

Imaging finer details of subsurface from seismic full waveform tomography and its application to field seismic data in Kerala-Konkan offshore

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Keywords: Traveltime tomography; full waveform tomography; frequency-domain, ocean-bottom seismic data

Summary

Delineating finer details of sub-surface is always a challenge, particularly in complex geological provinces such as the thrust fold belt and sub-volcanic regions from seismic traveltime tomography only. Further the traveltime modeling has a limited resolution in the order of Fresnel zone, whereas the state-of-the-art seismic full waveform tomography (FWT), which can exploit entire components (traveltime, amplitudes, frequencies, phases...) of data, can delineate finer details of the subsurface. We have successfully imaged the long-wavelength subsurface velocity models using traveltime tomography (TT) to the first arrival ocean bottom seismic (OBS) data along two cross lines in the Kerala - Konkan (KK) offshore basin. Further, we have employed the FWT to the same OBS data using the TT model as initial model to demonstrate the efficacy and practical feasibility of this modern tool that still lies at the nascent stage of development. The tomographic velocity images show the smooth velocity variations from 1.5 km/s to 7.1 km/s. The velocity-depth functions match quite accurately with the available high-frequency VSP velocity-depth function at well-A and well-B drilled within the study area.

Introduction

The KK basin (Fig.1) in southeastern part of the western continental margin of India has gained much interest because of its hydrocarbon potential. The basin lies to the south of Bombay offshore basin, the major hydrocarbon producer of India and is adjacent to east coast Cauvery basin with established hydrocarbons. The estimated resource base of the basin, covering an area of about 1, 69,000 sq. km, is of the order of 660 million tonnes, according to ONGC estimates (Forbes India, 2009). The first well was drilled in 1978. The large extent of the basin and its closeness to the prolific producing Mumbai

offshore basin in the north have made it significant for hydrocarbon exploration. But the exploration so far has not yielded any discovery, raising some doubt in the existence of a petroleum system in the basin. The KK basin is one of the vast deep water unexplored frontier regions. Here, we present the results of both traveltime and full waveform tomography of wide-angle OBS data in the deep water of the basin. We then have used the results to integrate with ancillary geo-scientific information with a view to imaging finer details of the subsurface including the sub-basalts.

Methodology

Successful FWT needs a very good starting model that will not suffer from trapping in local minimum. First, we have applied the traveltime tomography method of Zelt & Barton (1998) to wide-angle OBS data to derive long-wavelength model, which has been utilized as a starting model for the FWT. The reader may refer to Zelt et al. (2003) and more recent works (Vijaya Rao et al., 2015; Damodara et al., 2017) on traveltime tomography. Next, we have applied the frequency-domain FWT in acoustic sense (Ravaut et al, 2004; Operto et al, 2006). For more details on FWT, one can find an excellent review by Virieux and Operto (2009).

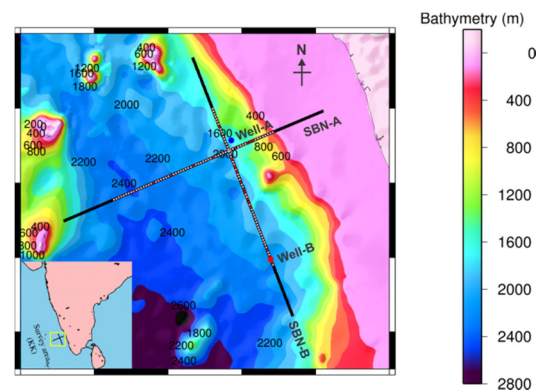


Fig.1. The Bathymetric map of the Kerala-Konkan (KK) basin along with the SBN-A & SBN-B lines, passing through two nearby well.

Tomography: Results

Data: The acquisition of OBS data along two lines (Fig.1) using 4 component sub bottom nodes (SBN) was carried out in the KK basin in 2012. Each SBN line with ~250 km-long has record length of 36 sec, shot interval of 37.5 m, SBN spacing of ~2 km and offset of ~60km. A representative SBN gather is displayed in Fig.2, and Table-1 shows the details of each SBN line.

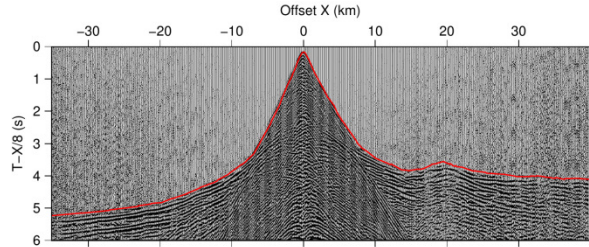


Fig.2. A representative OBS or SBN gather. The first arrivals are shown in red color.

Traveltime tomography: First of all, we pick the traveltimes of first arrivals for all SBN along both the lines (SBN-A & SBN-B), and have performed the traveltime tomography (Zelt & Barton, 1998; Zelt et al. 2003) to derive the smooth large-wavelength velocity structures (Fig.3). These traveltime tomography models are subsequently used in full waveform tomography to delineate the finer details of the subsurface. The initial and final data residuals along two SBN lines are shown in Fig.4. The extracted 1-D velocity depth functions from [traveltime tomography](#) are compared reasonably with available well logs (Fig. 5). Note that the well-A is far away from the lines and Well-A was drilled upto 4.874 km and well-B was drilled upto 6.205 km.

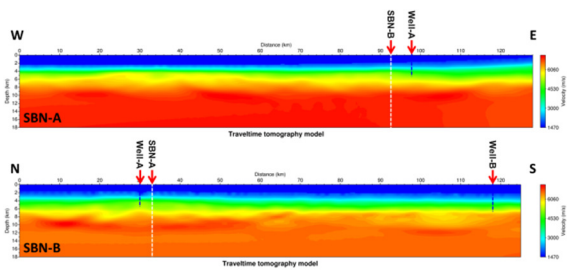


Fig.3. Traveltime tomography models along two SBN lines. The circles at the top represent the location of SBNs. The missed SBNs are shown in blue color.

Table-1

Profile Name	Profile length (km)	Total No. of SBN's deployed	No. of SBN's retrieved	No. of SBN's loss
SBN-A	200	65	57	8

SBN-B 200 63 51 12

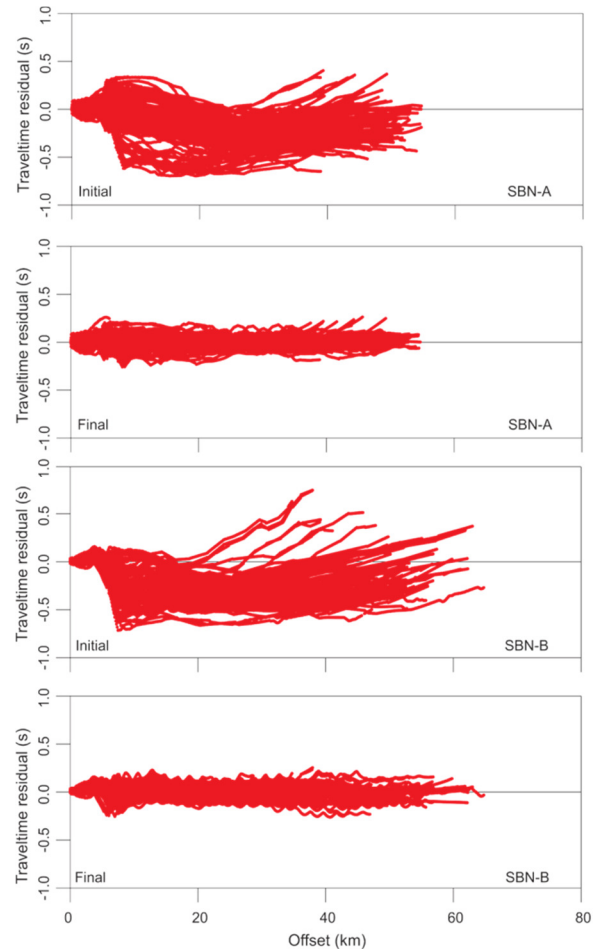


Fig.4. Initial data residuals (difference between the observed data and calculated response of the initial model) & final data residuals (difference between the observed data and calculated response of the final model) along the SBN-A (top two panels) and SBN-B (bottom two panels) respectively.

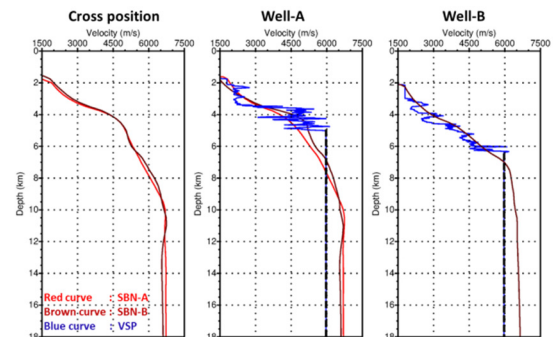


Fig.5. The comparison of 1-D models extracted from [traveltime tomography](#) at three different positions, mentioned at the top. The extracted models are falling in long wavelength trend of well logs. Note that the well-A is far away from the lines and Well-A

was drilled upto 4.874 km and well-B was drilled upto 6.205 km.

Full waveform tomography: Since we have applied the acoustic full waveform tomography, data pre-processing is necessary to improve the S/N ratio, mitigate or exclude arrivals and propagation effects in data which cannot be predicted from acoustic approximation. The pre-conditioning of SBN data includes trace editing, top and bottom muting, and band pass filtering etc. The sample pre-conditioned data for FWT is shown in Fig. 6. We use a band-pass filtered spike source in absence of actual source in the FWT.

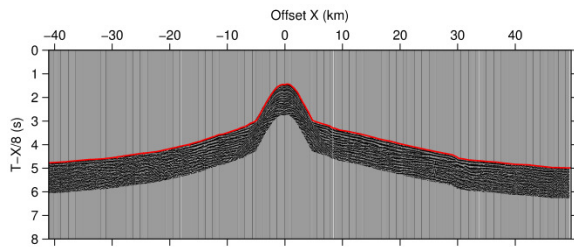


Fig.6. A representative SBN gather after pre-processing of the data. The pre-processed data is transformed into frequency-domain for FWT.

We have inverted the seismic data with frequencies ranging from 2 to 20 Hz with 0.5 Hz interval. These 37 frequencies are grouped into 36 groups with 2 frequencies per group along with the frequency overlap between successive groups. We have performed 30 iterations for each frequency group. The final velocity models along small segments around the cross point of two SBN lines are displayed in Fig.7, which show finer details of the subsurface that are not evident in the traveltome tomography models. Further, we have delineated sub-volcanic low-velocity sediments (probably Mesozoics?) that match reasonably with the lithologies available in the nearby well. These results can be improved further if we had used the actual source. We have performed the FWT on a server that has 4 nodes with 64 total cores populated as 16 core Intel Xenon 2.4 GHz processor per node. It has taken nearly 45 days to complete the FWT of 36 s wide-angle seismic data with 4 ms sampling interval along a 120-km long line with shot spacing of 37.5 m and station spacing of 2 km for all 36 frequency groups. The node spacing of modeling was 50 m.

Conclusions

We have derived large-wavelength velocity structure from traveltome tomography of wide-angle seismic data along two lines in the Kerala-Konkan offshore, which lacks in structural details. We have

successfully applied the full waveform tomography to the same wide-angle seismic data, and delineated thin low velocity limestone formation sandwiched between two formations of volcanic rocks, which was not evident in the traveltome model. The FWT results match reasonably with the available well data.

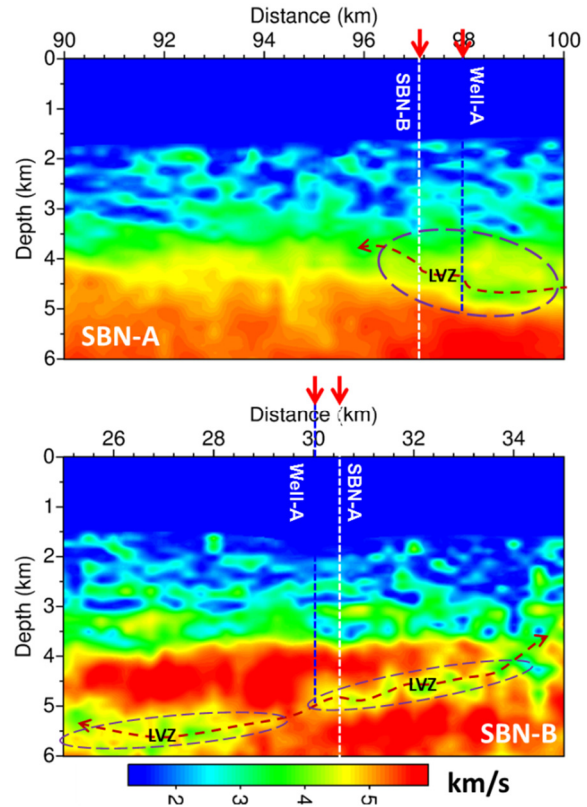


Fig. 7. The small segments of FWT models around the cross point of two SBN lines.

Acknowledgements

The Director, CSIR-NGRI is acknowledged for his permission to present this work. The Oil & Natural Gas Corporation Limited (ONGC) and Director (E), ONGC, India is gratefully acknowledged for approval to utilize the OBS data set. We also acknowledge the developers of different modeling & Inversion open source packages that have been used here. The Generic Mapping Tools (Wessel & Smith, 1998) software was used for plotting some of the figures. This is a contribution to FTT research of CSIR-NGRI under MLP-6106-28(KS).

References

Damodara, N., Vijaya Rao, V., Kalachand Sain., Prasad, A.S.S.R.S., and Murty, A.S.N., 2017. Basement configuration of the West Bengal

- sedimentary basin, India as revealed by seismic refraction tomography: its tectonic implications, *Geophys. J. Int.*, 208, 1490-1507.
- Operto, S., Virieux, J., Dessa, J.-X., & Pascal, G., 2006. Crustal seismic imaging from multifold ocean bottom seismometer data by frequency domain full waveform tomography: application to eastern Nankai trough. *J. geophys. Res.*, 111, B09306.
- Ravaut, C., Operto, S., Improta, L., Virieux, J., Herrero, A., & Dell'Aversana, P., 2004. Multiscale imaging of complex structures from multifold wide-aperture seismic data by frequency-domain full-waveform tomography: application to a thrust belt. *Geophys. J. Int.*, 159, 1032-1056.
- Vijaya Rao, V., Damodara, N., Sain, K., Sen, M.K., Murty, A.S.N., Sarkar, D., 2015. Upper crust of the Archean Dharwar Craton in southern India using seismic refraction tomography and its geotectonic implications. *Geophys. J. Int.* 200, 652–663.
- Virieux, J., Operto, S., 2009. An overview of full waveform inversion in exploration geophysics. *Geophysics*, 74, WCC127-WCC152.
- Wessel, P., & Smith, W.H.F., 1998. New improved version of generic mapping tools released, *Eos Trans. AGU*, 79(47), 579.
- Zelt, C.A. & Barton, P.J., 1998. Three-dimensional seismic refraction tomography: a comparison of two methods applied to data from the Faeroe Basin, *J. geophys. Res.*, 103, 7187–7210.
- Zelt, C.A., Sain, K., Naumenko, J.V., Sawyer, D.S., 2003. Assessment of crustal velocity models using seismic refraction and reflection tomography, *Geophys. J. Int.*, 153, 609-626