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The nature of the crust in southern India: Implications for Precambrian crustal evolution

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[1] We present crustal thickness and Poisson's ratio determinations from receiver function analyzes at 32 sites on the Archaean and Proterozoic terrains of South India. The crustal thickness in the late Archaean (2.5 Ga) Eastern Dharwar Craton varies from 34–39 km. Similar crustal thickness is observed beneath the Deccan Volcanic Province and the Cuddapah basin. The most unexpected result is the anomalous present-day crustal thickness of 42–51 km beneath the mid-Archaean (3.4–3.0 Ga) segment of the Western Dharwar Craton. Since the amphibolite-grade metamorphic mineral assemblages (5–7 Kbar paleopressures) in this part of Western Dharwar Craton equilibrated at the depths of 15–20 km, our observations suggest the existence of an exceptionally thick (57–70 km) crust 3.0 Ga ago. Beneath the exhumed granulite terrain in southernmost India, the crustal thickness varies between 42–60 km. The Poisson's ratio ranges between 0.24–0.28 beneath the Precambrian terrains, indicating the presence of intermediate rock type in the lower crust. These observations of thickened crust suggest significant crustal shortening in South India during the Archaean. *INDEX TERMS:* 7203 Seismology: Body wave propagation; 7205 Seismology: Continental crust (1242); 7299 Seismology: General or miscellaneous. **Citation:** Gupta, S., S. S. Rai, K. S. Prakasam, D. Srinagesh, B. K. Bansal, R. K. Chadha, K. Priestley, and V. K. Gaur, The nature of the crust in southern India: Implications for Precambrian crustal evolution, *Geophys. Res. Lett.*, *30*(8), 1419, doi:10.1029/2002GL016770, 2003.

1. Introduction

[2] The South India shield is an amalgamation of several crustal blocks formed by geodynamic processes operating from mid-Archaean to Neo-Proterozoic time. The main geological provinces in southern India are shown in Figure 1. The Dharwar Craton is an Archaean continental fragment with a continuously-exposed crustal section from low-grade gneisses and greenstone basins in the north to granulites in the south. At the surface, the craton is divided into the Western Dharwar Craton (WDC) and Eastern Dharwar Craton (EDC) by the 2.5 Ga Closepet granite. The central part of WDC hosts 3.4 Ga greenstone belts while the northern part constitutes the 2.6 Ga Dharwar Basins [*Taylor et al.*, 1984].

[3] The EDC crust consists largely of granitoid rocks, all juvenile additions to the continental crust from 2.6–2.5 Ga. To the east the EDC is wrapped by the Proterozoic Cuddapah Basin (CB) and the Eastern Ghat granulite terrain. The northern part of EDC and the Bastar Craton are separated by the Proterozoic Godavari Graben (Figure 1). The 65 Ma flood basalt province of the Deccan Volcanic Province (DVP) covers the NW part of Dharwar craton. It is not clear whether rocks of the WDC or EDC form the basement of the flood basalt province.

[4] The most important feature of the Dharwar craton is the transition from the low- to medium-grade granite - greenstone terrain in the north to the high-grade granulite terrain in the south, the Southern Granulite Terrain (SGT). The paleopressures gradually increase from 3 Kbar in the north to 5–7 Kbar in the center and 9–10 Kbar in the south of the Dharwar craton. The granulite evolution is thought to have occurred at around 2.5 Ga [*Grew and Manton*, 1984], coeval with the Closepet granite emplacement [*Harris and Jayaram*, 1982].

[5] South India has undergone a complex terrain accretion since the mid-Archaean and has poorly-defined tectonic boundaries at depth. The growth of the South Indian continental crust will be better understood once the variation in crustal structure across South India is known. In this study, we present constraints for crustal thickness and composition (from the Poisson's ratio) in South India derived from receiver function analyzes of teleseismic waveforms.

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2. Data and Methodology

[6] We analyze seismograms from 32 broadband seismographs in South India (Figure 1). The number of high signal-to-noise receiver functions varied from at least 20 to more than 100 for individual stations. Stacked receiver functions (5° distance and azimuth bins) for individual stations arranged by geologic provinces are shown in Figure 2. This plot shows significant variation in *Ps* arrival times, reflecting variations in crustal thickness and/or Poissons's ratio (σ). We estimated the crustal thickness and σ using the stacking procedure of *Zhu and Kanamori* [2000], with *Ps*, *PpPms*, *PsPms* + *PpSms* being weighted 0.7, 0.2 and 0.1 respectively. We used the average crustal *P*-wave speed of 6.45 km s^{-1} [*Kaila and Krishna*, 1992] in making the crustal thickness vs. V_p/V_s stacks. Figure 3 shows the contour plots for crustal thickness and V_p/V_s for several stations. The average error is $\pm$0.5 km and $\pm$0.015 for the crustal thickness and V_p/V_s, respectively.

3. Results

[7] Figure 4 is a Moho depth map for South India which combines the results from the 32 receiver function measurements and 14 estimates from seismic refraction studies employing ray tracing analysis [*Kaila and Krishna*, 1992; *Sarkar et al.*, 2001; *Reddy et al.*, 2003]. The crust beneath the EDC, DVP and CB is remarkably similar in both receiver function waveforms and crustal parameters with a fairly transparent crust containing no marked apparent mid-crustal interfaces. The crustal thickness varies from 34 to 36 km (except at KDR ~39 km) and the Poisson's ratio ranges from 0.24 to 0.27. *Gaur and Priestley* [1996], *Kumar et al.* [2001], and *Rai et al.* [2003] report similar observations from sparser receiver function measurements in South India.

[8] Surprising results come from the mid-Archaean WDC where the receiver functions are more complex and crustal thickness varies between 42–51 km. The Poisson's ratio at most stations in the WDC varies from 0.25 to 0.27, similar to that in the EDC. The thickest crust (~60 km) is observed beneath MTP located near the Nilgiri Hills (elevation 2.7 km) in the SGT. The other highly elevated station, KOD (2.4 km), has a 43 km-thick crust. The average crustal thickness in SGT is about 40–50 km and σ ~0.25–0.26 with the exception of MTP (H ~60 km, σ = 0.28). The crust beneath KDM in the Proterozoic Godavari Graben is 44 km-thick.

[9] Figure 5 shows the variability of the Moho depth along two crustal cross-sections across South India: AA′

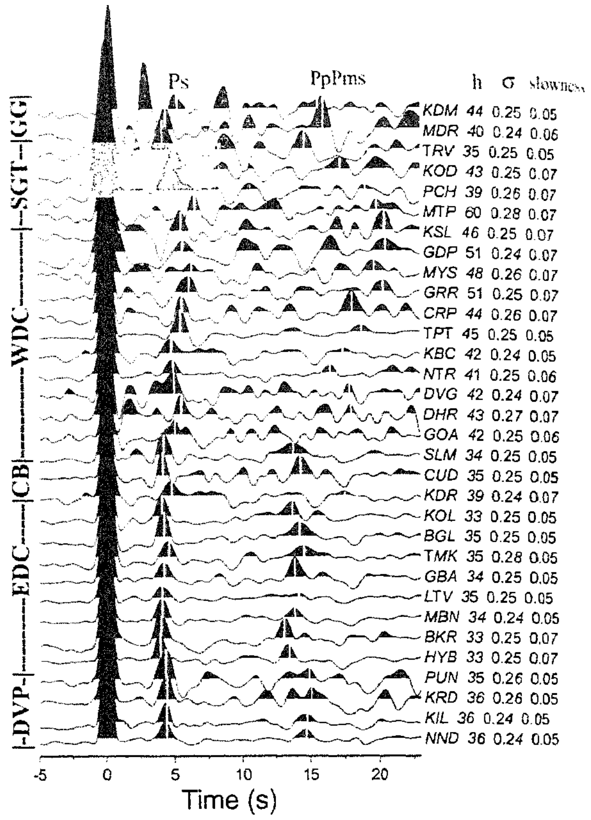

Figure 2. Stacked radial receiver functions organized according to geological provinces. The Moho conversion and reverberations are indicated on the receiver functions. The geological provinces are denoted to the left of the receiver functions and the crustal thickness, the average Poisson's ratio, and average slowness for the stack are given to the right of the receiver function. A clear time shift in the *Ps* phase is visible for stations in the WDC and SGT compared to stations in the EDC.

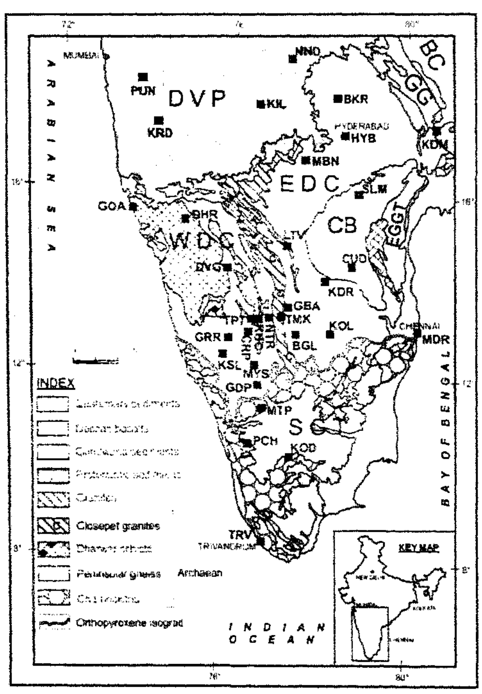

Figure 1. Generalized geotectonic map of south India. Important geological blocks include EDC - Eastern Dharwar Craton, WDC - Western Dharwar craton, DVP - Deccan Volcanic Provinces, SGT - Southern Granulite Terrain, CB - Cuddapah Basin, GG - Godavari Graben, EGGT - Eastern Ghat Granulite Terrain and BC - Bastar Craton. Location of broadband seismic stations are indicated by filled squares.

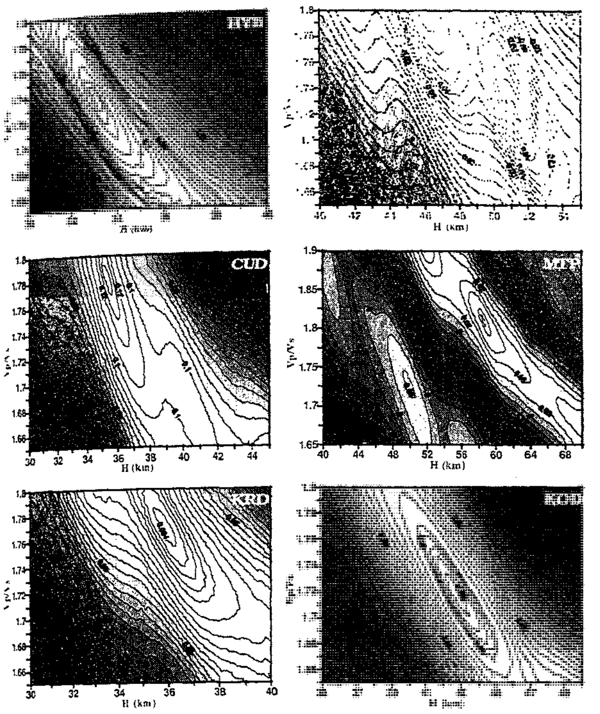

Figure 3. Vp/Vs ratio vs crustal thickness (H) stack for six stations in South India.

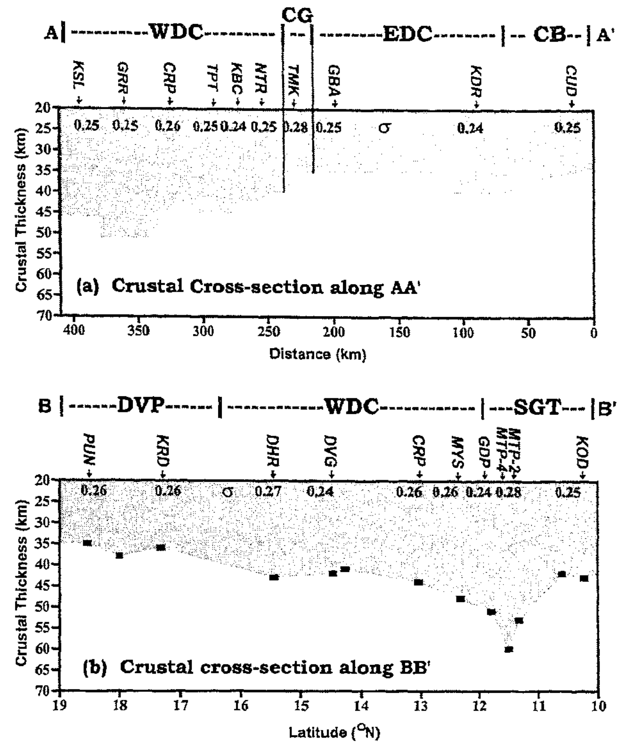

Figure 5. Cross-section depicting Crustal thickness and Poisson's ratio variation across: (a) SW-NE profile AA′ (b) NW-SE profile BB′.

from the CB across the EDC to WDC (Figure 5a) and BB′ from DVP across the WDC to the SGT (Figure 5b). The cross-section locations are shown on Figure 4. Figure 5a shows that the crust thickness beneath the EDC varies from 34–39 km, but beneath the WDC the crustal thickness ranges from 42–51 km. To discern the nature of the Moho depth variations, we examined the receiver functions at individual stations for a systematic delay of the *Ps* phase with azimuth and distance, but we do not observe significant variations in the arrival times or amplitudes of converted and multiples as expected for a dipping Moho. This suggests that the Moho is essentially horizontal and that the offsets occur at rather sharp boundaries which seem to coincide with major N-S shear zones [*Drury et al.*, 1984]. The thickest WDC crust (51 km) occurs beneath the mid-Archaean (3.4 Ga) greenstone belt - the nucleus of the Dharwar craton - a major low-strain zone which has not been subjected to any severe compressive deformation [*Chadwick et al.*, 1989]. In addition, this area is characterized by high *P*- and *S*-wave velocities [*Gupta et al.*, 2001] and lower mantle heat flow [*Gupta et al.*, 1991]. The crustal Poisson's ratio for both the EDC and WDC crust is 0.25 ± 0.1 except beneath TMK (σ = 0.28), which is situated on the K-rich mantle-derived Closepet granite. The cross-section AA′ from station CRP to KSL is representative of the amphibolite-grade metamorphic rocks whose paleopressures range between 5–7 Kbar, consistent with a 15–20 km erosion level, indicating that the Archaean crust in this part of the WDC may have been 57–70 km thick 3.4–3.0 Ga ago.

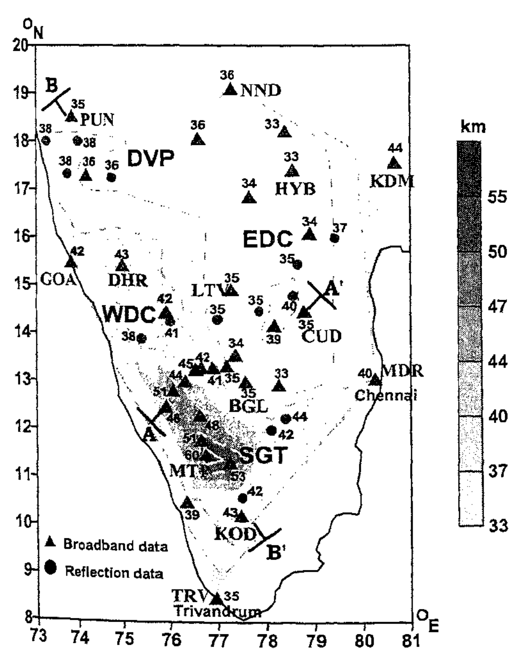

Figure 4. Crustal thickness map for South India derived from the receiver function analysis reported here and published reflection/refraction results. Numbers denote Moho depth. The locations of the two crustal cross-sections (AA′, BB′) shown in Figure 5 are indicated.

[10] Cross-section BB′ (Figure 5b) shows the Moho topography from undeformed Archaean crust beneath the DVP and northern WDC to the area of late Archaean to Proterozoic deformation responsible for the evolution and exhumation of granulite facies rocks in the southern parts of

India. In Figure 5b MTP-2 and MTP-4 refer to crustal thickness inferred beneath the station for events from 90–180° and 270–360° azimuths, respectively. Although the receiver functions for the two azimuthal ranges indicate a difference in crustal thickness, the transition between the two regions must be relatively sharp since there is no indication in the tangential receiver function of a dipping Moho. The DVP is underlain by 35–38 km thick crust, similar to the crustal thickness beneath the adjoining EDC. Progressive thickening with an increasing grade of metamorphism is observed southward across the WDC. The northern part of the WDC (DHR and DVG) consists of granite-gneisses terrain (paleopressures 3–4 Kbar) with a crustal thickness of 42–43 km, while the amphibolite grade central part (pressure 5–7 Kbar, CRP, MYS) thickens to 44–48 km. At MTP in the Nilgiri Hills, which consist of hornblende granulite facies rock, the present-day Moho is about 60 km deep. Since the exhumed granulite rocks were once buried to a depth of 25-30 km (10 Kbar paleopressure), the crustal thickness during the Precambrian could have been ~90 km. However, since the 2.5 Ga-old granulite terrain rocks are overprinted by the 550 Ma Pan-African event, it is difficult to determine when the crust attained this anomalous thickness.

4. Discussion

[11] The significant findings of the broadband teleseismic experiment in South India are: (i) very similar crustal architecture (thickness ~35 km, σ ~0.25) beneath the 2.5 Ga EDC, the DVP and the CB; (ii) significant crustal thickening (42–51 km) beneath the southern part of the WDC, (iii) a 42–60 km crustal thickness beneath the SGT, and (iv) that the Closepet granite forms the crustal divide at depth between the EDC and WDC. The average Poisson's ratio for the South Indian crust has values of 0.24–0.27 which are at the lower end of the global average [*Zandt and Ammon*, 1995] for the Archaean shields (0.27–0.31), implying felsic-to-intermediate composition. No significant differences are observed between the Archaean and Proterozoic crustal blocks as suggested elsewhere [*Durrheim and Mooney*, 1991].

[12] The overly-thick (>50 km) crustal block of the WDC coincides with >3.36 Ga amphibolite grade greenstone belt (5–7 Kbar pressure,) suggesting the existence of a 57–70 km thick crust during the mid-Archaean. The preservation of such an overly-thickened crust could only be possible where the crust is shielded from high mantle heat flow by a thick, insulating layer of lithosphere. The presence of such a thick, cool lithospheric root beneath this region has been demonstrated by *Srinagesh and Rai* [1996], *Gupta et al.* [1991], and *Gupta et al.* [2003]. Our crustal thickness observations are at odds with those of *Durrheim and Mooney* [1991] who proposed that the Archaean crust is thinner than Proterozoic crust. The northern part of granulite terrain, which is characterized by high paleopressures (8–10 Kbar), is conspicuous by the presence of the thickest crust (50–60 km). The fact that these 2.5 Ga rocks were exhumed from depths of 25–30 km indicates anomalous crustal thickening (75–90 km) during the Archaean, similar to that observed in the high Himalayan and Indus Tsangpo Suture Zone and suggestive of a possible Himalayan-type geodynamic event for granulite evolution in South India.

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