

Imaging Through the Deccan Basalts – New Lessons from IndiaSPAN II

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Introduction

GX Technology conducted a 5,500km long-offset deep-imaging IndiaSPAN I seismic campaign in 2006-2007 in the West Coast of India to understand the petroleum systems of the deepwater of the Western Indian Margin. This seismic campaign utilised large source and long offset to image the Western offshore to understand current tertiary plays and provide a better understanding of the new Cretaceous plays beneath the Deccan traps.

Analysis of the IndiaSPAN I data shows a significant Cretaceous and Jurassic section underneath the Deccan basalt offshore West India. Large scale compressional features appear as large anticlinal folds underneath the trap cover. The Deccan trap cover was found to be not as extensive as previously thought.

In late 2008, GXT began a second IndiaSPAN campaign to better image the Juro-Cretaceous sediments through the basalts. IndiaSPAN II seeks to infill the coverage from IndiaSPAN I while focussing on the petroleum systems likely to have resulted from the break-up related structural highs seen in IndiaSPAN I.

This paper will explore a new method of acquisition deployed in the Western offshore of India to improve the deep imaging and discuss how application of advanced multiple attenuation and imaging techniques resulted in improved sub-basalt resolution. A new model for the deepwater Cretaceous petroleum system will be presented for the West Coast. This well imaged deep dataset has provided new clues for the continent-ocean boundary for the West Coast and has begun providing new ideas for the future of the petroleum potential of the Margin.

Background

Several authors have pointed out that a 200km wide continental platform should exist in the West Coast of India. The analysis on which this conclusion is drawn stems in large part from margin reconstruction using magnetic, refraction and seismic studies. IndiaSPAN I has revealed the presence of a significant wide continental margin in the Western offshore. Sediments have been imaged down to 14-16 Km below the water bottom. Preliminary stratigraphic

analysis of the data and wells onshore Kutch shows that the section beneath the traps should likely be of sub-trappean age i.e. Cretaceous and Jurassic. GXT shot similar SPAN data in East Africa (Kenya, Tanzania, Madagascar and Seychelles) to establish the regional framework for the Indian Ocean and provide conjugate ties across East Africa, Madagascar, Seychelles and Western India. Reconstruction of seismic lines across the conjugate margin confirms the presence of Karoo grabens and Jurassic sedimentation across the Indian Ocean.

The original IndiaSPAN I dataset was primarily focussed west of Bombay High and to the North (offshore Kutch Saurashtra) and in the Kerala basin to the South. Data from IndiaSPAN I showed that a large source provided a good starting basis for imaging of sub-basalt sediments. Imaging of these sub-basalt sediments in IndiaSPAN I data provided the impetus to acquire additional data in the Western Margin in a subsequent project, called IndiaSPAN II. The IndiaSPAN II program infilled the original IndiaSPAN Phase I and provided some more coverage in the data gap area between Bombay High and Kerala basins.

Program Design

In IndiaSPAN II, lines were laid out in geological areas found to have exploration potential in IndiaSPAN I. A primary focus was to image through the Deccan traps to provide better controls on the major features such as the large scale pre-rift structures. Sediment thickness and the volcanism arising out of the India-Madagascar separation provided the control elements for the line lengths and positioning.

Data Acquisition

GX Technology conducted several previous studies to optimise the data penetration and imaging underneath basalts. These tests were conducted as part of the North East Atlantic SPAN offshore Faroes and the "Deep Tow Test" in Gabon as part of CongoSPAN survey. These studies show that seismic imaging beneath basalt flows benefits significantly from the use of High Fidelity, Low frequency acquisition. This low frequency acquisition is achieved by a careful balance of the following considerations:

- a) long receiver offset range to
- b) Minimum bubble interference

c) A signature that is well behaved and minimum phase

In order to construct an adequate source, it is imperative to balance the spectral bandwidth of the source deployed with the dispersion and reverberations caused by a too large source size. A very important consideration for imaging beneath basalts is to tow it sufficiently deep so that lower frequencies of the spectrum are enhanced by constructive interference between the primary pulse and the free-surface source ghost. The towing depths directly affect the bandwidth of recorded signal and need to be moderated by considerations to limit bubble related reverberations which cause the data to be ringy. We shall present results on the optimum selection criteria for this acquisition.

Streamer tow depth is another important criteria that needs to be controlled during acquisition. Towing streamers significantly deeper pushes the streamer ghost to lower frequencies restricting bandwidth. Furthermore, streamer tow depths need to be controlled such that it can meet the operation criteria for the cable retrievers on the streamers.

IndiaSPAN I was acquired using a very powerful source (approximately 235 bar-m) towed at 8.5m. The streamer was towed at 9.5m.

In IndiaSPAN II, the acquisition parameters were modified for the source to enable deeper penetration without significantly impacting recording bandwidth. The IndiaSPAN II survey was acquired with a slightly smaller source of approximately 170 bar-m (with a source volume of 5,860 cu.in). The source was towed at 12.5m and the streamer at 13.5m tow. This towing configuration produces a high energy, low frequency spectrum to 50HZ with minimal bubble interference and acceptable wavelet shape. This helps excellent acquisition compromise for recording good signal quality and bandwidth beneath the basalt layer.

The following figure illustrates the difference between a shallow source signature and a deeper source such as the one used for IndiaSPAN II. Notice the higher amplitudes at lower frequencies obtained by towing the source deeper.

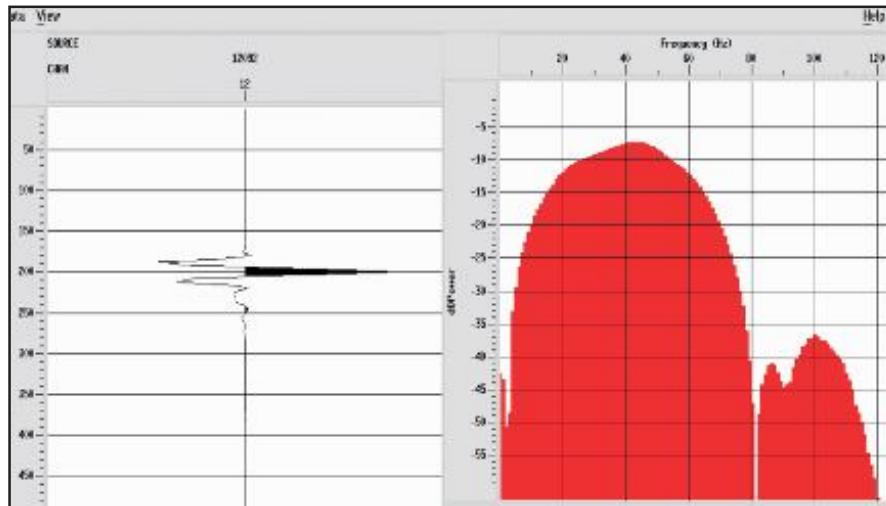


Fig.1 IndiaSPAN II source towed at 8.5m (regular tow depths)

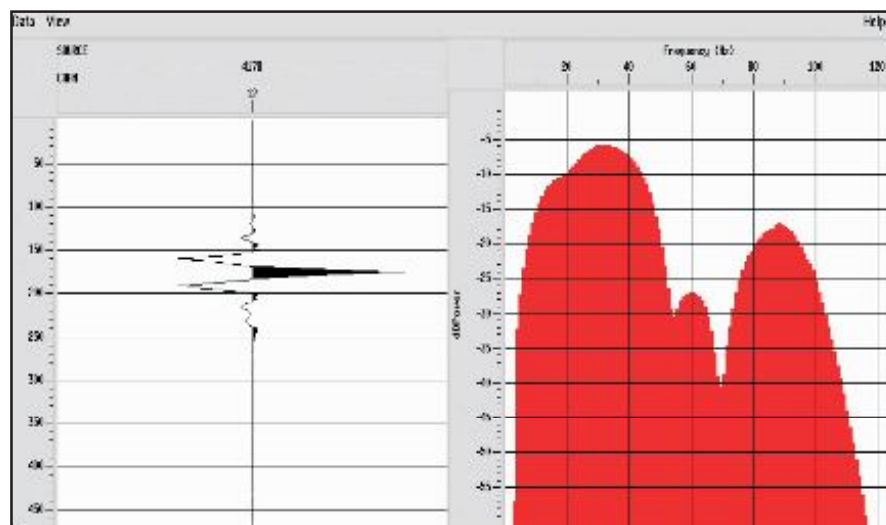


Fig.2 IndiaSPAN II source towed at 13.5m (deeper tow)

Processing IndiaSPAN II

There are two basic problems when processing data in regions where basaltic layers severely degrades the incidence energy. The first main challenge is to preserve the signal to noise ratio underneath the basalt and the second challenge is to improve the multiple suppression by addressing issues related to inter-bed multiples and diffracted multiples. The latter are caused due to fractured basalts and surface reliefs found in the West Indian Coast that displaces the moveout of the parabolas to non-zero finite offsets. These diffracted multiples cannot be addressed by industry standard applications of radon transforms. Towing the streamer deep at 13.5m has the tremendous advantage of recording in a quiet zone for ambient noise thereby making the inherent signal to noise ratio (with respect to ambient noise only) very high.

GXT developed a robust processing algorithm to address issues related to multiple attenuation. A cascaded series of multiple attenuation involving tau-p decon, surface multiple attenuation (SMA or SRME) and high resolution beam radon was applied on the datasets. In addition, GXT applied its proprietary “Apex-Shifted Multiple Attenuation (ASMA)” technique that addresses the diffracted multiples very effectively. The cascaded series of multiple attenuation techniques applied to the data very effectively reduced the impact of multiples underneath the basalt rendering the data very effective as input for subsequent depth migration algorithms.

Velocity modelling for IndiaSPAN II benefited tremendously from the experiences of IndiaSPAN I, the results of which were presented at SPG 2008 by the lead author of this paper. Models for post-basalt sequence used a standard application of PSDM velocity analysis i.e high resolution automatic pick of velocities using gather flattening methodology. Underneath the basalts, it was not possible to use a sweeping application of gather flattening methodology because of the inherent low content of coherent primary energy. A combination of velocity scans, tomography and gather flattening mechanisms were used to derive the final velocity models. A gravity and magnetic modelling was done along each line to verify densities from potential field data. This was then inverted for velocities which provided an independent verification for the velocities for the PSDM velocities. The authors highly recommend obtaining refraction profiles in the West Coast to provide additional ancillary data to velocity modelling as has been done in the African, Brazilian and Faroes margins.

Results of IndiaSpan Phase II

Results obtained from preliminary images show unprecedented quality and deep reflectors beneath the Deccan traps.

The location of the profiles for which the seismic images are presented is shown below:

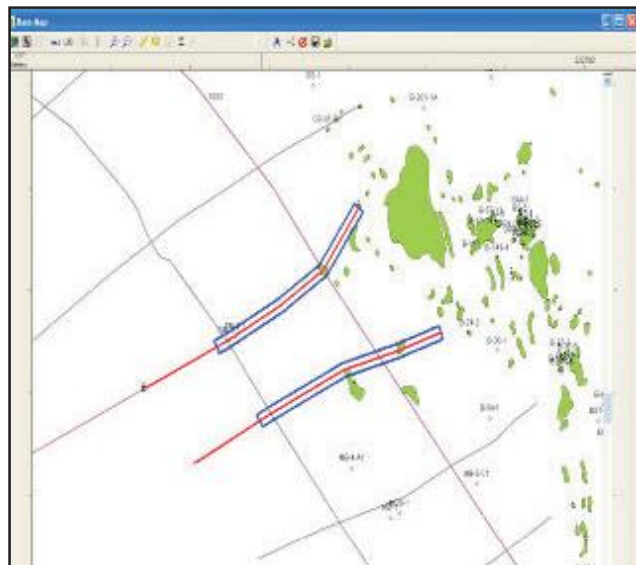


Fig.3 Location of the two seismic profiles. Line to the North is IW-4000 from IndiaSPAN I and line to the South is IW-4200 from IndiaSPAN II. Both lines are just West of the prolific Bombay High fields.

Pre-stack time migration results for the two lines are shown below. Both images have been displayed identically to 15 secs with the annotations along time axis representing 1 second each. Notice the higher primary signal content in IndiaSPAN II image as a consequence of improved acquisition parameters.

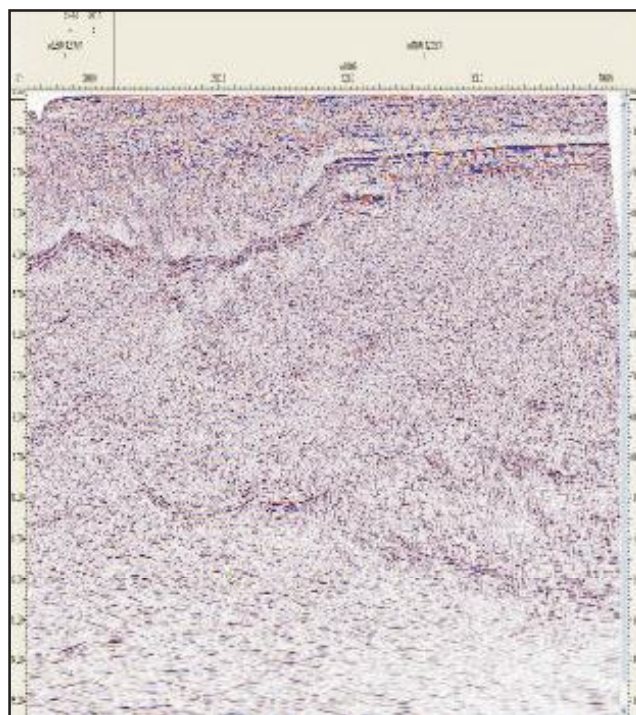


Fig.4 PTSM of part of line 4000 (IndiaSPAN I)

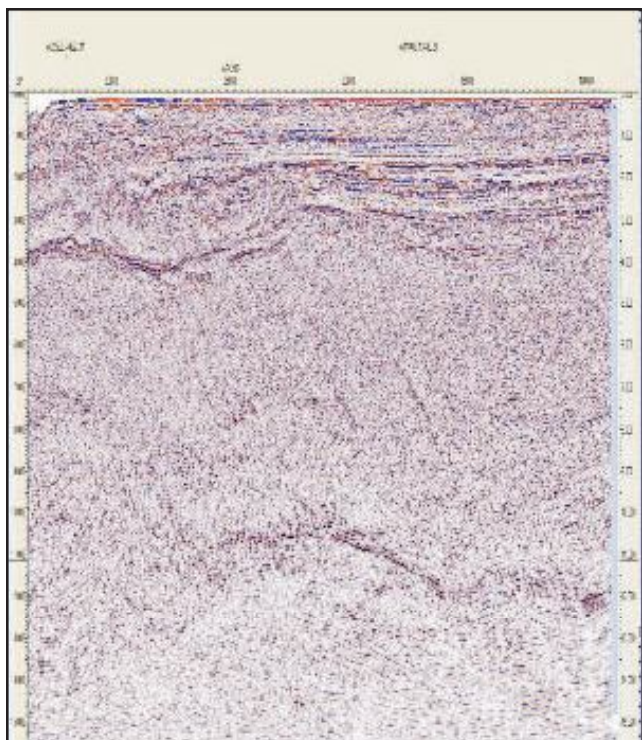


Fig.5 PSTM of part of line 4200 (IndiaSPAN II)

The following two sections show the PSDM images from line 4000 from IndiaSPAN I and line 4200 from IndiaSPAN II respectively. Both images are shown down to 6km. Notice the excellent quality of IndiaSPAN II imaging around and underneath the faulted basalts.

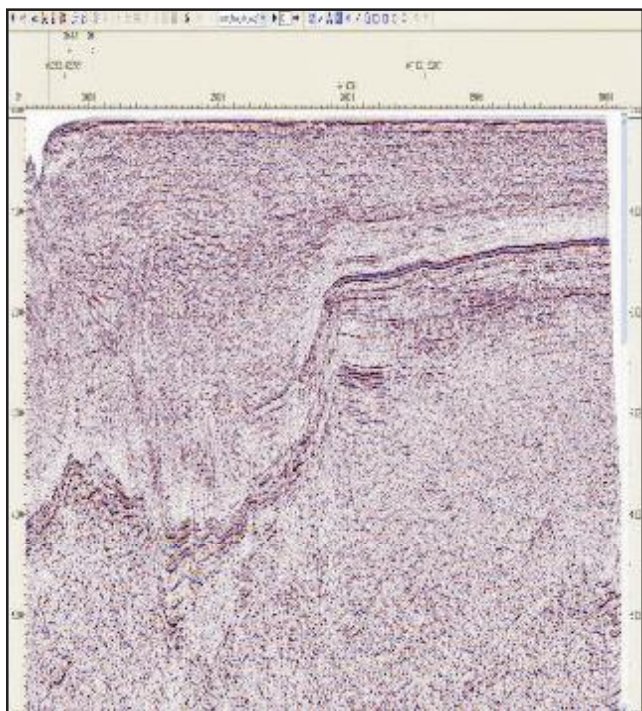


Fig.6 PSDM of part of line 4000 (IndiaSPAN I)

Fig.6 PSDM of part of line 4000 (IndiaSPAN I)

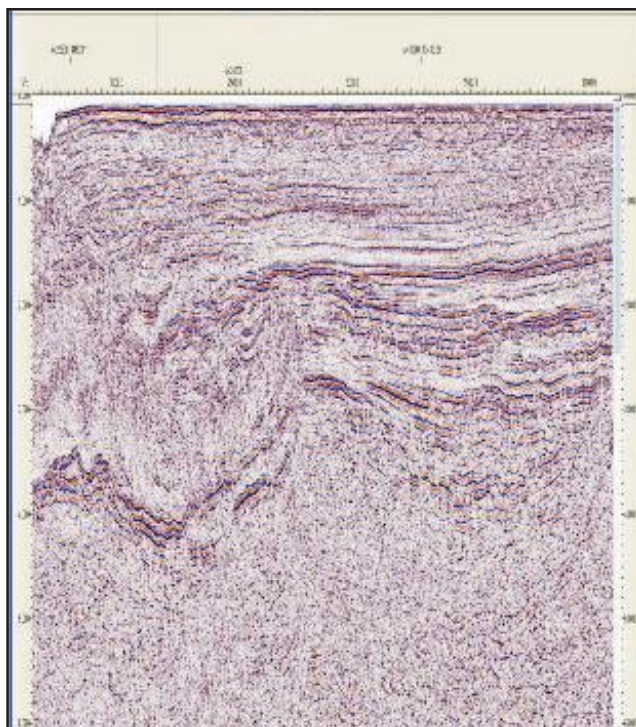


Fig.7 PSDM of part of line 4200 (IndiaSPAN II)

Seen in the following figure is a composite line made up of part of a line from IndiaSPAN I and merged with another part of line from IndiaSPAN II. The exact location of the two lines is shown in yellow in the adjoining map. The dip line 3000 is from IndiaSPAN I and strike line 2500 is from IndiaSPAN II.

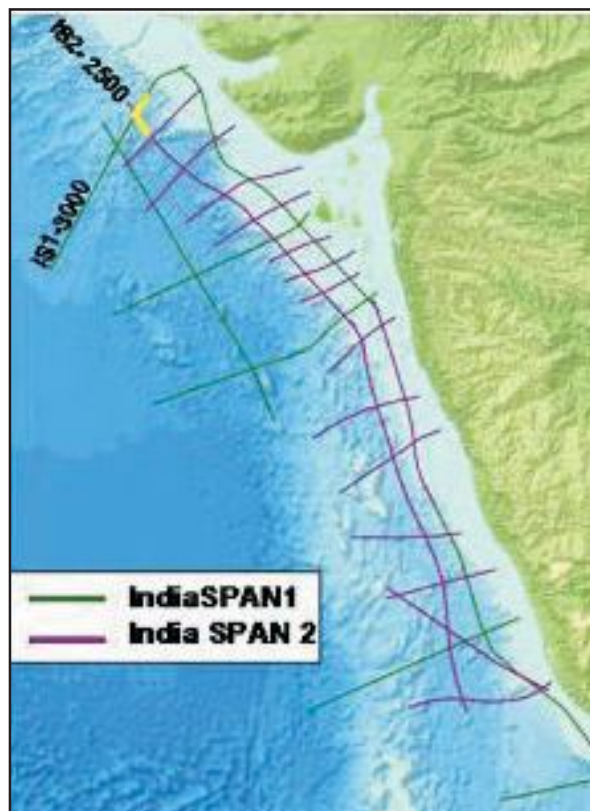


Fig.8 Location map for seismic examples in following figure

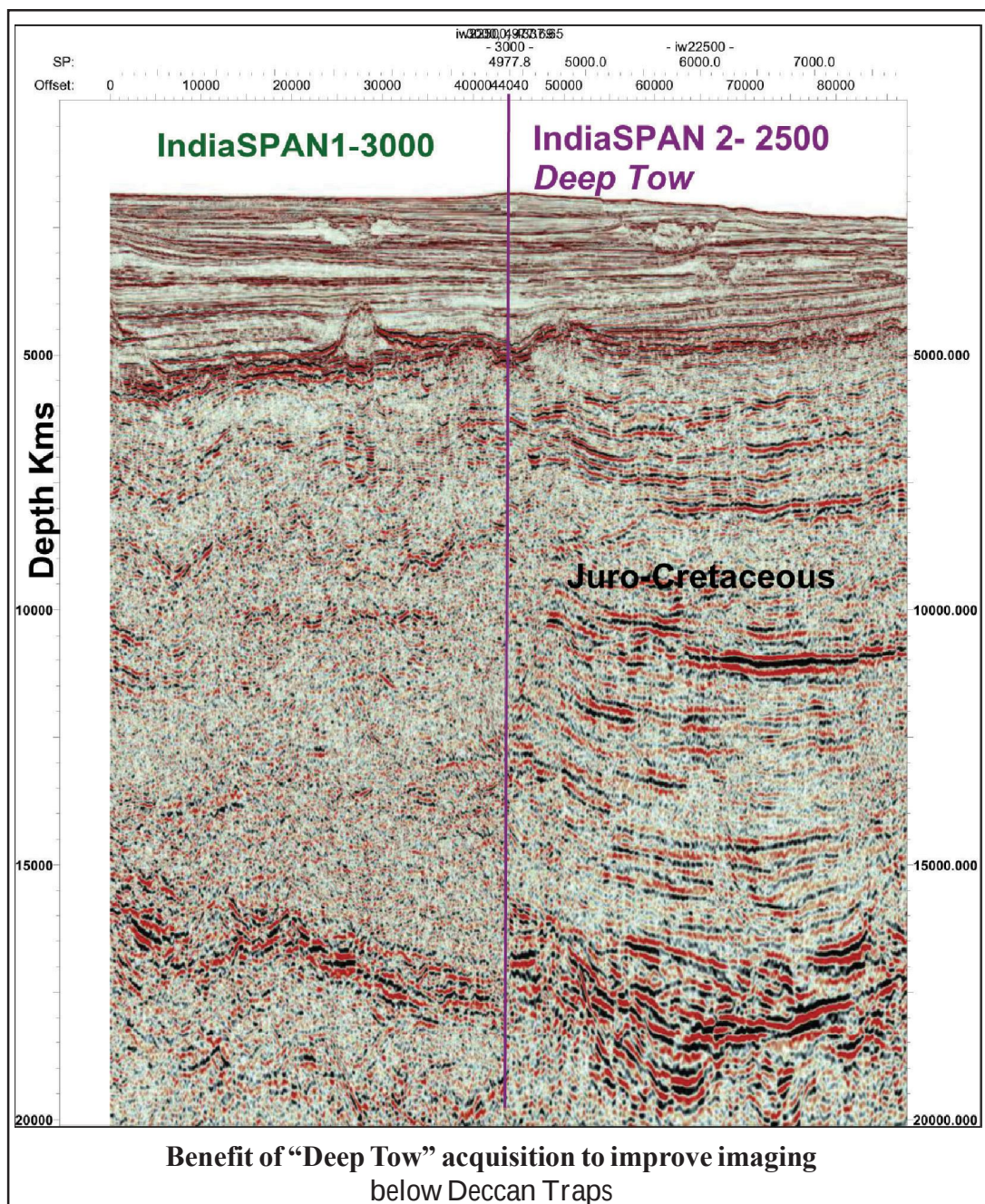


Fig.9 PSDM of part of line 3000 from IndiaSPAN I (left) merged with PSDM of part of line 2500 from IndiaSPAN II (right)

Some main highlights of the new IndiaSPAN Phase II Deep Tow data in the West Coast are:

- ★ Strong signal strength underneath the traps.
- ★ Large scale structures that can be mapped to > 50km.
- ★ Better resolution of the Ocean-Continent boundary in the West Coast.
- ★ Better signal quality and strength in the Konkan area where no previous IndiaSPAN data exist.
- ★ Dataset has advanced new exploration plays in India's West Coast.

Conclusion

Carefully designed “Deep Tow” acquisition in the West Coast of India is revealing excellent seismic imaging underneath the Deccan Traps. The basalt layers are not seen to be as extensive as previously thought and large scale structures underneath the basalt are now becoming clearly visible.

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