Velocity Structure of Sub-Basalt Mesozoics around the Lodhika Well in Saurashtra Peninsula from Traveltime Inversion of Wide-Angle Seismic Data

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Summary

Mapping Mesozoic sediments hidden below the basalt cover in the Saurashtra peninsula has been a difficult problem by the conventional seismic reflection profiling due to its inherent limitation. However, the oil industries show keen interest to image such sediments for hydrocarbon exploration. Wide-angle seismic experiment using both refractions and reflections has been an efficient tool for delineating the sediments in such a geological setup. Drilling near Lodhika in the Saurashtra peninsula has revealed the Mesozoics beneath the exposed basalt flow. With a view to image the lateral extent of sub-basalt Mesozoics, NGRI has run a ~45 km long profile crossing the Lodhika well with five equally spaced shots and ~100 m geophone spacing. Here we perform the traveltime inversion of seismic refractions and identified wide-angle reflections to image the sub-basalt sediments along the profile. The result reveals the Mesozoics sandwiched between the exposed and underlying basalt flows. The basalt with average velocity of 5.1 km/s is almost flat (~1.4 km). The thickness of Mesozoic sediments (4.3 km/s) varies from 0.9 to 1.6 km. The underlying basalt flow with velocity of 5.15 km/s has thickness variation from 1 to 2 km. The basement with variable velocity (5.80 to 5.95 km/s) has an average depth ~4 km. The derived velocity model closely matches with the lithology of the Lodhika well and this demonstrates the potential of the wide-angle seismic technique for sub-basalt imaging.

Introduction

In the northeastern part of the Saurashtra peninsula (Fig.1), the Mesozoic Dhrangadhra Sandstone is exposed. The Oil & Natural Gas Commission of India has confirmed the presence of this sediment below the basalt cover by drilling near Lodhika. The oil industries show much interest to image the sedimentary formations hidden below the basalt cover for hydrocarbon exploration. However, the impedance contrasts within the basalt flow caused by interbeds, breccia and vesicles generate noise such as multiples and scattering waves (Pujol et al. 1989), which contaminate the primary signals. Thus the standard near-vertical reflection profiling often fails to image the sub-basalt formations due to poor signal/noise ratio. On the other hand, the wide-angle recording with large sources provides high-amplitude reflections from the sub-basalt horizons at large distances where the effect of above noise is less prominent (Jarchow et al. 1994; Sain & Kaila 1996). The National Geophysical Research Institute of India has conducted a 45 km long wide-angle seismic profiling (Sain et al., 2002) across the Lodhika well with geophone intervals of ~100 m and five roughly equally spaced shots. The first arrivals of the shot gathers show two prominent phases ($P_1$ and $P_2$) with apparent velocities of about 5.1 and 5.9 km/s (Fig.2). Three large-offset reflected phases ($P''_1$, $P''_2$ and $P''_3$) are also observed. We pick the traveltimes of first arrivals and identifiable wide-angle reflections, and assign them with picking uncertainties of 25 ms (half of the dominant cycle of the data). Using the method of Sain and Kaila (1996) for the interpretation of first arrivals, we derive a two-layered 1-D velocity models for five shot gathers. The reflection times predicted from the first layer do not fit any of the observed reflections ($P''_1$, $P''_2$ and $P''_3$). This suggests that the derived velocity is not valid for the region. Using the method of Sain & Kaila (1994) for traveltime inversion of reflected phases, we then derive the 1-D velocity–depth functions from five shot gathers. The velocity models are then merged to form an initial model for 2-D inversion using the ray-based inverse method of
Zelt & Smith (1992) with a view to image the lateral extent of the sub-basalt Mesozoic sediment.

Figure 1: The seismic profile (thick solid line) across the Lodhika well (indicated by a plus sign within a circle). Locations of shots are marked by filled circles and are numbered 1 through 5. The inset shows the study area in the Saurashtra peninsula, covered by basaltic rock (indicated by ‘v’). Solid squares mark nearby towns.

Figure 2: Specimen field record sections plotted with a reduction velocity of 7.0 km/s showing various P wave refracted ($P_1$ and $P_2$) and reflected ($P_1$, $P_2$ and $P^3$) phases for SP 1. Lines represent the predicted response for the final velocity model. Alternate traces are plotted for clarity.

Figure 3: Rays of refracted and reflected phases traced through the final velocity model for all five shots. The bottom panel shows the comparison between observed (vertical bars) and theoretical (lines) traveltimes for all phases. The length of vertical bars corresponds to picking uncertainties. Every 18th ray is plotted for clarity.

Figure 4: The color-plot of the velocity model in which the numbers within the model represent the average velocities in km/s. The circles at the top of the model represent the shot positions. The lithology of the Lodhika well is superimposed for comparison.

Modeling

A ‘layer stripping’ modeling approach is employed in which the successively deeper layers are determined using both first and wide-angle reflection data. Traveltime comparisons and rays traced through the final velocity model for each shot are shown in Fig.3. The final velocity model derived with 16 velocity nodes and 18 boundary nodes is displayed in Fig.4. The simplified lithological units comprising the basalt cover, Mesozoic sediment and underlying basalt flow from the Lodhika well (Singh et al. 1997) are superimposed on the velocity model and this shows a close correspondence. The well did not reach the basement, the depth of which is estimated as ~4 km in the present study.

Conclusions

The first layer representing the exposed basalt flow (5.05 to 5.18 km/s) is almost flat (average thickness of 1.37 km). The velocity of the second layer, corresponding to the Mesozoic Dhrangadhra Sandstone, is 4.3 km/s. The thickness of this layer is ~1.5 km in the southern half of the profile and ~0.8 km in the northern half. The third layer with velocity of 5.15 km/s represents another basalt flow and is thicker (~2 km) in the north compared with the south (~1 km). The velocity of the basement varies from 5.95 km/s in the north to 5.80 km/s in the south. The study has revealed the hidden low-velocity Mesozoic sediment sandwiched between the high-velocity exposed basalt and underlying basalt flows. This information is important for oil exploration as more oil resources are anticipated from the Mesozoic sediments. The derived velocity can also be useful in performing prestack depth migration for delineating the finer details of the sedimentary formations.
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References


