

Value addition in subsurface imaging in the Nohta-Damoh-Jabera area of Vindhyan basin through local angle domain imaging

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Keywords

EarthStudy360 (ES360), Local angle domain imaging, Grid tomography, and Constrained Velocity Inversion (CVI).

Summary

In the present study, three volumes of seismic were merged and used as one volume for depth imaging. One of the major challenges that interpreters were facing, while working on the earlier PSTM data, was in mapping of lateral continuity and fault extent at Nagod, Kaimur, Rohtas, Mohana, Jardepahar, Kajrahat, and Basement level. With an aim to delineate these formation tops and proper imaging of faults in the study area, local angle domain imaging technique was used for depth imaging, with grid tomography to iteratively update the interval velocity volume. The subsurface imaging resulted into better reflection continuity as well as discontinuity at the required formation levels.

Introduction

The present study area i.e. Nohta-Damoh-Jabera (NDJ) is shown in fig. 1, which is situated in the north central part of Madhya Pradesh and falls in the Son Valley of Vindhyan Basin and to the south-east of Bundelkhand Massif. Vindhyan Basin of Central India forms one of the complex geotectonic segments of the Indian subcontinent which is associated with complex thermo-tectonic history. Southern part of this basin is known to contain favorable conditions for hydrocarbon entrapment (Ravi P. Srivastava and

et al. 2009). Keeping this in mind, 3D seismic surveys (MP33, 34, 35) were planned in the area to map major geological formations during the field season 2013-16. For the first time, depth imaging was carried out in this area. All the three seismic volumes were merged and used as one volume.

CDP gathers and interval velocity volume were input to the ES360 or Local Angle Domain Imager. The ES360 Imager is a multifaceted cluster-based depth migration that simultaneously uses the full recorded wavefield within a given aperture to generate amplitude preserved, subsurface angle gathers. ES360 is a bottom up ray tracing method. Unlike conventional ray-based imaging methods (e.g. Kirchoff), it uses a point-diffractor operator to shoot rays from subsurface grid points to surface, forming an accurate system for mapping the recorded surface seismic data into the subsurface to Local Angle Domain (LAD) at each image point (Ravve, I. and Z. Koren, 2011). This procedure ensures maximum illumination of the image points from all subsurface directions and surface source-receiver locations; all arrivals are taken into account, amplitude and phases are preserved.

The imager gives two outputs namely, reflection and direction angle gathers. Reflection angle gathers consist of traces, each of which shares the same reflection angle whereas direction angle gathers consist of traces, each of which shares the same dip angle (Koren, Z. and I. Ravve, 2011). Direction angle gathers enable specular and diffraction imaging, resulting in simultaneous emphasis on continuous structural surfaces and discontinuous objects such as faults or fractures. On the other hand, reflection angle gathers are used for automatic picking of full azimuth angle domain residual moveouts (RMO). Picked RMOs together with the horizons are used to update the interval velocity model through grid tomography method.

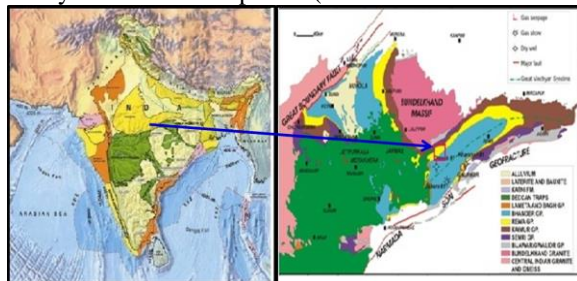


Figure 1: Red box in the map shows the study area.

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Geology of the area

The Vindhyan Basin is grossly bounded by two major structural entities: Great Boundary Fault to the north-west and Son-Narmada Geofracture to the south along which folded structures have developed (fig. 1). Among these, ENE-WSW trending folded structures are Jabera, Kharkhari and Aloni-Salaiya anticlines and Murwara syncline. The Son–Narmada Fault zone manifests as a series of ENE-WSW trending reverse splays. N-S trending cross faults is also observed. The folded structures manifest the surface morphology. Presence of several geomorphic features explains the neo-tectonic activities in this basin.

In north-central India, vindhyan basin was a site for middle Proterozoic shallow marine sedimentation that comprises ~5500m of sediments ranging in age from 1400 to 550 Ma. The entire sequence is known as the Vindhyan Super Group and considered as one of the best preserved Proterozoic sequences in India. It consists of stratified marine un-metamorphosed rocks with sandstone, shale and limestone as the main rock types. Sedimentation in the Vindhyan Basin took place in two major depocenters viz., Son Valley in the east and Chambal Valley in the west. The Vindhyan sediments comprise two sequences, the Lower Vindhyan consisting of Semri Group and Upper Vindhyan consisting of Kaimur, Rewa and Bhandar Groups. The two sequences are separated at places by a well-marked erosional unconformity and gradational contacts elsewhere.

Methodology

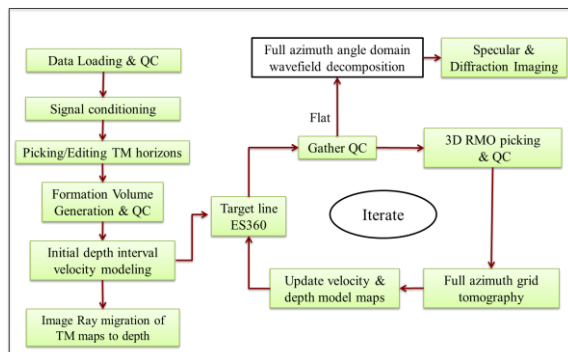


Figure 2: Processing flowchart

Fig. 2 shows the processing flow used in this study. Depth imaging began with loading of merged residual statics applied CDP gathers and RMS velocity volume to Paradigm internal format. These CDP gathers were used as input to ES360 Imager. Horizons were edited or picked on the earlier PSTM stack, wherever necessary. TM (Time Migrated) models were created from the horizons. Formation volume was generated from the TM models and checked properly, for any leakage. Initial interval velocity volume which is shown in fig. 5 was created from the RMS velocity volume and formation volume using Constrained Velocity Inversion (CVI) technique. Unlike simple Dix inversion technique which relies fully on the data without assuming any error in it, CVI is a constrained Dix inversion technique. CVI gives flexibility in hands of the user to put confidence according to the data, trend of the data and damper to reduce oscillations while performing inversion.

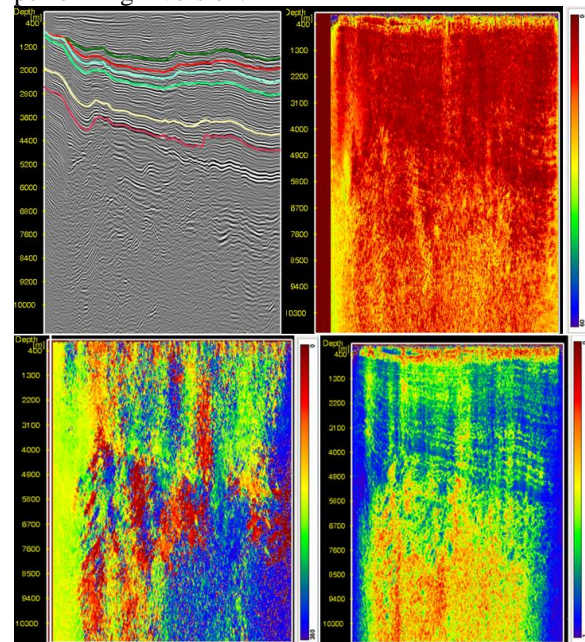


Figure 3: (Top-left) Specular stack from initial ES360 run with Upper Rohtas(dark green), Middle Rohtas(dark red), Lower Rohtas(sky blue), Mohana(light green), Jardepahar(light yellow),Kajrahat(dark pink); (Top-right) Dip section; (Lower-left) Azimuth section; (Lower-right) Specularity section.

Initial PSDM imaging was done using the initial interval velocity volume and input to ES360 gathers. Different values of full aperture tests were carried out and suitable aperture was chosen to image the subsurface. EarthStudy360 angle domain imager

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generated reflection and direction angle gathers. Initial specular stack was generated from the directional gathers which is shown in fig. 3. QC was done of specular stack and reflection angle gathers for proper imaging and flatness respectively.

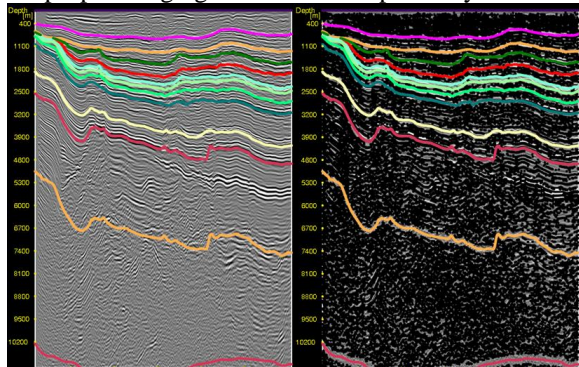


Figure 4: Pencils picked on specular stack (left); Residual Moveout (RMO) points (right) automatically picked between pencils for better control while performing velocity update.

Image Ray Migration was run on TM maps. This had corrected lateral mispositioning of time migrated image. TM interpretation or 3D model maps and interval velocity volume were used for this process. Depth interpretation maps were generated as a result and used as one of the inputs while creation of pencils. For refining of interval velocity volume, grid tomography technique was used. Grid tomography required two pre-requisites, pencils and auto-picker. Pencils were created using the depth model horizons, Dip, Azimuth and Continuity or Specularity (DAC) volume (fig. 3).

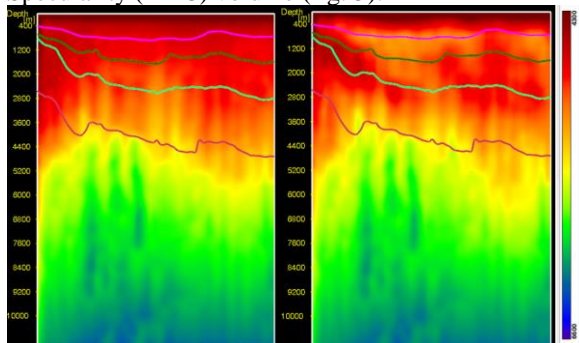


Figure 5: Initial interval velocity (left); Final interval velocity (right). Red colour indicates lower velocity whereas blue colour indicates higher velocity.

Pencils played multiple crucial parts in the tomography process (fig 4). At the auto-picker stage, they served as seed points. After creating pencils, auto-picker was run to pick points and move-outs in between the pencils (fig 4). Refining of velocity

volume in grid tomography is an iterative process. Output of first pass tomography was used as input for second pass tomography and this had continued until reflection angle gathers became flat. In practice, gather flatness, reflection continuity of events in specular stack, and agreement in well and tomography derived interval velocity (fig. 6) were looked for suitable number of iterations. Four iterations were carried out to obtain the final updated interval velocity.

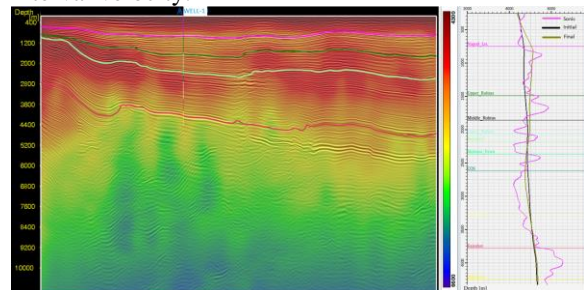


Figure 6: Velocity calculated from well (pink), initial interval velocity (black), final interval velocity after four tomographic updates (light brown) is shown at WELL-1 location.

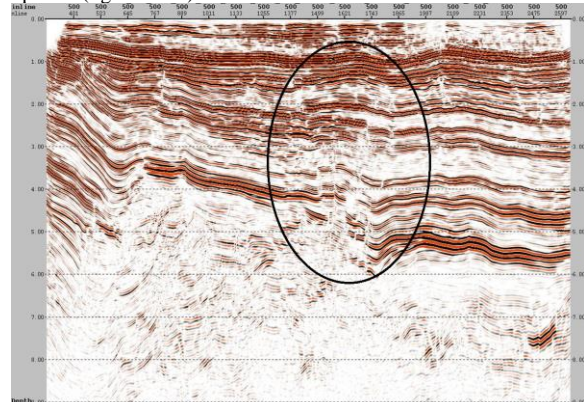


Figure 7: Section showing specular stack (depth) along inline 500.

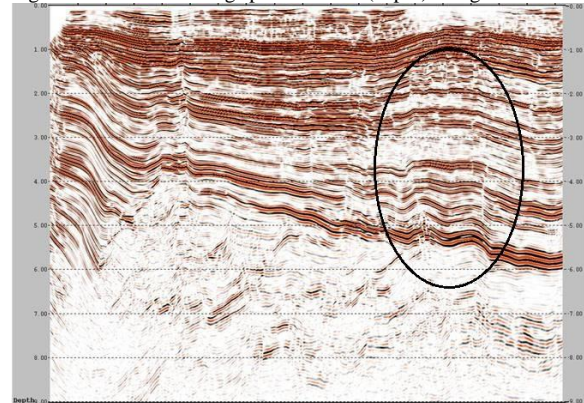


Figure 8: Section showing specular stack (depth) along inline 600.

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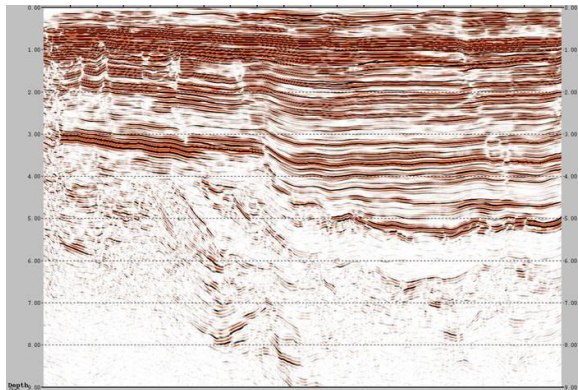


Figure 9: Section showing specular stack (depth) along crossline 700.

Final imaging was done using the final updated interval velocity volume (fig. 5) and input to PSDM gathers with suitable parameters. Specular stacks were generated from directional gathers. The post stack processing sequence included, random noise attenuation, time variant filter and post stack mute.

Analysis of the results

Fig. 5 shows the initial interval velocity section and shows the final interval velocity section, which was obtained after four iterations of grid tomography. As evident from fig. 5, the initial interval velocity model did not contain any significant high velocity layer at the Nagod (pink horizon in fig. 5) formation level. But after repetitive iterations, a high velocity layer at Nagod formation came up as a result of gradual flattening of reflection angle gathers. This high velocity signature in seismic is in accord with the well data passing through the section (fig. 6).

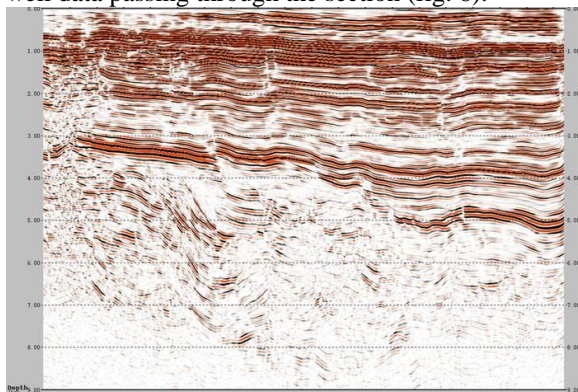


Figure 10: Section showing specular stack (depth) along crossline 800.

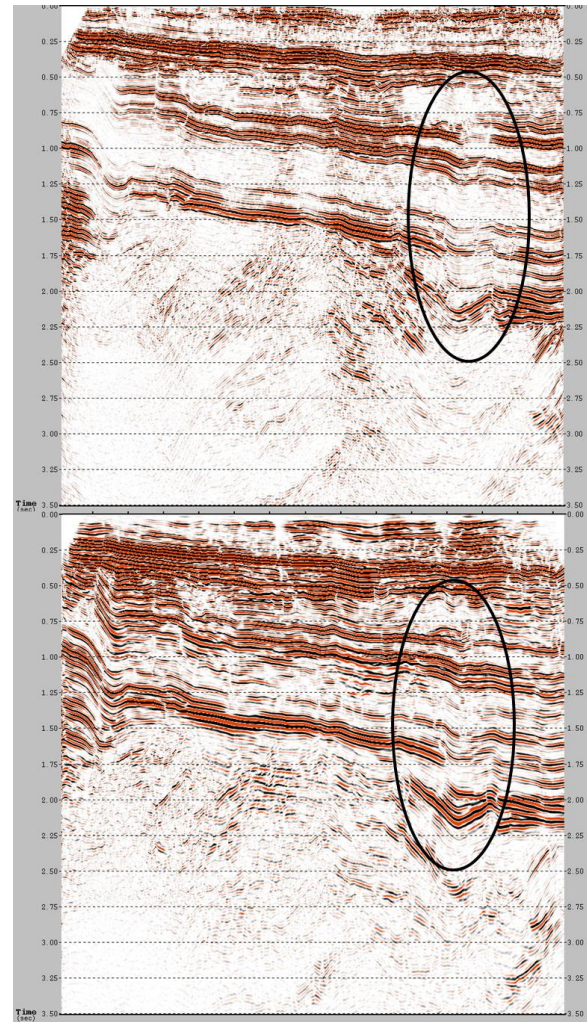


Figure 11: Comparison between earlier PSTM stack (upper) and specular stack scaled to time (lower) along inline 300.

Geologically, this signature is attributed to the presence of limestone, often characterized by high velocity in comparison to shale and sandstone, at this level.

Fig. 7 & 8 shows the specular stack in depth along inline orientation at two different positions in the survey area, which was obtained from directional angle gathers after imaging using final interval velocity. In these sections, we can very well see a positive flower structure which is representative of a compressional and reverse fault regime, encircled in black color ellipse. On the other hand, fig. 9 & 10 shows the specular stack in depth along crossline

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orientation. As evident from these sections, ES360 imaging have enriched the continuities in the overall basin, at the same time, it has also highlighted major discontinuities starting from Nagod upto basement level.

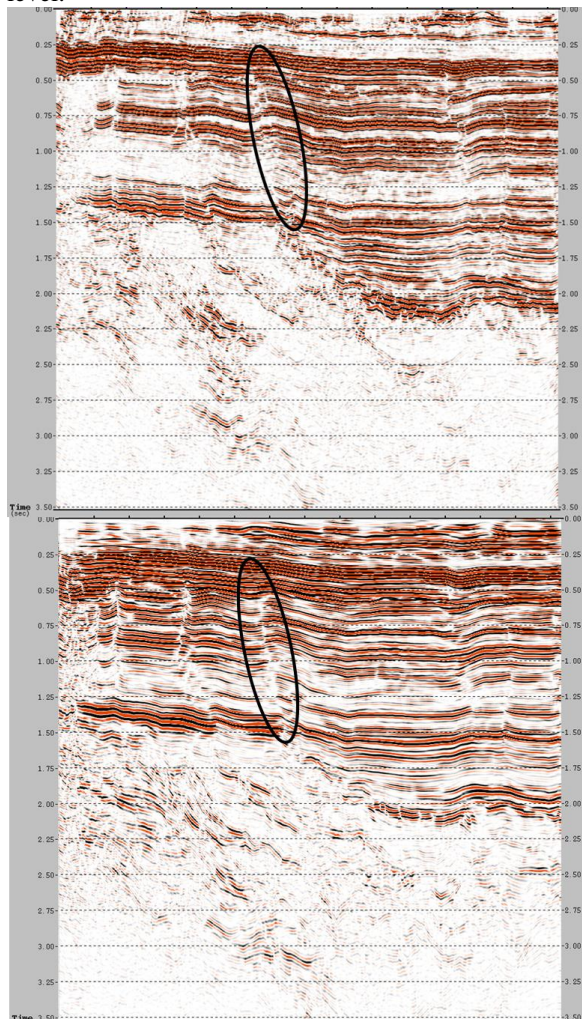


Figure 12: Comparison between earlier PSTM stack (upper) and specular stack scaled to time (lower) along crossline 750.

Fig. 11 & 12 shows the comparison of earlier PSTM stack with the specular stack scaled to time in the study area along inline and crossline orientation respectively. The upper half of the figure represents the earlier PSTM stack whereas lower half represents the specular stack scaled to time.

In fig. 11, we can see enhancement in reflection character and continuity from Nagod level to basement level, with maximum improvement at basement level in specular stack scaled to time in

comparison to earlier PSTM stack. In fig. 12, there was an ambiguity regarding the presence of a fault/discontinuity in the earlier PSTM stack whereas specular stack clearly indicated the presence of a fault starting from lower Rohtas to Basement.

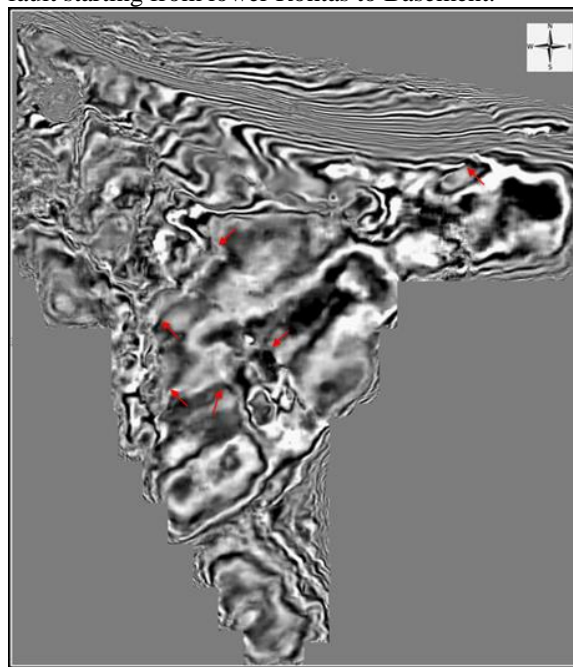


Figure 13: Depth slice at 1385m of specular stack.

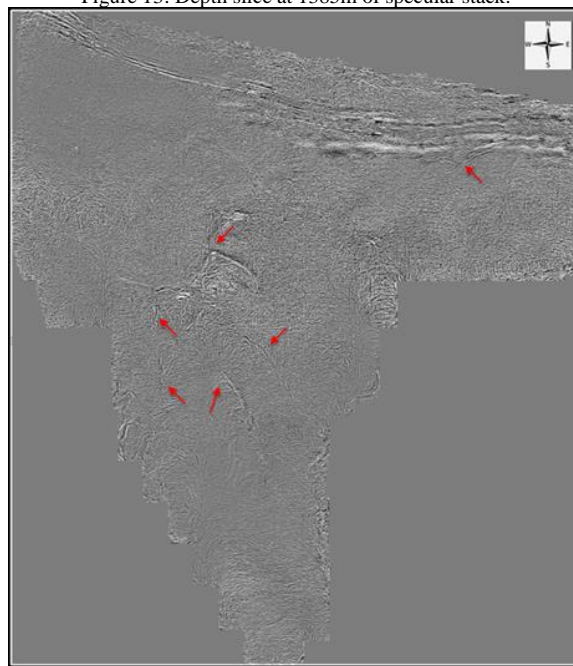


Figure 14: Depth slice at 1385m of diffraction stack.

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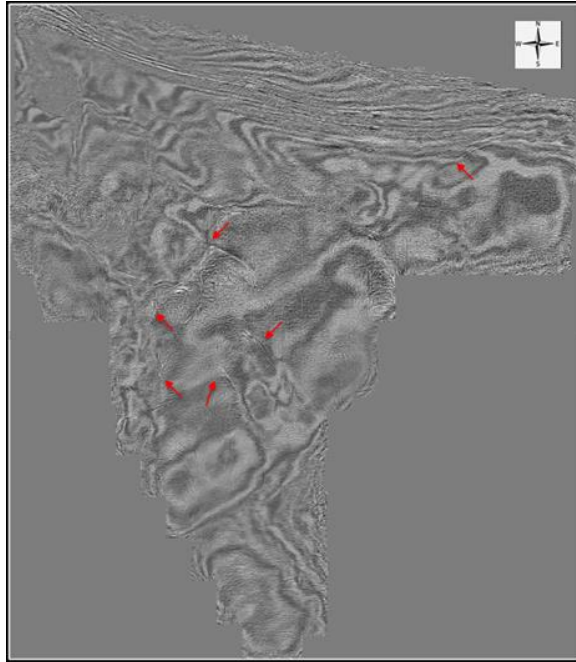


Figure 15: Depth slice at 1385m: blending of specular and diffraction stack highlighting discontinuities and reflection continuities by red arrow in the image.

Fig. 13 & 14 shows the depth slice at 1385m of specular and diffraction stack. Red arrows in both the figures indicate the break in continuity, confirming the presence of fault. Combined use of diffraction stack with specular stack can give a good estimate of presence of a fault as well its lateral extent as shown in fig. 15.

Conclusions

Final interval velocity obtained after four iterations of grid tomography is in good agreement with the well derived velocity. The subsurface imaging brought out by the local angle domain imaging, in general, has shown better reflection continuity at all formation levels, compressional structures imaging such as positive-flower, and fault extent mapping along with bringing out subtle stratigraphic features. Blending of specular and diffraction stack has helped in evaluating the presence of a discontinuous objects such as faults as well as its lateral extent. The processed outputs are expected to meet the exploration challenges faced by geoscientists working in this area and can help in formulating the exploration strategies for the area.

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