Lake Nasser in southern Egypt, and thinner crust (25–26 km) within 50 km of the Red Sea coast in southern and central Egypt. Additionally, for a single station in northeastern Egypt (station KEG), Salah (2011) modeled PRFs and obtained a crustal thickness of 33 km.