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2-D Velocity structure of Kerala-Konkan region using seismic traveltime Inversion

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Summary

Existence of gas-hydrates in the marine sediments elevates the velocity of seismic waves, whereas even a small amount of underlying free-gas decreases the seismic velocity considerably. These changes in velocities can be used for the assessment of gas-hydrates. The traveltime inversion is an effective method to derive a 2-D velocity structure from the seismic data. We have applied the method to the Multi Channel Seismic (MCS) data for inferring gas hydrates and underlying free-gas in the Kerala-Konkan offshore region. A six layer 2-D velocity model has been generated from the reflection traveltimes using a ray tracing technique. The topmost sediment layer is ~165 m thick with velocity ranging from 1,680 m/s and 1,740 m/s. The second layer is ~110 m thick with velocity ranging between 1,890–1,950 m/s. The third layer with velocity of 2,100-2,180 m/s and thickness of ~125 m is interpreted as the gas hydrate-bearing sediment, below which the velocity drops to 1,620–1,720 m/s. The velocity drop in the fourth layer (~180 m) may be due to the presence of free-gas. The bottommost sedimentary layer is marked with a velocity of 2600-2700 m/s.

Introduction

Gas-hydrates are ice like crystalline substance composed of water and light hydrocarbons (mainly methane), found in the permafrost regions and outer continental margins of the world where methane concentration exceeds the solubility limit (Sloan, 1998; Paull and Dillon, 2001; Taylor and Kwan, 2004). The occurrence of hydrates is often inferred from the identification of BSR on seismic section (Shipley et al. 1979). The presence of gas-hydrates increases the acoustic velocity of sediments (Lee et al. 1996; Helgerud et al. 1999; Jakobsen et al. 2000; Gei and Carcione 2003; Chand and Minshull 2003; Chand et al. 2004). The presence of underlain free-gas below the hydrate-bearing sediments decreases the seismic velocity. The change in velocity builds the impedance contrast across the hydrate/free-gas interface, which gives rise to the BSR. Distribution of hydrates in sediment may be localized which produces lateral and vertical velocity variations (Pecher and Holbrook 2003). Detailed velocity analysis of seismic data constrains the quantitative estimates of gas-hydrates and free-gas volume, as well as their presence (Hyndman et al. 1992). Hence, a detailed velocity analysis of the study area may infer the gas-hydrates and underlying free gas zone A review for the identification and quantification of gas-hydrates is available in recent literatures (Sain and Gupta, 2008; Sain and Ojha, 2008). Gas-hydrates have already been studied in the Kerala-Konkan offshore region (Satyavani et al 2002; Thakur et al 2007). In this paper, we have tried to map the 2-D velocity structure of the Kerala Konkan Offshore region (Figure1) to infer the presence of gas-hydrates and free gas.

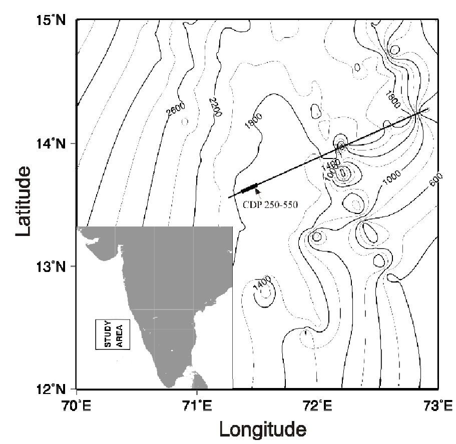

Figure 1: Location map of the study area showing the seismic line.

Methodology

A 2-D isotropic velocity structure having a number of layers (six in the present study) with variable-block-size is assumed for modeling. An example is illustrated in figure-2 which has a five layer and 12 blocks. Each layer boundary is specified by an arbitrary number and spacing of boundary nodes connected by linear interpolation; the number and position of nodes may differ for each boundary (Zelt and Smith 1992). The traveltimes and their partial derivatives with respect to the velocity and boundary node values are calculated during ray tracing, and the forward response of the starting model is compared with the observed data. Damped least-squares inversion is used to determine the updated model parameters of those selected for adjustment, both velocities and boundary nodes simultaneously. The parameters of the model are then updated using the correction vector obtained from a damped least-squares inversion of the traveltime residuals. The iterative process is continued until a satisfactory fit corresponding to a normalized Chi-Square (χ^2) misfit value of one is achieved. The inversion approach is layer stripping in which the parameters (velocities and depths of boundary nodes) are determined layer-by-layer. The travel times of the first segment corresponding to all shots are inverted simultaneously using the iterative procedure until the root mean square (RMS) residual between the theoretical response and the observed data is reduced to a minimum value or to the level of data uncertainties. By holding fixed the velocity of the first layer, travel time data of second segment associated with all shots are inverted in a similar way. The difference between the observed and computed travel time curves is minimized by changing the velocity and the depth. The slope of the travel time curve is changed by changing the velocity and by changing the depth node position, the estimated arrival travel time can be made slower or faster. Velocities and depths are then modified until a satisfactory match between the observed and computed traveltimes is attained. In the inversion process, rays are traced through the starting model and travel times are predicted, and then compared with the observed travel-times.

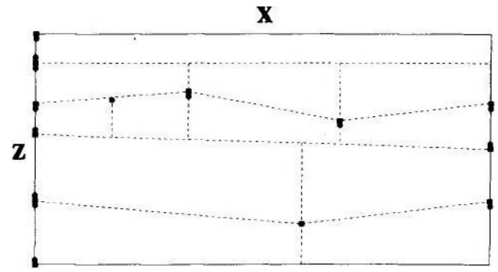

Figure 2: An example of the velocity model parameterization. (after Zelt and Smith 1992).

The difference, in the form of a χ^2 error, is used to update the starting model. The model parameters i.e., either velocity or vertical coordinate (depth), or both, are modified iteratively. The process is repeated until the updated model predicts seismic travel-times that agree with the observed values to a degree determined by the assigned pick uncertainties.

Modeling

We have taken six shot points each shot at an interval of fifty shots, which is equivalent to 6.25 Km of length. The shot and the geophone group interval both are 25 m, and each shot is having 96 channels in the data used here. The arrival times have been picked at every 50^{th} shot with 1.25 Km spacing. Spectral analysis of MCS data in this region indicates that the spectral band covering the frequency range of 20 to 60 Hz (with the dominant peak at 35 Hz) contributes mainly to the amplitude (NGRI 2001). The travel-times of five phases and direct arrivals from shot gathers are picked from common shot gathers (Figure 3). However, direct arrivals are not being modeled in the present study. A 'layer stripping' modeling approach is applied whereby successively deeper layers are determined (Zelt 1999). Assuming water velocity of 1450 m/s, we determine the thickness of water layer by inverting the traveltimes of the first phases for all shots together. In the next step, we hold fixed the parameters of the water layer and determine the velocity and thickness of the first sedimentary layer by inverting the traveltimes of the second phases. Keeping fixed the model parameters of above layers, the traveltimes inversion of the third phases produce the interval velocity and thickness of the second sedimentary layer. Similarly, we determine the velocity-structure of the third, fourth and fifth sedimentary layers. For the inversion of data, damping factor is taken as 1.0.

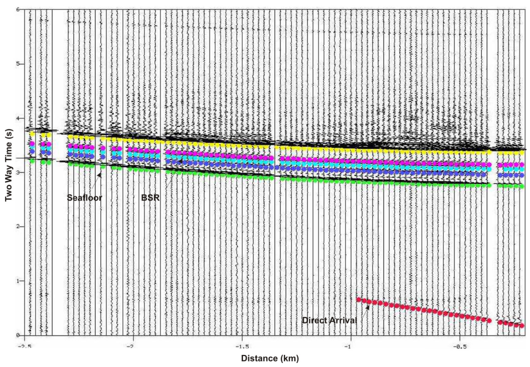

Figure 3: Figure shows the six phases that are picked from common shot gathers and utilized for traveltime modeling. Sea floor and BSR are shown in the figure.

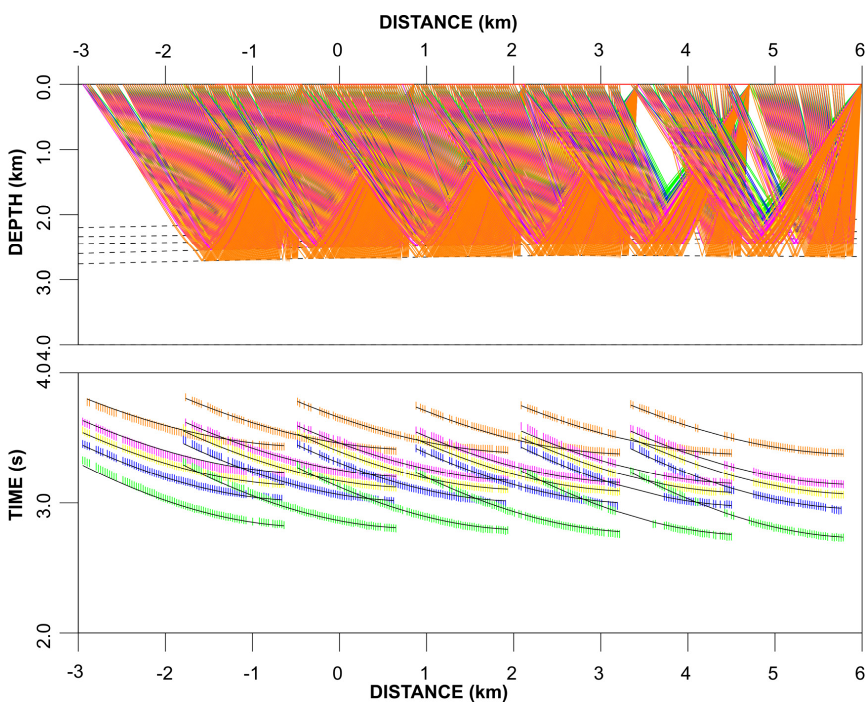

Figure 4: Rays traced from all the phases and shot points through the final model. Best possible fit for the observed and estimated traveltime after the inversion. All traveltime data is best fitted. Solid black line indicates the observed traveltime and dots with different colours indicate the estimated travel time for different phases picked for analysis.

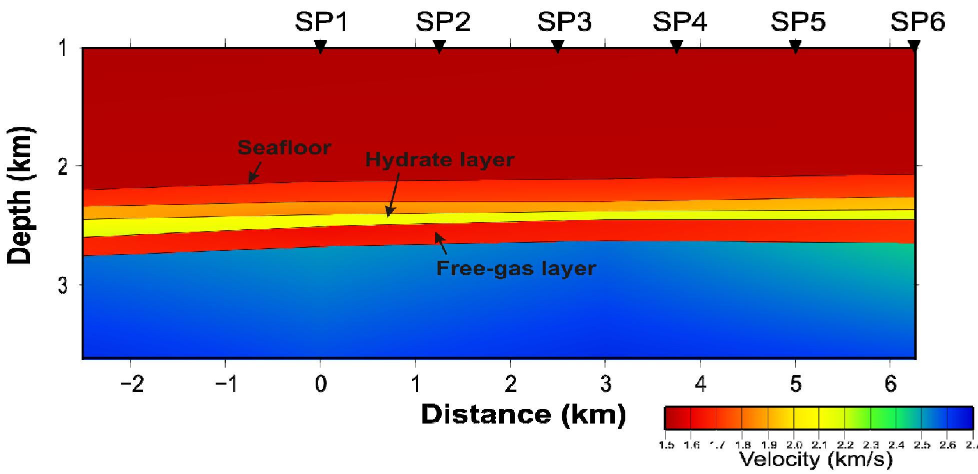

Figure 5: Final velocity Model depicting the high velocity gas-hydrate layer underlying by low velocity free-gas layer.

The maximum uncertainty of the estimated velocity is 100 m/s and that of the boundary node is 100 m throughout the model. The traveltimes and the rays generated for each of the six shots are shown in Figure 4. The final velocity model (Figure 5) obtained from 2-D traveltime inversion consists of six layers and 18 blocks (trapezoids). The number of total rays generated is 9283. The total number of data points used to model the data is 2485. RMS traveltime residual is 0.020 and normalized Chi-Square value is 0.907. The thickness of the first sedimentary layer varies from 140-190 m with velocity ranging between 1,680 m/s to 1,740 m/s. The second layer has a velocity of 1,890–1,950 m/s and thickness of ~110 m. The layer with high velocity of 2,100-2,180 m/s below the second layer is interpreted as the hydrated layer, the thickness of which varies from 100 to 150 m. The next layer with a low velocity of 1,620–1,720 m/s represents the gas-bearing sediments with thickness varying between 160-200 m. The low-velocity layer is underlain by a sedimentary rock with velocity of 2600-2700 m/s

Conclusion

From traveltime inversion of reflection phases of the MCS data, we conclude that the final shallow velocity model consists of six layers including the water column. The maximum velocity (2180 m/s-2100 m/s) is observed in third layer, below which there is considerable velocity drop (1620 m/s-1720 m/s). This high velocity underlain by low velocity layer may be due to the presence of gas-hydrates and free-gas respectively. The maximum uncertainty of 100 m/s in estimated velocity and 100 m in the boundary node shows the velocity structure derived here is reliable.

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