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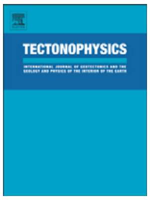

Review Article

Precambrian crustal structure in Africa and Arabia: Evidence lacking for secular variation

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ABSTRACT

We review the thickness and shear wave velocity structure of Precambrian crust in Africa and Arabia, where over 90% of the landmass is comprised of Archean and Proterozoic terranes, and examine the data for evidence of secular variation. The data come from many published 1D shear wave velocity profiles obtained by jointly inverting receiver functions and surface wave dispersion measurements, 35 new 1D shear wave velocity profiles for locations in eastern Africa, and a new map of crustal thickness for Africa and Arabia derived from modeling satellite gravity data. We find for both Archean and Proterozoic terranes a similar range of crustal thicknesses (~33–45 km), similar mean crustal shear wave velocities (~3.6–3.7 km/s), and similar amounts of heterogeneity in lower crustal structure, as reflected in the thickness of lowermost crust with shear wave velocities ≥4.0 km/s. There is little evidence for secular variation in crustal structure, indicating that there may have been few changes over much of Earth's history in the processes that form the continental crust. Post-formation tectonic events also may have modified many of the terranes to such an extent that secular trends arising from crustal genesis may be difficult to recognize.

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1. Introduction

Secular variation in Precambrian crustal structure has long been debated and is important for understanding the genesis and evolution of continental crust because most continental crust worldwide formed during the Precambrian (Goodwin, 1996). Is Archean crust thinner and less mafic than Proterozoic crust, for example, as suggested by Durrheim and Mooney (1991, 1994), reflecting a change in mantle temperature and/or the style of plate tectonics through time, or does Archean and Proterozoic crust have similar thickness and composition, suggesting that tectonic processes affecting crustal genesis and evolution have not changed significantly during the Precambrian (e.g., Rudnick and Fountain, 1995)?

In this study, we address that question by examining the shear wave velocity structure and thickness of Precambrian crust in Africa and Arabia obtained from seismic and gravity models. Point estimates of crustal thickness and velocity structure are taken from 1D shear wave velocity models constructed by jointly inverting receiver functions and surface wave dispersion measurements. Using velocity models constructed with the same inversion method applied to similar kinds of data (i.e., receiver functions and surface wave dispersion) makes it simpler to determine the variability, or the lack thereof, in crustal structure between terranes. To increase the number of terranes for which 1D shear wave velocity models are available, we also present new velocity models for 35 locations in eastern Africa. The number of Precambrian terranes for which 1D shear wave velocity models are available far exceeds the number of terranes for which other kinds of velocity models are available, in particular P wave models derived from seismic refraction profiles.

For examining Precambrian crustal structure in regions where there are no seismic constraints, we use a model of crustal thickness derived from satellite gravity data benchmarked against many (377) receiver-function estimates of crustal thickness. Combining results from both methods (seismic and gravity) enables us to examine in greater detail than previously possible similarities and differences between Archean and Proterozoic crustal structure over large parts of Africa and Arabia.

The results of this study, which show no obvious secular trends in Precambrian crustal structure, lend support to previous studies arguing that few differences exist, if any, between Archean and Proterozoic crust. This study also serves as a review of Precambrian crustal structure in Africa and Arabia, which represents 29% of Precambrian crust globally (Goodwin, 1996). For clarity, we refer to “crustal thickness” in this paper as the total thickness of the crust from the surface to the Moho, and we use the term “Moho depth” to indicate the distance from sea level to the Moho.

2. Geologic background

The Precambrian terranes in Africa and Arabia are diverse, including a number of Archean cratons of various size and numerous Paleoproterozoic, Mesoproterozoic, and Neoproterozoic mobile belts. Several interior basins hosting Precambrian through Cenozoic sediments cover parts of many of these terranes. The Neoproterozoic Pan-African orogenic system is extensively developed across most of Africa and Arabia and separates the Precambrian framework into five regions, southern (Kalahari), central (Congo), north-central (East Saharan), northwestern (West African), and northeastern (Arabian-Nubian Shield) (Goodwin, 1996). We briefly summarize the Precambrian geology (terranes and sub-terranes) of the regions for which crustal shear wave velocity profiles are available (Table 1), as well as review results from previous work on seismic imaging of crustal structure. We refer the reader to Begg et al. (2009) for a review of the geology of the other regions.

2.1. Precambrian tectonic framework and crustal structure of the southern region

At the core of the Precambrian framework of southern Africa is the Archean Kaapvaal and Zimbabwe Cratons sutured together by the Archean and Paleoproterozoic Limpopo Belt (Fig. 1). To the west of the Zimbabwe Craton lies the Paleoproterozoic Okwa-Magondi Belt, and to the south and southwest of the Kaapvaal Craton lies the Mesoproterozoic Namaqua–Natal Belt and the Kheis Province (de Wit et al., 1992) (Fig. 1).

The Kaapvaal Craton is an Archean granite-greenstone terrane that formed between 3.7 to 2.7 Ga (de Wit et al., 1992). It can be divided into several sub-terranes based on the age distribution of outcropping rocks and major structural boundaries. The major sub-terranes include the Kimberly (3.0–2.8 Ga), Pietersburg (3.0–2.8 Ga), Witwatersrand (3.6–3.1 Ga), and Swaziland (3.6–3.1 Ga) blocks. The Tokwe terrane forms the core of the Zimbabwe Craton and consists of granite-greenstone belts that formed between 3.6 and 2.5 Ga (Dirks and Jelsma, 2002). The Limpopo Belt consists of highly metamorphosed granite-greenstone and granulite terranes that underwent a series of orogenic events between 2.0 and 3.0 Ga during the collision of the Kaapvaal and Zimbabwe Cratons (Krammers et al., 2006; McCourt and Armstrong, 1998).

The Magondi Belt formed between 2.0 and 1.8 Ga and is dominated by the passive margin shelf sediments of the Magondi supergroup thrust eastwards onto the Zimbabwe Craton during the Magondi Orogeny (McCourt et al., 2001). In the Okwa Belt, which formed about 2.05 Ga, rocks correlate to the Magondi Belt suggesting a continuous northeast trending orogenic belt.

The Namaqua–Natal Belt is comprised of igneous and supracrustal rocks accreted against the Kaapvaal Craton during the Namaqua Orogeny (1.2–1.0 Ga) (Cornell et al., 2006). The Kheis Province separates the Kaapvaal Craton from the Namaqua–Natal Belt and is comprised of siliciclastic rocks of the Olifantshoek supergroup (1.2–1.0 Ga).

Early studies of the crust in southern Africa mainly used seismic recordings of mine tremors associated with gold mining activity in the Witwatersrand basin (e.g., Gane et al., 1949, 1956; Hales and Sacks, 1959; Willmore et al., 1952). Hales and Sacks, 1959 describe a two-layered crust in the eastern Kaapvaal Craton with a crustal thickness of 37 km and a ~24 km thick upper crustal layer with P and S wave velocities of 6.0 and 3.6 km/s, respectively. They also found a lower crustal layer ~13 km thick with P and S wave velocities of 7.0 and 4.0 km/s, respectively. In an early surface wave study, Bloch et al. (1969) inverted Rayleigh and Love wave group and phase velocities from regional earthquakes and obtained a Poisson's ratio of 0.28 for the lower crust in the northern Kaapvaal Craton and a crustal thickness in the range of 40–45 km. The first seismic refraction studies in and around the Witwatersrand basin yielded a crustal thickness of 35 km and lower crustal P wave velocities in the