High Velocity-Gradients in West Bengal Sedimentary Basin, India from Travel-Time Inversion of Wide-Angle Seismic Data and Multiples of First Arrivals

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Summary

The wide-angle seismic data recorded in the West Bengal sedimentary basin show high-energy later arrivals in arcuate-shapes with the urvatures concave downwards, defined as multiples of first arrivals. To extract subsurface velocity model, conventionally we model only the first arrivals and wide-angle reflections, and discard these multiples. Here we demonstrate through traveltime inversion of multiples and wide-angle seismic data along the Gopali-Port canning profile in Bengal sedimentary basin that a better constrained velocity model can be derived, which can explain all phases observed on the field seismograms. The main feature of the study is the derivation of very high velocity-gradients (1.44-0.22 km/s/km) in the top four layers, which are not observed in other sedimentary basins of India.

Introduction

Based on forward modeling of first arrivals and wide-angle reflections, Kaila et al. (1992) derived four/five layered sedimentary basin above the basement along three EW profiles (Beliator – Burdwan - Bongaon, Gopali - Port canning, Bishnupur – Palasi - Kandi) and one NS profile (Taki - Arambagh). The field seismograms along all profiles exhibit strong later arrivals which are arcuate in shape and have downward curvatures. These phases are nothing but the reflected first arrivals from the free-surface and are defined as multiples of first arrivals. The velocity model of Kaila et al. (1992) can not explain these multiples. Through synthetic seismogram and traveltime modeling of these phases, earlier several researchers (Sarkar et al., 1995; Reddy et al., 1998; Prasad et al., 2003) demonstrated that velocity-gradients of sedimentary layers play an important role for the generation of high-energy later arrivals. To exploit the advantages of semi-automatic inverse modeling, here we invert traveltimes of all phases along the Gopali – Port canning profile with a view to derive a better-constrained velocity model within limited time, and to provide a measure of resolution and uncertainties of the estimated model parameters along with an assurance that the data have been fitted according to a least squares norm.

Methodology

2-D traveltime inversion (Zelt and Smith, 1992; Zelt, 1999) is used to determine the velocity model, and uncertainty and resolution of estimated parameters. The method is based on model parameterization and a method of ray tracing suited to the forward step of inverse method. The correction vector is calculated based on the damped least squares inversion and the model is updated iteratively unless the difference between the model response of the updated model and the data matches satisfactorily corresponding to a normalized c2 value of almost one.

Example

We derive the velocity model along the E-W trend Gopali - Port canning profile (Figure 1) in West Bengal basin. Figure 2 displays a specimen field seismogram recorded along the profile that shows prominent high-energy later arrivals with curvatures concave downwards, defined as the multiples of first arrivals. We pick traveltimes of first arrivals and their multiples along with identifiable wideangle reflections,

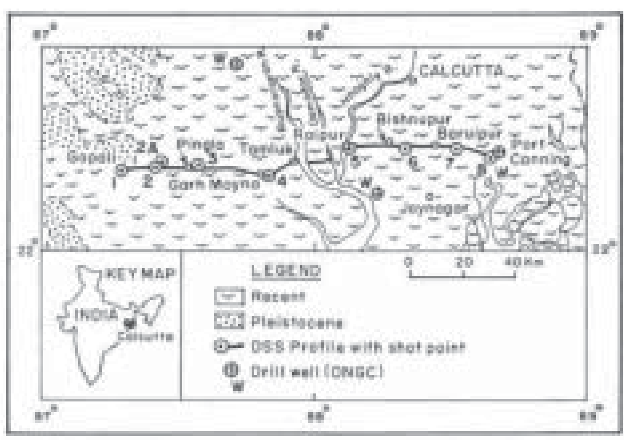

Fig. 1: Location of E-W trend Gopali - Port canning profile in the West Bengal basin superimposed on the geological map of the region.

and assign uncertainties of 50ms to the picked data. The data are modeled using the damped leastsquares inversion (Zelt et al., 1992; Zelt, 1999). The ray tracing and the traveltime fit for a shot along the profile is shown in Figure3. The derived velocity model (Figure 4) is complicated in nature and consists of five layers above the crystalline basement. The velocity gradient of the first layer (1.50 km/s) is very high (~1.44 km/s/km) and the thickness of the layer varies from 0.35 km to 0.70 km from west to east. The layer corresponds to the alluvium or recent sediments. The second layer with velocity of 2.70 km/s represents the upper Tertiary (Pliocene-Miocene-Oligocene) formation High-velocity gradients in Bengal basin and has the velocity gradient of 0.72 km/s/km. The third layer with velocity of 3.85 km/s and velocity gradient of 0.50 km/s/km corresponds to the Eocene sediment. The fourth layer with velocity of 4.8 km/s velocity, which appears from the middle to the east the profile, corresponds to the Paleocene-Cretaceous-Jurassic formation. The fifth layer with velocity of 5.5 km/s is the Singhbhum group of rocks that are exposed in the Singhbhum craton west of the profile. Both the fourth and the fifth layers have moderate velocity gradients of 0.22-0.24 km/s/km, and we observe that the velocity gradients of different layers decrease with the depth of their occurrences. The last layer with velocity of 5.88 to 6.00 km/s represents the crystalline basement (granitic in nature) above which lies a low-velocity zone (3.8 km/s), derived using the reflection times, in the middle of the profile.

The resolution of the estimated model parameters can be obtained from the diagonal elements of the resolution

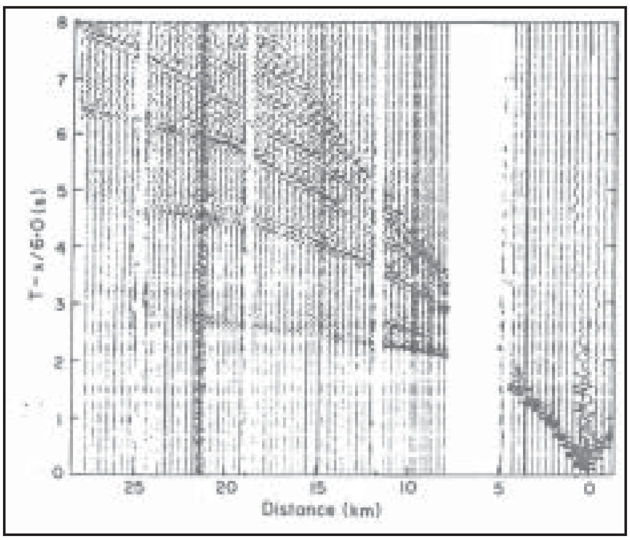

Fig. 2: A specimen field seismogram recorded along the Gopali – Port canning profile, which shows first arrivals and their free-surface multiples.

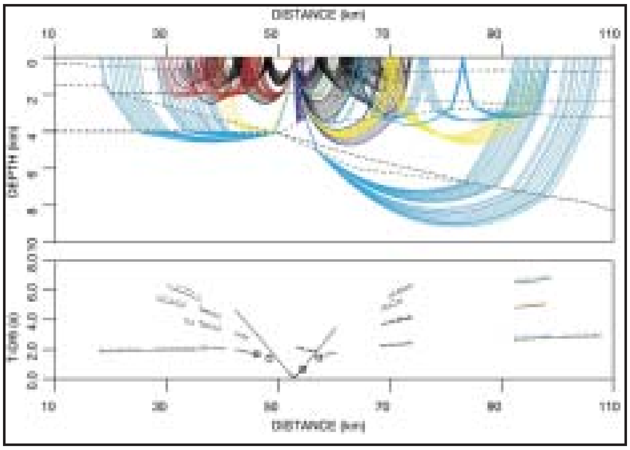

Fig. 3: Ray diagram (top) and the traveltime fit (bottom) corresponding to a shot along the Gopali – Port canning profile.

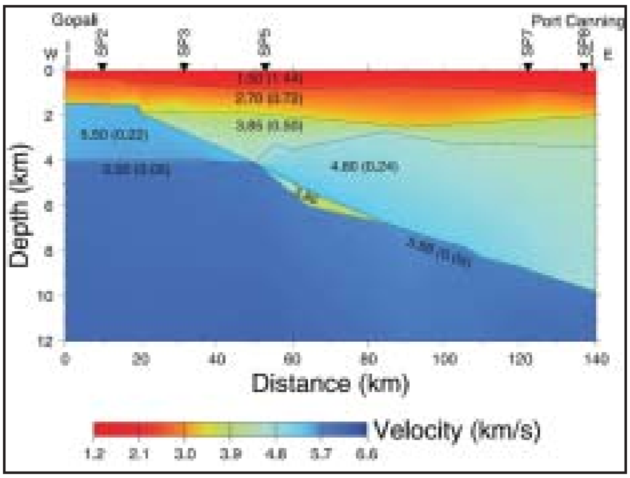

Fig. 4: Velocity model derived from the traveltime inversion along the Gopali – Port canning profile. Numerical values are the velocities at the top of layers. The values within brackets represent the velocity gradients.

matrix. Most of the velocity and boundary nodes have resolution values greater than 0.8, which indicates that the model is well resolved. The uni-parameter uncertainty test shows that the velocity uncertainties are less than 0.025 km/s and the depth uncertainties are less than 0.03 km. The overall c2 value of 1.19 corresponding to the final model also indicate that the model has been fitted well.

Conclusions

We derive a complex velocity structure using the traveltime inversion of first arrivals, their multiples and few wideangle reflections along a profile in the West Bengal sedimentary basin. The main result of the study is the derivation of high velocity gradients (1.44-0.22 km/s/km) in the top four layers of sedimentary formation, the values of which decrease with the age of the formation. The Bengal basin is known to have a very shallow water table that might have played a role to the high velocity gradients in the shallow level, which is responsible for the generation of high energy multiples of first arrivals.

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Acknowledgements

We are thankful to the Director, NGRI for his kind consent to present the results.