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Continental lithosphere of the Arabian Plate: A geologic, petrologic, and geophysical synthesis

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ABSTRACT

The Arabian Plate originated ~25 Ma ago by rifting of NE Africa to form the Gulf of Aden and Red Sea. It is one of the smaller and younger of the Earth's lithospheric plates. The upper part of its crust consists of crystalline Precambrian basement, Phanerozoic sedimentary cover as much as 10 km thick, and Cenozoic flood basalt (harrat). The distribution of these rocks and variations in elevation across the Plate cause a pronounced geologic and topographic asymmetry, with extensive basement exposures (the Arabian Shield) and elevations of as much as 3000 m in the west, and a Phanerozoic succession (Arabian Platform) that thickens, and a surface that descends to sea level, eastward between the Shield and the northeastern margin of the Plate. This tilt in the Plate is partly the result of marginal uplift during rifting in the south and west, and loading during collision with, and subduction beneath, the Eurasian Plate in the northeast. But a variety of evidence suggests that the asymmetry also reflects a fundamental crustal and mantle heterogeneity in the Plate that dates from Neoproterozoic time when the crust formed.

The bulk of the Plate's upper crystalline crust is Neoproterozoic in age (1000–540 Ma) reflecting, in the west, a 300-million year process of continental crustal growth between ~850 and 550 Ma represented by amalgamated juvenile magmatic arcs, post-amalgamation sedimentary and volcanic basins, and granitoid intrusions that make up as much as 50% of the Shield's surface. Locally, Archean and Paleoproterozoic rocks are structurally intercalated with the juvenile Neoproterozoic rocks in the southern and eastern parts of the Shield. The geologic dataset for the age, composition, and origin of the upper crust of the Plate in the east is smaller than the database for the Shield, and conclusions made about the crust in the east are correspondingly less definitive. In the absence of exposures, furthermore, nothing is known by direct observation about the composition of the crust north of the Shield. Nonetheless, available data indicate a geologic history for eastern Arabian crust different to that in the west. The Neoproterozic crust (~815–785 Ma) is somewhat older than in the bulk of the Arabian Shield, and igneous and metamorphic activity was largely finished by 750 Ma. Thereafter, the eastern part of the Plate became the site of virtually continuous sedimentation from 725 Ma on and into the Phanerozoic. This implies that a relatively strong lithosphere was in place beneath eastern Arabia by 700 Ma in contrast to a lithospheric instability that persisted to ~550 Ma in the west. Lithospheric differentiation is further indicated by the Phanerozoic depositional history with steady subsidence and accumulation of a sedimentary succession 5–14 km thick in the east and a consistent high-stand and thin to no Phanerozoic accumulation over the Shield. Geophysical data likewise indicate east–west lithospheric differentiation. Overall, the crustal thickness of the Plate (depth to the Moho) is ~40 km, but there is a tendency for the crust to thicken eastward by as much as 10% from 35–40 km beneath the Shield to 40–45 km beneath eastern Arabia. The crust also becomes structurally more complex with as many as 5 seismically recognized layers in the east compared to 3 layers in the west. A coincident increase in velocity is noted in the upper-crust layers. Complementary changes are evidenced in some models of the Arabian Plate continental upper mantle, indicating eastward thickening of the lithospheric mantle from ~80 km beneath the Shield to ~120 km beneath the Platform, which corresponds to an overall lithospheric thickening (crust and upper mantle) from ~120 km to ~160 km eastward. The locus of these changes coincides with a prominent magnetic anomaly (Central Arabian Magnetic Anomaly, CAMA) in the extreme eastern part of the Arabian Shield that extends north across the north-central part of the Arabian Plate. The CAMA also coincides with a major structural boundary separating a region of northerly and northwesterly basement trends in the west from a region of northerly and northeasterly trends in the northeastern part of the Plate, and with the transition from high-stand buoyant Shield to subsided Platform. Its coincidence with geophysically indicated changes in the lower crust and mantle structure suggests that a

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fundamental lithospheric boundary is present in the central part of the Arabian Plate. The ages and isotopic characteristics of xenoliths brought to the surface in Cenozoic basalt eruptions indicate that the lower crust and upper mantle are largely juvenile Neoproterozoic additions, meaning that the lower crust and upper mantle formed about the same time as the upper crust. This implies that the lithospheric boundary in the central part of the Arabian Plate dates from Neoproterozoic time. We conclude that lithospheric differentiation across the Arabian Plate is long lived and has controlled much of the Phanerozoic sedimentary history of the Plate.

Contents

1. Introduction

This paper is a review of public-domain information about the composition and structure of the continental lithosphere of the Arabian Plate (Fig. 1). This is the twelfth largest and one of the youngest of the Earth's lithospheric plates, having originated ~25 Ma ago when rifting to form the Gulf of Aden and Red Sea split off a fragment of the African continent. Its crust comprises Precambrian crystalline basement, well exposed in the west and locally exposed in the east, a Phanerozoic sedimentary succession that is up to 10 km thick, and fields of Cenozoic basalt (harrat) unconformable on the crystalline basement and Phanerozoic sedimentary rocks in the western and northwestern parts of the Plate. The Arabian Shield is mostly Neoproterozoic but locally contains tectonically intercalated Archean and Paleoproterozoic rocks. Crystalline basement in the east of the Plate is also Neoproterozoic, but appears to have a geologic history different to that of the Shield.

The primary objective of our review is to summarize current information about the continental lithosphere of the Arabian Plate with the aim of highlighting regional similarities and differences in composition and structure. This is done for two purposes. One is to determine whether lithospheric differences are discernable across the plate that may correlate with or point to tectonic boundaries within the Plate. The other is to consider possible causes for the topographic and geologic asymmetry of the Plate. The upper crust of the Plate displays a long and complex history of crustal accretion, mostly during Neoproterozoic time (1000–544 Ma). It evolved through a large variety of magmatic, depositional, structural, and metamorphic events, and has a large geographic extent. It is pertinent, therefore, to consider whether the lower crust and upper mantle are similarly complex and whether tectonic boundaries recognized in the upper crust are mirrored by variations in the lower crust and upper mantle. These variations in lithospheric structure may be important for understanding along-strike variations in the Arabia–Eurasian convergence zone, as briefly discussed by Stern and Johnson (2008). It is also pertinent to question whether the geologic and topographic asymmetries of the Plate originated recently or reflect a long-lived cause. The Plate's surface lies 2000–3000 m above sea level on the eastern margin of the Red Sea and northern margin of the Gulf of Aden (Bosworth et al., 2005) and descends to sea level in the Gulf and near sea level in the Euphrates–Tigris valley. Precambrian rocks of the Arabian Shield dominate the western part of the Plate, but Phanerozoic rocks dominate elsewhere and form a succession that is progressively younger and thicker away from the Shield. The immediate cause of these asymmetries is marginal uplift associated with Red Sea and Gulf of Aden rifting and mantle processes which have operated during the past 25 million years since the onset of rifting, resulting in a gentle tilt of the Plate toward the north and east. But a further issue is whether the asymmetries also reflect a fundamental east–west contrast in crustal and upper-mantle structure and composition that pre-dates Cenozoic rifting and may have existed since at least the end of Precambrian time.

Geologic, petrologic, and geophysical data about the thickness, structure, and composition of the continental crust and upper mantle of the Arabian Plate are summarized and synthesized as a means of addressing these questions. Extensive geologic and geophysical, mainly magnetic, surveying over the Shield provides a rich multidisciplinary dataset constraining the origin and vertical structure for the continental crust in the western part of the Arabian Plate. Establishing the origin and structure of buried Arabian Plate continental crust is more problematic, at least partly because public-domain geologic and geophysical data are relatively sparse, and other datasets are proprietary, having been acquired during petroleum exploration over the Arabian Platform. Consequently, modeling the crust away from basement exposures