Tectonic model of the Arabian-Nubian Shield and the Saharan Metacraton, Northeast Africa, derived from magnetotelluric data

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1. Introduction

Northeast Africa, which today includes the Arabian-Nubian Shield and the Saharan Metacraton, experienced a complex and long history of tectonic events. These include cratonization, which resulted in the thickening of the lithosphere and formation of stable cratons, and decratonization, which occurred as a result of the remobilization and reactivation of the tectonic domains through subsequent orogenies, or destruction of the cratonic root during extensional events.

One outstanding question is the present-day architecture of the lithosphere across this region, including the location of tectonic boundaries and the causes of the vast remobilization events. Several geophysical investigations have been conducted to study the lithosphere, including density and velocity modeling; however, they have mainly focused on the hydrocarbon-rich areas offshore and onshore close to the Gulf of Suez, in addition to a few regional-scale studies.

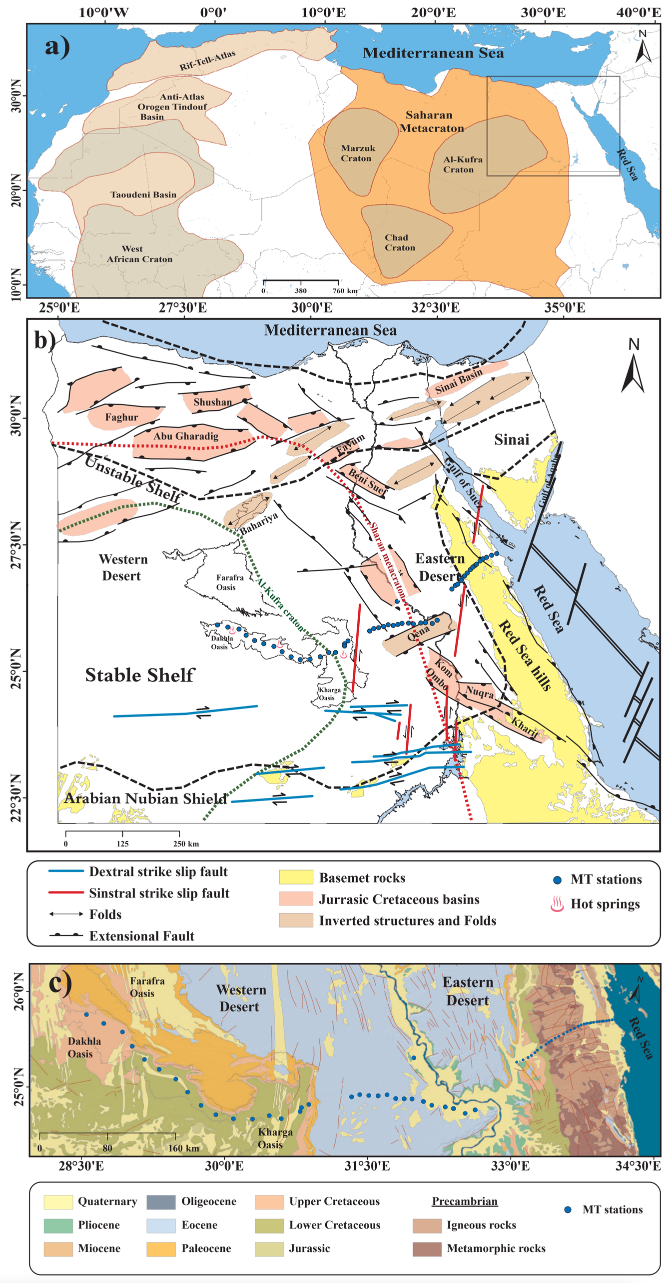

Fig. 1: a) Simplified tectonic map of Northern Africa with the location and extent of the Craton and intra-cratonic basins [1]. **b)** The location of the major extensional rift basins (Mesozoic and Cenozoic), the inverted structures, and the major uplifted fold-fault structural belts of the Late Cretaceous Syrian Arc tectonics [2]. **c)** Geological map of central Egypt and locations of MT stations.

3. Results

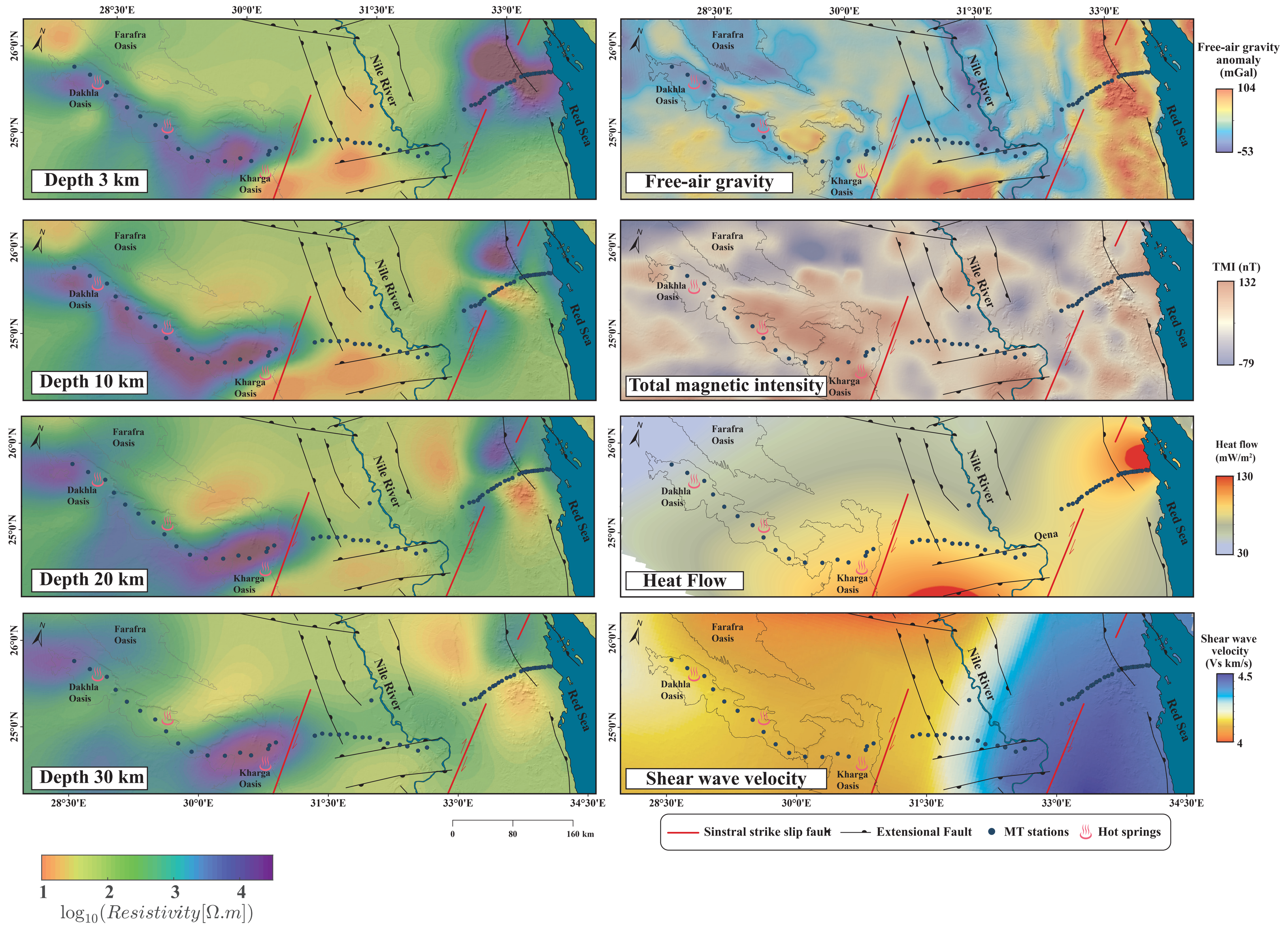

Fig. 4: Depth slices extracted from 3D inversion of MT data at depths of 3, 10, 20, and 30 km. The results are correlated with other geophysical datasets; Free-air gravity anomaly map [4], Total Magnetic Intensity (TMI) [5], Heat flow map [6], , and Shear wave velocity map [7].

- We used the Modular Electromagnetic Inversion system (ModEM [8]) for the 3D inversion. The initial model grid spans over 2500*2200 km with a total depth of 1500 km. It was assigned a homogeneous resistivity of 100 Ωm, taking into account the boundary and bathymetry of the Red Sea. The preferred 3D model presented in this study was obtained through inverting all components of the impedance tensor for periods 10^{-3} - 10^{3} s.
- Depth slices extracted from the preferred model reveal the electrical signature of the Arabian Nubian Shield and the resistive behavior of the remobilized Saharan Metacraton. Comparing the results with existing regional geophysical data shows a good correlation for most of the features observed in the MT dataset, even for the off-profile features such as the conductive anomaly in the center of the area, Qena basin.
- The remobilized Sharan Metcraton exhibits a massive resistive feature interlocated with a more conductive feature, revealing the location of the cratonic remnants that still hold some of its cratonic signatures. A clear structure boundary can be observed between the resistive Arabian Nubian Shield and the more conductive River Nile, promoting the presence of a tectonic boundary that is related to the Late Paleogene-Early Neogene abandoned rift segments [9].

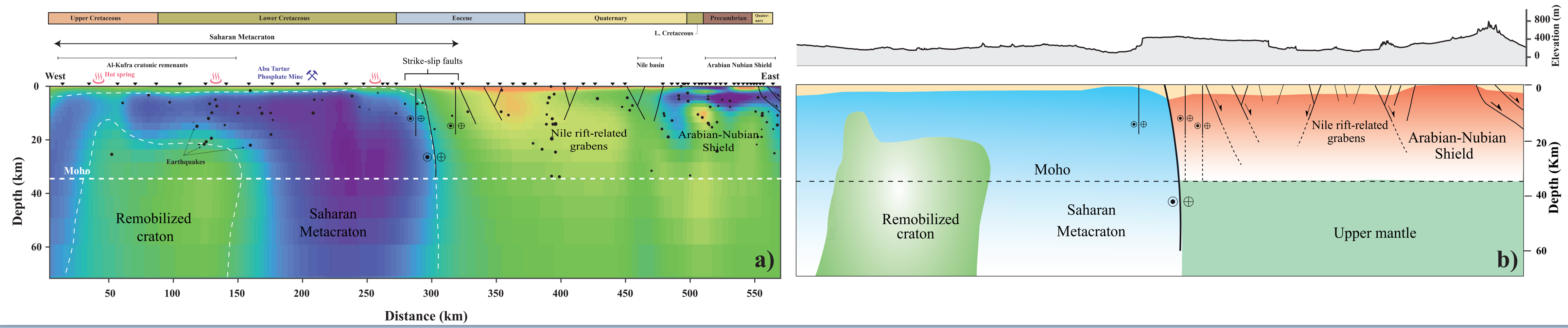

Fig. 5: a) 2D representation of the electrical resistivity along the measured profile with the distribution of earthquake foci [6] and the moho depth [10]. In addition, the variations in the surface geology and main tectonic boundaries are shown in the top panel. **b)** Schematic illustration of the main tectonic boundaries as inferred from MT and prior geological studies.

2. Data and Method

Magnetotelluric (MT) measurements across the central part of Egypt were acquired through 57 stations distributed around most of the tectonic boundaries in the area, such as the Arabian Nubian Shield (ANS) in the eastern desert, the River Nile in the center to Sharan metacraton in the western desert in addition to its cratonic remnants (Al-Kufra). On average, the measurement spacing is about 10 km, although it is denser in some regions (e.g., near ANS) and sparser in others (e.g., near Qena) due to local conditions.

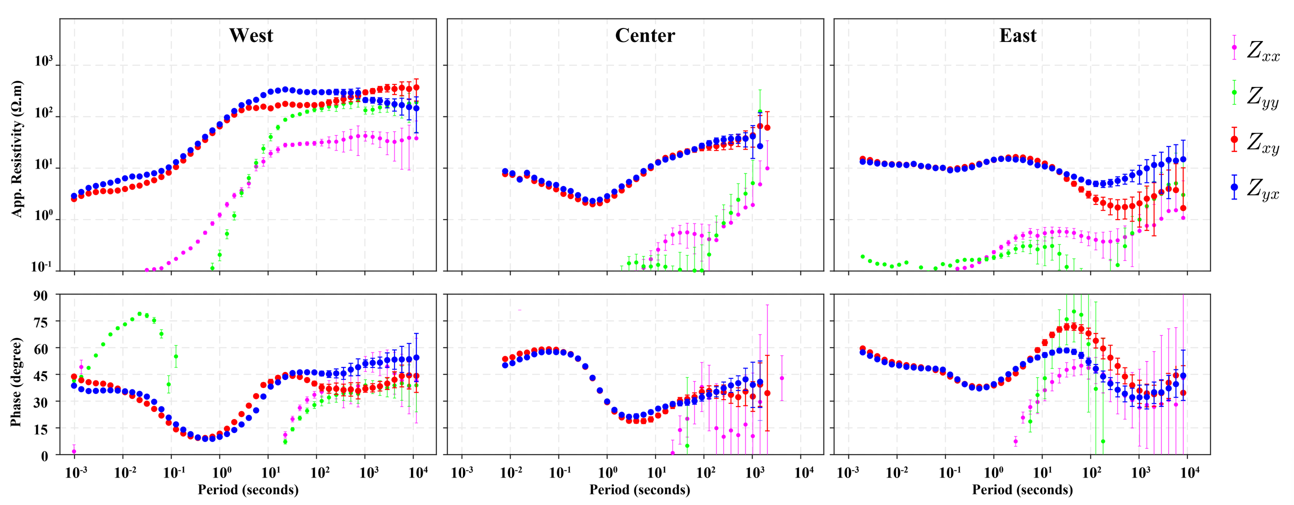

Fig. 2: Selected stations along the profile showing the measured impedance tensors from east to west at ANS, Qena basin, and Sharan Metacraton.

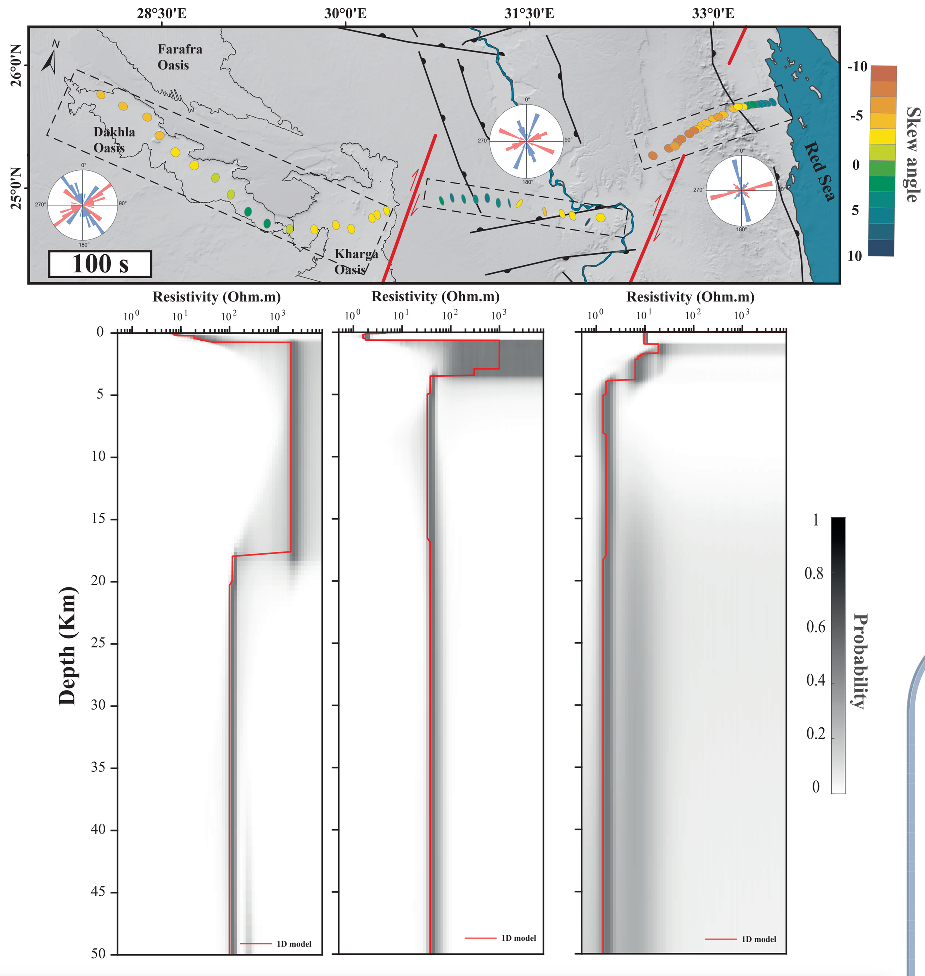

Fig. 3: Top panel shows the geoelectrical strike analysis for the eastern, central, and western sections for periods 1-1000s. Bottom panel demonstrates the probability of resistivities distrubition obtained from 1D probabilistic inversion of the mean impedance tensors of each segment.

Dimensionality and directionality analyses were carried out to assess the complexity of the MT dataset. The regional strike reveals a preferred directions NW–SE, parallel to the Red Sea rift systems. High skew angles (above ±3∘) at higher periods in the eastern desert promote the existence of a complex structure and the necessity of using a 3-D inversion scheme to fully represent the acquired dataset. In addition, probabilistic 1D inversion [3] was performed on the mean impedance tensors at each segment in order to obtain an overview of the range, distribution, and probability of the electrical conductivity in the study area.

4. Conclusion

- The present study unveils novel insights into the lithospheric architecture of Northern Africa, through the introduction of a new dataset based on magnetotelluric (MT) surveys.
- This dataset effectively delineates the distinct crustal structures in the region, including the Arabian-Nubian Shield and the Saharan Metacraton, and accurately clarifies the boundary between these major structures.
- The data reveals a diverse range of structures such as grabens along the Nile valley and Red Sea coast, which are predominantly associated with Cenozoic extensional events.
- In addition, the MT data effectively highlights the presence of a prominent strike-slip fault system in the Western Desert, likely linked to the reactivation of pre-existing structures in the basement.
- Results obtained from the MT survey are consistent with previous findings from regional geophysical data (shear wave velocity, gravity, and magnetics studies). The integration of the MT data with regional geophysical data contributes to a more comprehensive understanding of the geological evolution of the region.

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