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Imaging sub basalt Mesozoics along Jakhau-Mandvi and Mandvi-Mundra profiles in Kutch sedimentary basin from seismic and gravity modelling

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Summary

We have performed 2-D travel time inversion of first arrival and wide-angle reflection data along Jakhau-Mandvi and Mandvi-Mundra profiles in the Kutch basin for imaging sub-basalt sediments. It has brought out a five layer velocity model with average interval velocities of 2.0, 4.6, 3.2, 5.3, and 3.5 km/s in successive layers above the granitic basement (5.9 km/s) along Jakhau-Mandvi profile and a four layer velocity model along Mandvi-Mundra profile with average velocities of 2.0, 4.65, 3.1, and 5.2 km/s above the basement (5.95 km/s). By comparing with lithologs available in a nearby well, we associate these layers to the Tertiary, Late Cretaceous - Early Paleocene Deccan Trap, Late Mesozoic sediments, Mesozoic Limestone, and Early Mesozoic sediments. We have delineated the Late Mesozoic sediments with varying thickness of 1 to 2 km below thin Deccan basalt, and Early Mesozoic sediments with 700 to 1200 m thickness below the Limestone formation in the Jakhau-Mandvi region. The Early Mesozoic layer is found to be thinning towards Mandvi, and is not traceable along the Mandvi-Mundra profile. The model reveals a deep seated structure with significant hump in the basement at the middle of the Mandvi-Mundra profile. The seismically derived structure has been assessed by gravity modeling along the lines.

Keywords: *Mesozoics, velocity, density, sedimentary basin, skips*

Introduction

Half of the global oil is found in Mesozoic sediments. In India, a vast tract of Mesozoics is hidden below the basalt flow that has made the standard reflection profiling incapable of probing them due to contamination of near-vertical primary seismic waves with multiples, mode conversion and scattered waves generated by interbeds, breccia and vesicles within the basalt. The effect of these noises becomes less prominent as the source-receiver offset increases, and the primaries carrying sub-surface information stand out at the wide-angle range. Travel time inversion of wide-angle seismic data including both first arrivals and wide-angle reflected phases has been able to derive the large-wavelength velocity structure of basalt-covered sedimentary formations in the Saurashtra, central India and Mahanadi basins (Sain and Reddy, 1995; Sain and Kaila, 1996; Sain et al., 2002a, b; Sridhar et al., 2009). The Kutch basin in the western India is one of the Indian basins that have considerably thick Mesozoic sediments hidden below the Late Cretaceous - Early Paleocene Deccan basalt. The Controlled Source Seismology (CSS) group of CSIR-National Geophysical Research Institute (NGRI) acquired seismic refraction/wide angle reflection data along 72 km long Jakhau-Mandvi (NW-SE) and 57 km long Mandvi-Mundra (W-E) profiles in the Kutch basin for the exploration of sub-basalt Mesozoics in 1996-97 (Fig.1). Recently, Prasad et al. (2010) delineated 2-D shallow velocity structure along the said profiles by forward modeling (Rayamp-PC, 1987) of first arrival travel time data. They have also used the 'skip' phenomena to map the Mesozoic sediments below the basalt cover. We have picked the travel times of both first arrivals with 'skips' and identifiable wide-angle reflected phases, and inverted them simultaneously as has been carried out in the Saurashtra peninsula, Mahanadi delta and central India for sub-basalt imaging (Sain et al., 2002a, b; Sridhar et al., 2009) using RayInvr Program of Zelt and Smith (1992) to have better constraints on both the velocity and boundary structures. We have performed the gravity modeling to assess whether the seismically derived velocity-structure can explain other geophysical data like gravity.

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Basin History

The Kutch represents the northernmost part of the Atlantic type, western passive margin of India and lies close to the western convergent boundary of the Indian plate with Eurasian plate (Besse and Courtillot, 1988). Kutch is a pericontinental basin between subsurface ridge of Nagar-Parkar in the north, Radhapur arch in the east, and Kathiawar uplift in the south (Biswas, 1987; Malik et al., 2000). The basin is filled with sediments ranging in age between middle Jurassic and Holocene. The Deccan basalts of Late Cretaceous to Early Paleocene age sratigraphically divided the sedimentary formations into Mesozoic and Tertiary sections. The Mesozoic sediments (more than 2.4 km thick) fill the major part of the basin whereas the Tertiary sediments (more than 300 m thick) are present in the outer parts of the basin bordering the Mesozoic uplift (Biswas, 1982). The Kutch, Cambay and Narmada basins are three major marginal rift basins in the western margin platform of the Indian craton. The basins occur close to each other in the mid-western part of the Indian continent. These basins are bounded by intersecting faults whose trends follow three important Precambrian tectonic trends of Delhi, Aravalli and Satpura. According to Biswas (1987), these rifting events are synchronous with the major events in India's drift history.

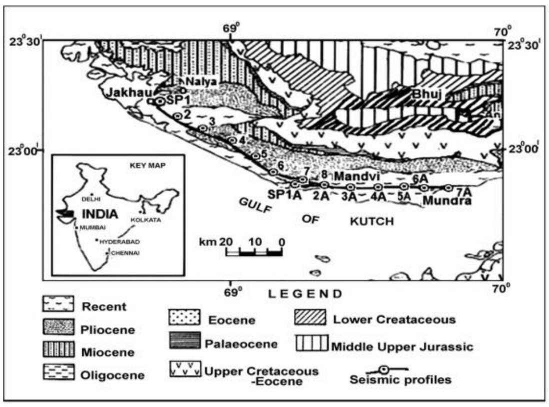

Fig.1: Location of seismic profiles on geology map of Kutch basin (Courtesy, NGRI Technical Report No.NGRI-2000-EXP-296)

Modeling of seismic data

To gain advantage of inversion, we have applied the 2-D travel time inversion of Zelt and Smith (1992) to the first arrivals and identifiable reflected phases from all shots along 72 km long Jakhau-Mandvi (NW-SE) profile, and 57 km long Mandvi-Mundra (W-E) profile with a view to build basement configuration and delineate overlying sedimentary formations along the two profiles. The forward modeling is based on efficient ray tracing equations (Zelt and Ellis, 1988). The data are assigned with uncertainties of 50 ms. The assignment of uncertainties is subjective and based on one period of dominant frequency (20 Hz) of the data. The model is parameterized by linear interpolation between an irregular grid of boundary nodes and upper and lower layer velocity nodes. A smooth layer boundary simulation is used to avoid scattering and focusing of ray paths and to stabilize inversion. The travel times and their partial derivatives with respect to velocity and boundary nodes are calculated during the ray tracing. The calculated response of the model is compared with the observed data, and the model parameters are updated using the correction vector obtained from the damped least-squares inversion (Zelt and Smith, 1992; Zelt, 1999). The process is repeated until we achieve a satisfactory fit corresponding to a normalized χ^2 value of nearly 1. However, it is not always possible to obtain $\chi^2 = 1$ while maintaining acceptable resolution of model parameters because of data sampling at small-scale heterogeneities that cannot be resolved by modeling (Zelt, 1999). The ray diagram and final velocity models showing the low-velocity Mesozoics below the basalt cover are shown in Figs 2 and 3. The data were fitted with rms travel time residuals of 57 ms and 58 ms corresponding to normalized χ^2 values of 1.29 and 1.34 for the Jakhau-Mandvi and Mandvi-Mundra profiles, respectively.

Velocity Structure

The thickness of the Tertiary sediments (2.0 km/s) varies between 500 m to 850 m from SE to NW along the Jakhau-Mandvi profile. The second layer (4.6 km/s), representing the Deccan basalt, shows variable thickness from 250 m in the NW to 600 m in the SE of the profile. Underlying this layer lies the thick low velocity (3.2 km/s) Late Mesozoic sediments, the thickness of which is maximum (2000 m) near 45 km profile distance. The low velocity Mesozoics is underlain by a thick high velocity (5.2 km/s) Mesozoic Limestone with thickness varying from 1000 m in the NW segment to 2600 m in the SE segment of the profile. This layer is underlain by another low velocity (3.5 km/s) layer corresponding to the Early Mesozoic sediments which is truncated near Mandvi. The last layer (5.9 km/s) is the granitic basement, which deepens from 3800 m in NW to 5750 m in SE.

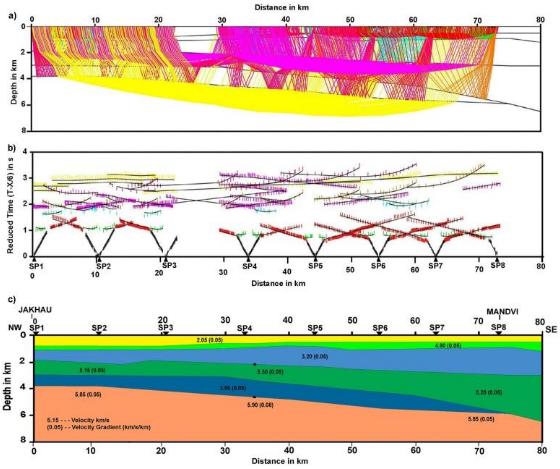

Fig. 2 a) Ray diagram and b) observed (vertical bars) and calculated (lines) travel times through derived velocity model from eight shots used in the inversion. Colors represent various phases of refractions and reflections, and corresponding rays. c) 2-D velocity structure along Jakhau-Mandvi profile exhibiting Mesozoic sediment (3.20 km/s) below the Deccan basalt (4.50-4.80 km/s).

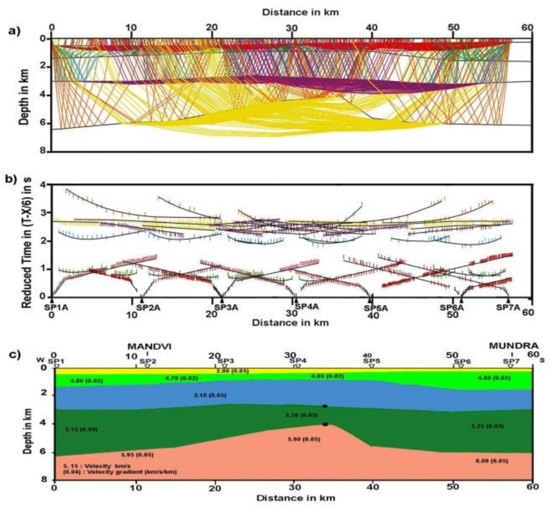

Fig.3(a) Ray diagram and b) observed (vertical bars) and calculated (line) travel times through derived velocity model from seven shots used in the inversion. Colors represent various phases of refractions and reflections, and corresponding rays. c) 2-D velocity structure along Mandvi-Mundra profile exhibiting Mesozoic sediment (3.20 km/s) below the Deccan basalt (4.60-4.80 km/s).

The early Mesozoic sediments, delineated along the Jakhau-Mandvi profile, are not traceable along the Mandvi-Mundra profile. The thickness of the top Tertiary sediments (2.0 km/s) varies between 200 m in the east to 500 m in the west. The second layer, representing the Deccan basalt (4.65 km/s) is thicker than that delineated along the Jakhau-Mandvi profile. On either side of the profile, the layer thickens and reaches to the maximum value of 1.4 km near Mundra. The thickness of the low velocity (3.1 km/s) Late Mesozoic sediments is throughout thicker (~1.6 km) than that along the Jakhau-Mandvi profile, and is little broader in the middle. The next layer with velocity of 5.2 km/s is thin (1.4 km) near 35 km profile distance, and thickens on either side to ~3.2 km. This is underlain by the granitic basement (5.95 km/s), which shows an uplift at 35 km profile distance.

The Gravity modeling

To assess whether the seismically derived velocity structure can explain other geophysical data like gravity, we have performed gravity modeling along the two lines. For gravity modeling, we convert the derived seismic velocity models into initial density models using the velocity-density relationship of Nafe and Drake (1957) and Ludwig et al. (1970), as has been demonstrated by Zelt and Smith (1992). The layers of the P-wave velocity model define respective layers of the gravity model. The densities are marginally adjusted to match the observed gravity data as closely as possible using the forward modeling approach of Zelt (1989) based on gravity algorithm of Talwani et al. (1959).

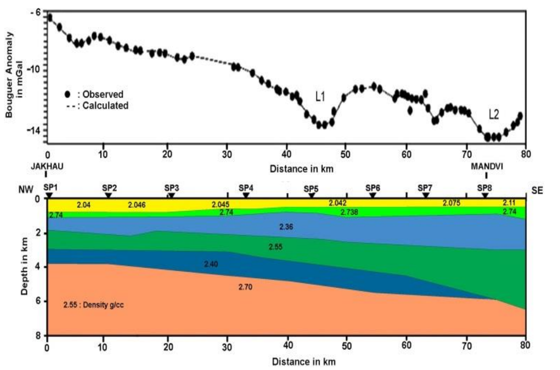

Fig.4: Density model along the Jakhau-Mandvi profile.

The gravity data along the Jakhau-Mandvi and Mandvi-Mundra profiles have been taken from the Bouguer gravity anomaly map (NGRI Technical Report no.NGRI-2000-EXP-296) of the southern part of the Kutch Basin. The Bouguer anomaly along the Jakhau-Mandvi profile

(Fig.4) shows a large wave length gradient decreasing from NW to SE and it is superimposed by several small wavelength lows and highs, which represent local/shallower features. The large wavelength Bouguer anomaly decreases towards SE (Mandvi) with two gravity lows (L1 and L2) at 47 and 74 km profile distance. The final gravity model presents a five-layer model with densities of 2.07, 2.74, 2.36, 2.55, 2.40 g/cc overlying the basement with density of 2.70 g/cc (Fig.4). The subsurface density model shows thickening of sedimentary column towards SE of the profile, corroborating the work of Chandrasekhar and Mishra (2002).

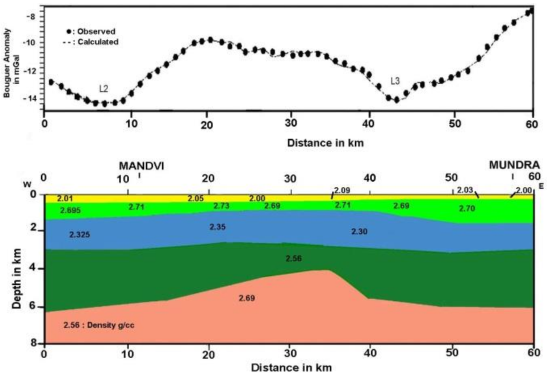

Fig.5: Density model along Mandvi-Mundra profile.

The Bouguer anomaly along the Mandvi-Mundra profile (Fig.5) shows two gravity lows (L2, L3) on either side with high in the center. The subsurface density model of the profile consists of four layers with densities 2.05, 2.71, 2.32 and 2.56 g/cc underlain by a basement of density 2.69 g/cc. The basement and the overlying sediments are uplifted in the center suggesting an anticlinal structure, and faulted basement at ~35 km along the profile. The gravity lows L2, L3 representing the depressions on either side of the uplift are primarily caused due to sediments. The uplift coincides with the N-S extending Median High reported in this region from the geological studies (Biswas, 1987).

Discussion and Conclusions

The thickness of the Tertiary layer with velocity of 2.0 km/s and average density of 2.05 g/cc varies between 500m in the NW part of the profile to 850 m in the SE part along the Jakhau-Mandvi profile. The second layer with velocity of 4.6 km/s and density of 2.73 g/cc is associated with the Deccan basalt of the Upper Cretaceous age. The Trap layer is very thin in the NW segment of the profile compared to the SE segment of the profile with the thickness variation of about 600 m from NW to SE. Underlying this layer lies thick Late Mesozoic low velocity (3.2km/s) and low density (2.23g/cc) sediments, the thickness of which is maximum (2000 m) near 40 km profile distance. The Mesozoic low velocity layer is underlain by a thick high velocity (5.2 km/s) and high density (2.55g/cc) layer, representing the Mesozoic Limestone. The thickness of limestone is found to increase from 1000 m in the NW segment to 2500 m in the SE segment of the profile. This layer is underlain by another low-velocity (3.5km/s) and low density (2.40g/cc) layer corresponding to the Early Mesozoic sediments. It exhibits a truncated structure in the SE segment of the profile near Mandvi. The last layer is the granitic basement with velocity of 5.9 km/s and density of 2.70 g/cc, and exhibits deepening from 3800 m in NW to 5500 m in SE.

The early Mesozoic sediments, delineated along the Jakhau-Mandvi profile, are not observed along the Mandvi-Mundra profile. We have been able to derive a four-layered velocity and density model. The thickness of the top layer (Tertiary sediments) with velocity of 2.0 km/s and density of 2.05 g/cc varies between 200 m in the east to 500 m in the west. The second layer (Trap) with velocity of 4.65 km/s and average density of 2.71 g/cc is thin in the middle and thickens on either side, reaching to a maximum value of 1.4 km near Mundra. The third layer with velocity of 3.1 km/s and average density of 2.30-2.34 g/cc, representing the low velocity Mesozoic sediments, is quite thick (~1.6 km) with little thicker in the middle. The next layer with velocity of 5.2 km/s and density of 2.56 g/cc is thickest (3.2 km) near Mandvi; thins (1.4 km) to the center 35 km profile distance; and again thickens to 3 km near Mundra. This is underlain by the granitic basement (5.95 km/s velocity and 2.69 g/cc density), which shows an uplift coinciding with the N-S extending Median High reported by Biswas (1987) from the geological studies, and by Chandrasekhar and Mishra (2002) from gravity studies.

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