Crustal Velocity Structure of the Western Part of the Narmada-Son Lineament - A Case Study using DSS Data

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Summary

A five-layered crustal model with 5.9-6.2, 6.0, 6.3, 6.6 and 7.0 kms⁻¹ velocities is derived with seismic refraction / wide-angle reflection data along the Thuadara-Sendhwa-Sindad profile in central India. The profile traverses across the western part of the Narmada-Son lineament in the N-S direction. The data is subjected to 2-D forward modelling using both travel times and amplitudes. Refracted waves (P_n) from the Moho observed as first arrivals at a distance of about 200 km are used to derive the upper mantle velocity of 8.1 kms⁻¹. The Moho is well constrained both from the P_n and wide-angle reflections from four shot points. The main features of the velocity structure is the delineation of a low velocity layer (6.0 kms⁻¹) in the upper crust and a 12-16 km thick high velocity (7.0 kms⁻¹) layer at the base of the crust. The high velocity lower crustal layer, representing the magmatic under plating in the region, may be related to the formation of the Narmada basin and the Deccan volcanic episode. The Deccan Volcanism may be a consequence of Reunion mantle plume activity. The crustal thickness varies between 37 and 43 km along the profile and the thickest crust is found between the Narmada and Tapti rivers. Deep-seated faults responsible for the evolution of Narmada basin are inferred from the present study.

Introduction

The Narmada-Son Lineament (NSL) is the most conspicuous geological feature in central India. The geophysical anomalies, number of hot springs and a remarkable seismicity all along NSL are the manifestations of inner dynamics of the region. The NSL has been the subject of extensive geological and geophysical investigations to understand the tectonic evolution of the region. Seismic refraction / wide-angle reflection studies were carried out along five Deep Seismic Sounding (DSS) profiles across the NSL, in the north – south direction (Kaila and Krishna, 1992), to delineate the crustal structure and hence to understand the tectonic evolution of the region. In the present study, seismic refraction / wide-angle reflection data acquired along the 260 km long Thuadara-Sendhwa-Sindad profile (Fig.-1), situated on the western part of NSL is analysed. The analog seismic data along the profile are digitised and interpreted using the merits of combined kinematic and dynamic forward modelling techniques. In the present study, an attempt is made to derive a well-constrained velocity structure to explain the observed geological / tectonic features of the region, using both travel times and synthetic seismogram modelling.

Geology and Tectonics

The Narmada-Son lineament situated in the central...
part of the Indian shield is a unique feature extending about 1500 km from west coast of India to Jabalpur in central India and beyond Shillong Plateau in the east. The Proterozoic Vindhyan rocks are confined only to the north and the Gondwana sediments only to the south of the NSL. From various geological studies it is clear that this lineament is situated close to the fractures west of early Precambrian, Cretaceous and post-Deccan Trap period (Kaila et al. 1989).

A major volcanic eruption took place in the region during the late Cretaceous and is represented by the Deccan traps / flood basalts. The Deccan volcanics cover about 5,00,000 sq.km area in the central and western India and are found all along the NSL. The aim of the present study is to bring out a comprehensive picture of the crust from seismic and gravity along with heat flow data available in the area.

**Data, Analysis and Modelling**

The seismic data were acquired in analog form using 60-channel equipment, with 200 m geophone interval during the year 1984-85 (Kaila et al., 1989). In order to obtain the structural information up to the basement, the shot points were located at about 10 km interval and recorded up to a distance of 40 km. To obtain deep crustal information, shot points were located at 40 km interval and recorded up to a distance of 180-200 km. SP 0 was recorded to a distance of 160 km, whereas SP40 and SP235 to a distance of 240 km to observe head waves (Pn) from the Moho.

The seismic record sections along the Thuadara-Sendhwa-Sindad profile show a number of reflected phases after first arrivals. Important phases are the wide-angle reflections P6.0, P6.3, P6.5 and P6.8 from several intracrustal boundaries and Moho respectively. In the present study, P6.0, P6.3, P6.5 and P8.1 phases are observed as first arrivals at different distances from various shot points with velocities of 6.0, 6.3, 6.5 and 8.1 kms\(^{-1}\) respectively. First three phases represent refractions from different crustal layers, whereas, the last one is the head wave from the crust- mantle boundary. These phases are identified after checking the reciprocal times between pairs of shot points and their continuity for long distances. A crustal velocity model is derived using both refraction and wide-angle reflection data.

The refracted first arrival phase, P6.0 suggests a velocity of 6.0 kms\(^{-1}\) for the first layer. P6.3 and P6.6 phases are used to calculate thickness of the first layer using forward modelling of travel time data. The P6.0 phase is observed shortly after the first arrival in the distance range of 20-65 km in various record sections and phase P6.3 is observed subsequent to it. These are used to constrain the second layer parameters keeping the first layer parameters fixed. Extensive travel time and amplitude modelling results indicate that it is difficult to fit the observed data by a model with a positive velocity contrast corresponding to the P6.0 phase. Because, a very small increase of velocity at a supposed discontinuity although produces a travel times fit with this phase, the corresponding synthetic amplitudes are comparatively weaker than the observed ones. Further, the first arrivals computed for such small velocity jumps also appear much earlier, revealing higher apparent velocity than the observations. However, presence of a LVL (6.0 kms\(^{-1}\)) in the upper crust explains both these phases. P6.0 and P6.3 phases could be successfully modelled as reflections from the top and bottom of the upper crustal LVL situated between 6.5 and 7.5 km depth. P6.5 and P6.8 phases are modelled by adjusting thickness and velocity of third layer, keeping the parameters of first two layers constant. Then, P6.5 and P7.0 phases are used to constrain the velocity and thickness of fourth layer. Similarly, P8.1 phase is modelled as the wide-angle reflection from the crust-mantle boundary.

The observed and calculated travel times for refracted phases from various crustal layers from SP40 and SP235 are identified and modelled using Cerveny’s SEIS81 program. The reflections from the top of 6.5 kms\(^{-1}\) velocity layer, even though continuously observed all along the profile from SP 0, SP 40, SP 80, SP 110, SP 140, SP 170, SP 200 and SP 235, do not show strong band of reflections. The corresponding synthetic seismograms also reflect the same behaviour. However the observed reflections from the top of lower crustal high velocity (7.0 kms\(^{-1}\)) layer are strong and match well with the observed ones. P6.5 corresponds to the layer at a depth of 15 km. The phase P7.0 corresponds to the lower crustal high velocity layer at a depth of 26 km. The top of deepest layer in the crust with a velocity 7.0-7.1 kms\(^{-1}\) is located at depth of 26 km. Refracted waves from this layer couldn’t be observed as first arrivals from any shot point. However, strong wide-angle reflections (P7.1) were observed from this layer in the record sections of 8 shot points. The wide-angle reflections (P8.1) from the Moho boundary are recorded from shot points SP40, SP235 and SP0. The P8.1 reflection from the top of the Moho is also observed as first arrivals in the distance range from about 180 km to the end of the profile. The depth of Moho varies between 39 km and 41 km. The increase in depth starts gradually around SP 80 and reaches 41 km around studies in India and major discoveries, Current Science, v.62, pp.117-154, Krishnaswamy, V.S., and Ravi Shanker, (1980) Scope of
development, exploitation and preliminary assessment of geothermal resource potential of India, Rec. Geol. Surv. India, III (3), pp.17-40. SP 140. The deepest part is located between the Narmada and Tapti rivers (Fig.-2).

Discussion and conclusions

From seismic, gravity and heat flow studies, a comprehensive picture of the crust and the thermal structure of the lithosphere, has been derived in the present study. It provides evidence for the tectonic evolution of the region since 65 Ma, which might have modified the earlier crustal features. Despite the presence of a sedimentary graben, Bouguer gravity values in the Narmada- Tapti graben are higher by about 20 mGal as compared to the area beyond the graben. The gravity high is due to the combined effect of thick Deccan Trap layer and the high velocity (7.1 kms\(^{-1}\)) underplated material accreted at the base of the crust. Origin and evolution of the underplated layer, at ~26 km depth, in a thermally disturbed zone like the Narmada may be correlated to the late Cretaceous geodynamics of the Indian subcontinent. Presence of magmatic underplating below the Deccan volcanic extrusions suggests that they may be related to each other. They might have taken place in a single geodynamic process similar to that of the volcanic continental margins. Such events observed in various parts of the world are related to mantle plume activity (Coffin and Eldholm, 1994). The assumption of a rather young (65Ma) high velocity/high density underplated material is also compatible with the estimated high heat flow and existing hot springs all along the NSL (Krishnaswamy and Ravi Shanker, 1980; Ravi Shanker, 1988). In view of the known relation between high heat flow and electrical conductivity (Adam, 1978), the high velocity lower crustal layer may be associated with a partial melt zone in the crust or upper mantle beneath the area of the triple junction and Satpura ranges (Arora and Reddy, 1991). This intra-crustal, thermally disturbed layer with high current concentration conforms well, with the present accreted igneous layer. The influence of Deccan volcanism is less to the east as demonstrated by the thickness of Deccan volcanics, varying from 3000 m to 100 m from west to east.

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References