

Sub-Coal Imaging of Lakwa-Sonari Field, A&AA Basin, using Local Angle Domain Wavefield Decomposition

Saheb Ghosh*, V P Singh, KS Negi
Oil and Natural Gas Corporation Limited
ghosh_saheb@ongc.co.in

Keywords

Sub-Coal Imaging, Constrained Dix Inversion, Full Azimuth Reflection Tomography, Local Angle Domain Imaging, Specular and Diffraction Imaging

Summary

Sub-coal imaging is one of major exploration objectives in Lakwa-Sonari field. Apart from coal, Sonari field has a high velocity zone above coal that causes structural distortion of sub-coal sequences. High impedance contrast of Barail coal causes a low illumination of underneath source rock and Lower Barail Sands (LBS). So, successful sub-coal imaging demands a reliable estimation of interval velocity model from poorly illuminated reflection signal and a migration algorithm to reduce coal generated wavefield distortion. In this work formation dependent constraint dix inversion and full azimuth reflection tomography is used for initial modelling and refinement of depth interval velocity. The final velocity model has coal imprints and clearly brought out high velocity zone above coal in Sonari field. Multi-dimensional local angle domain wavefiled decomposition, specular and diffraction imaging is then carried out for migrated wavefield separation. Specular stack shows enhance reflection continuity of sub-coal sequences and diffraction stack delineates sub-surface discontinuities. Final image has improved continuity of sub-coal source rock Kopili, Lower Barail Sands (LBS) and Basement. Sub-coal structural changes in Sonari is also clearly addressed and verified with well data.

Introduction

Reservoir characterization below coal is one of the major hydrocarbon exploration challenges. Coal layer has high impedance contrast that causes low energy penetrations. Also coal causes waveform distortion and frequency attenuation that made it difficult to image underneath structures. So, success of sub-coal imaging requires a geologically viable depth-interval velocity and a good migration algorithm that can place reflection energy at a correct vertical and lateral position. More over to image sub-coal sequences reflection energy enhancement in migrated scattered wavefield is required.

The area under study, Lakwa-Sonari field, falls in UAN, Assam & Assam-Arakan Basin, a Tertiary onland basin in the north-eastern part of India and the data used in the study is a 3D onland data of area 400 Sq Km with a bin size of 25x25m. The area is both structurally and stratigraphically complex due to presence of Barail coal, complex fault networks and proximity to thrusts. In Lakwa below Barail Coal Shale (BCS), Kopili acts as a main source rock and the Lower Barail Sands (LBS) are potential hydrocarbon reserves. Apart from the LBS sands, Sonari field has a high velocity anomaly above coal that causes structural distortion from Tipam sand to basement. So, enhancing reflector continuity and imaging of pre-barail sequences are very significant to map lateral extents of hydrocarbon entrapments in Lakwa. In Sonari imaging objective is to build a geologically correct velocity model that is able to address the structural distortion caused by velocity anomaly and the imaging of sedimentary deposition below coal. Moreover, the coal layer acts as a rapid internal scatterer that generate reflection as well as diffraction. In conventional processing/imaging algorithm this diffraction energy is normally suppressed due to applied summation and averaging processes but its separation from total scattered wavefield will delineate subsurface discontinuity. Constrained dix inversion (Koren, 2006) and full azimuth grid based tomography are used to build depth-interval velocity model. Local Angle Domain (LAD) directivity driven specular and diffraction imaging [Koren & Ravve, 2011] are performed for structural continuity enhancement in specular image and to delineate small-scale structural discontinuities in diffraction image.

Geology of the Study Area

Assam & Assam Arakan Basin is a typical poly- history basin having more than one phase of tectonics and sedimentation. It is bounded by the Eastern Himalayan fold belt in the North, the Mishmi hills in the North East and the Patkai – Arakan fold belt in the East. The Northward movement of the Indian plate towards the Eurasian and Burmese plates essentially influences the evolution of the basin.

Sub-Coal Imaging of Lakwa-Sonari Field, A&AA Basin, Using Local Angle Domain Wavefield Decomposition

The oldest fault trend in the area is NE-SW, transected by the younger E-W to NW-SE trend creating a number of fault blocks. Upper Assam North (UAN) is separated from Dhansiri Valley by the major E-W trending Jorhat wrench fault.

The hydrocarbon plays, which have been established in UAN Block so far, are Tipams, Barails, Kopili, Tura, Sylhet and Girujans. In Lakwa area, Tipam and Barails are the most prolific producers and have reached a matured stage of exploration. Barails have alteration of coal and sand. The coal thickness varies from 400m to 800m in Lakwa-Sonari area. Sub-coal Lower Barail Sands (LBS) are also potential hydrocarbon reservoir and many wells show hydrocarbon indications. The current exploration objective in this area is to characterize hydrocarbon reserves in sub-coal LBS sands and Tura, which requires a better imaging of sub-coal sequences for strati-structural interpretation.

- Surface recorded wavefield is then decomposed in insitu full azimuth local angle (LAD) domain. Slant stacking in shot-receiver Fresnel zone [Koren & Ravve, Part-I, 2011] is utilized to increase signal-to-noise ratio of sub-coal sequences. Slant stacking also dampen out non-coherent reflections like short periods multiples or reverberations.
- Directivity driven specular and diffraction imaging is performed on 3D LAD directional angle/azimuth gather. The specular and diffraction imaging separate out reflection and diffraction energy from total migrated scattered wavefield [Koren & Ravve, Part-II, 2011]. Hence an enhancement in continuity of the seismic reflection in specular image and clear delineation of stratigraphic discontinuities in diffraction image.

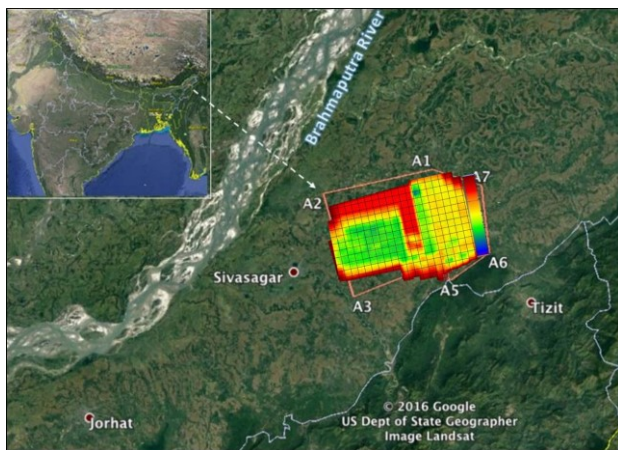


Figure.1: Location map of study area

Methodology

Sub-coal imaging requires a reliable estimation of depth-interval velocity and a migration algorithm that is able to handle complexities arising due to presence of coal, like ray bending and amplitude preservation. These velocity and migration algorithm will then place surface recorded energy at an accurate vertical and lateral subsurface position. Figure.2 describe detailed steps for velocity modelling and depth imaging workflow. Below are the key processes of this work:

- Building a depth-interval (V_{int}) velocity that is consistent with underneath geological structure. For that initial depth interval velocity estimation is performed using constrained dix inversion and depth interval velocity refinement is performed through full azimuth reflection grid tomography.

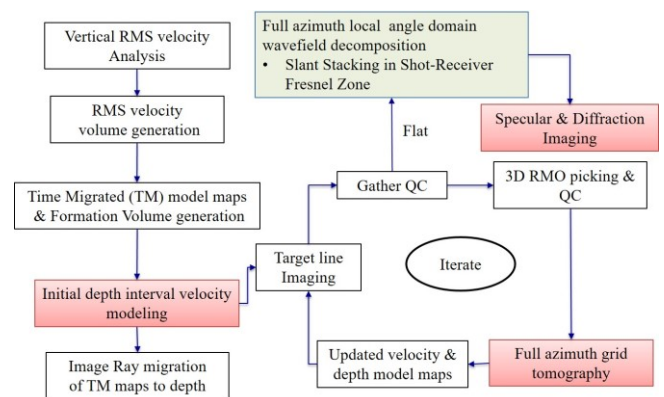


Figure.2: Interval velocity modelling and depth-imaging workflow

Depth Interval velocity modelling

Estimation of geologically correct depth-interval velocity above and below coal needs a reliable starting model. For that vertical semblance based RMS velocity analysis is performed. Time migrated horizons of prime geological interest are used to generate a formation volume. Formation volume represents a layer cake model of subsurface structures. Initial depth interval velocity modelling is then performed using constrained dix inversion. Constrained dix inversion (CVI) imposes geological boundary conditions in inverting rms velocity to interval velocity. CVI takes gradually compacted sedimentary basin model with initial exponential, asymptotically bounded interval velocity trend [Koren, 2006]. During inversion a “Cost Function” is calculated and minimized, it includes three components: RMS velocity misfit (Data misfit), velocity-trend-model misfit and the antioscillatory damping energy.

Sub-Coal Imaging of Lakwa-Sonari Field, A&AA Basin, Using Local Angle Domain Wavefield Decomposition

The first term assign confidence on picked RMS and the last two terms improve robustness and stability of inversion. Optimizing the weightage of these three terms is always a tradeoff between accuracy and stability. Here RMS velocity analysis is performed vertically, so structural consistency will not be present. The formation volume is used to preserve that structural consistency. Also low signal-to-noise (S/N) ratio below coal gives less confidence in RMS picking that demands more weightage on the last two terms to stabilize the inversion process. Based on RMS picking confidence, formation dependent weight is assigned for cost function calculation. For formations above coal more weightage is given on RMS velocity misfit that gives good estimation of interval velocity and for formations below coal more weightage is given on trend and damping to get a stable interval velocity. This formation based weight assignments preserves lateral consistency, does not alter the confidence of picked V_{RMS} and gives a stable initial depth interval-velocity model with structural imprints.

Depth-interval velocity refinement is then performed using four iteration of the full azimuth grid based tomography at an update cell of 400mx400mx250m (XYZ). Residual moveouts (RMOs) are auto picked in 3D LAD reflection angle-azimuth gathers in a dense manner. RMO auto picking seed points are decided by dip-azimuth-continuity volume (DAC), additionally depth model maps are also given to ensure RMO picking (figure.3) at the position of geologically important horizons.

Tomographic principle is applied to convert depth errors of migrated common image gathers (CIGs) to travel time error along ray pairs. Travel time change along the rays are then related to perturbation in slowness and layer depth [Kosloff, 1996].

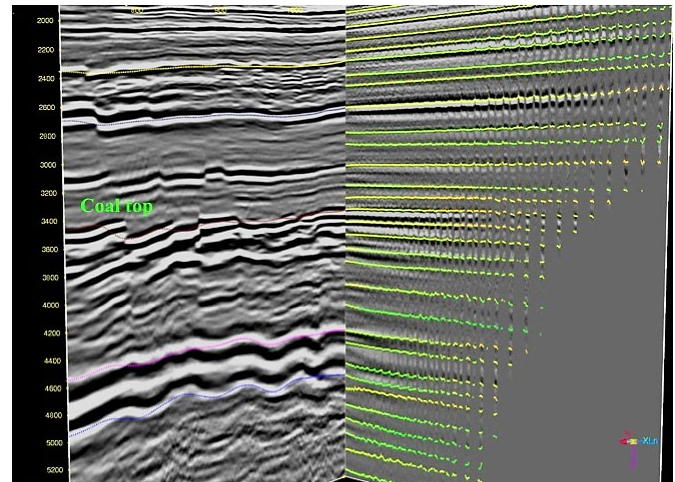


Figure.3: Autopicked residual moveouts (RMOs) at a cdp location

So an unique assignment of depth error to reflection path (ray pair) is necessary for reliable sub-coal velocity estimation, but multi pathing or multi arrivals phenomena is the main problem in transforming depth RMOs into travel time delay along ray pair. This non-uniqueness problem is resolved in LAD domain. 3D LAD reflection angle-azimuth CIGs contains information from wide angle and azimuth and uniquely mapped multi arrivals at separate opening angle and opening azimuth [Koren, 2014]. So, the travel time error calculated from depth RMOs (figure.3) of LAD CIGs are uniquely associated to subsurface reflection path. This unique assignment ensures the convergence of tomographic solution and leads to a geologically close velocity for sub-coal sequences.

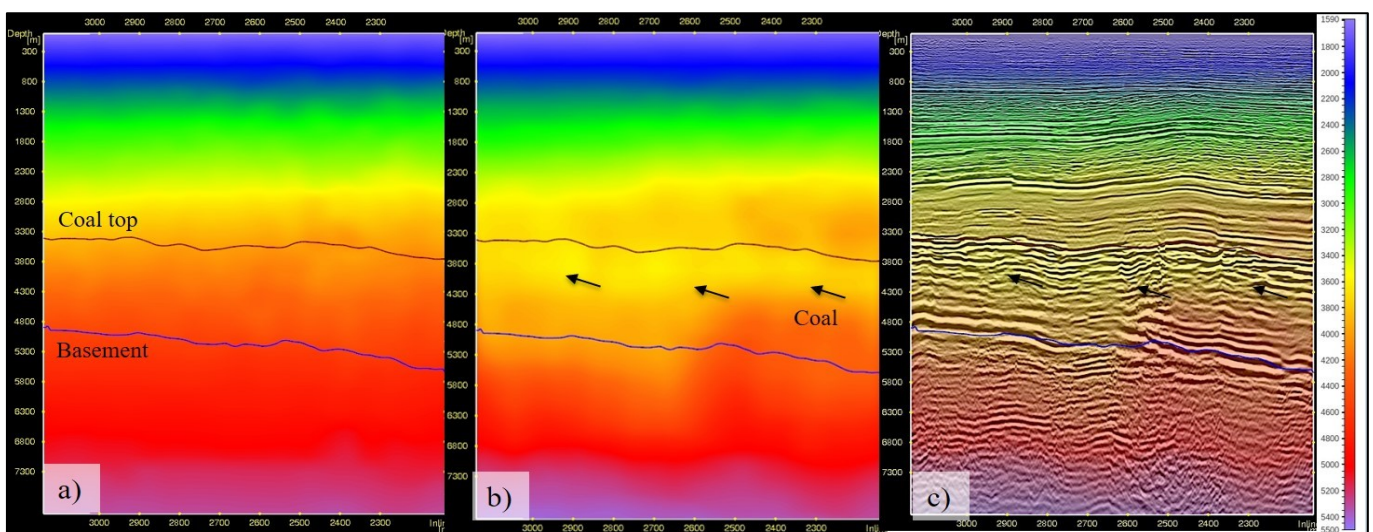


Figure.4 a) Initial Interval velocity b) Final interval Velocity and c) Final Interval velocity on stack

Sub-Coal Imaging of Lakwa-Sonari Field, A&AA Basin, Using Local Angle Domain Wavefield Decomposition

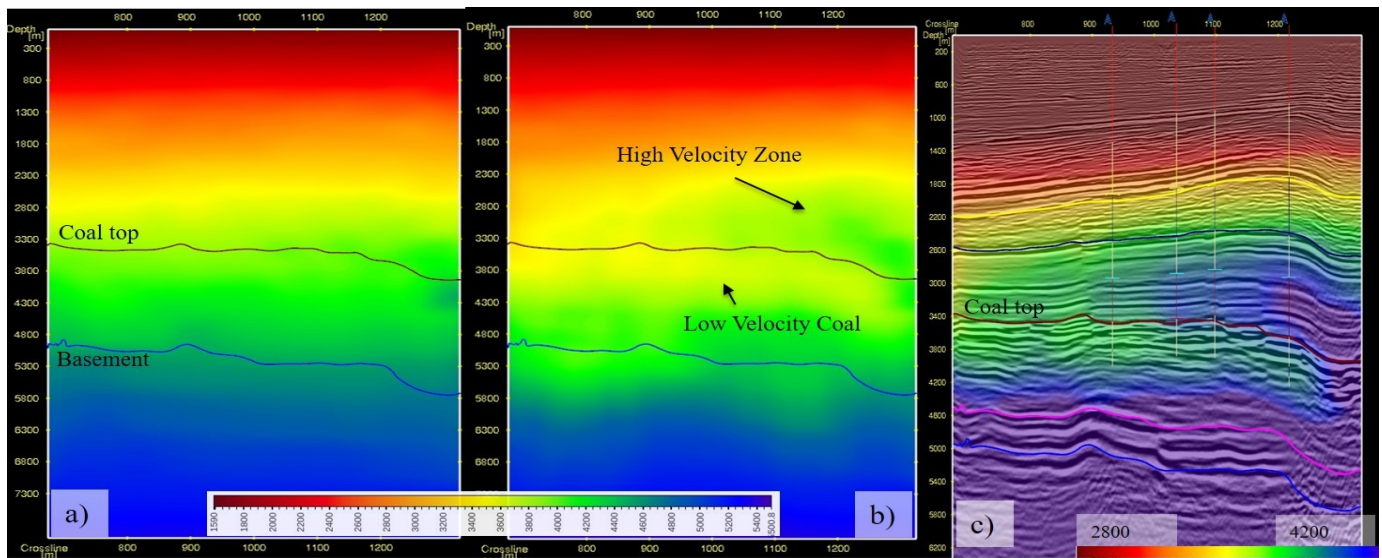


Figure.5 Inline passing through Lakwa Sonari field a) Initial interval velocity b) Final interval velocity and c) Interval velocity on stack with well markers.

Setting up of tomographic matrix is also a very fast prestack migration. Tomographic matrix relating depth RMOs to travel time error is built and solved in isotropic mode. Successive tomography iterations are then performed that compensate the RMOs, flatten the gathers, updates interval velocity and give updated depth model maps. Figure.4 shows initial and final interval velocity model at Lakwa. The final model has velocity lowering in the coal region and it is consistent with coal layers (figure.4c).

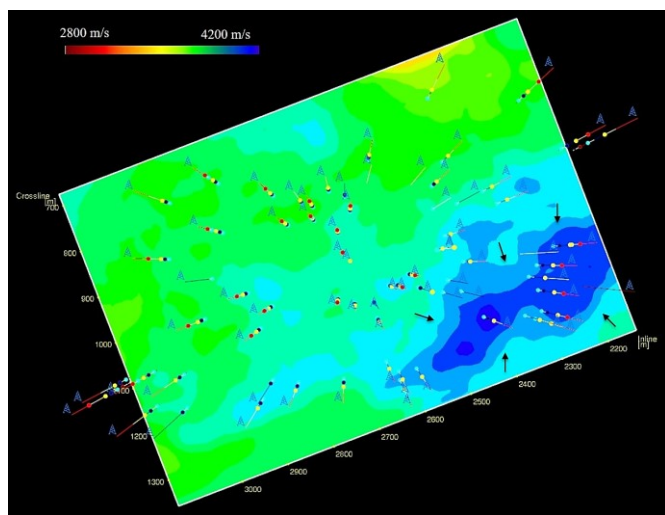


Figure.6 Lateral extent of high velocity zone at Sonari, Depth Slice: 3150m

Figure.5 is a line passing through Lakwa-Sonari field, the high velocity zone above coal is brought out very clearly by full azimuth tomography. In figure.5c the velocity scale is squeezed to highlight the high velocity zone and figure.6c gives its lateral extent at depth of 3150m. Clastic sediments are there and the strata above coal is folded. So high compaction may be a possible reason for this high velocity. Consistency of depth structure is also verified by Lakwa-Sonari (left to right) well markers (figure.5c). Resolving this velocity anomaly is necessary to image sub-coal structure in Sonari. Final updated V_{int} is structurally consistent and gives flat reflection angle-azimuth gather at image location.

Wavefield Decomposition and Imaging

Full azimuth local angle domain imaging (Koren & Ravve et al 2011) decomposes surface recorded wavefield in 3D reflection angle-azimuth gather and in 3D directional angle-azimuth gather. LAD imaging has the ability to decompose migrated wavefield in reflections and diffractions directly at the image location. It preserves true reflections amplitude and takes care for multi arrivals. Moreover LAD imaging utilizes slant stacking in shot-receiver Fresnel zone. Here one way diffracted rays are traced from subsurface image point to surface shot-receiver location. The Fresnel zone associated to the rays are calculated up to the recording surface. Shot-receiver data within the Fresnel zone are then slant stacked and migrated to image location. This slant stacking increase the signal-to-noise ratio, dampen out non-coherent energy like multiples and reverberations hence an improvement in sub-coal signal.

Sub-Coal Imaging of Lakwa-Sonari Field, A&AA Basin, Using Local Angle Domain Wavefield Decomposition

3D directional angle-azimuth gather represents migrated scattered energy distribution with respect to subsurface dip and dip-azimuth. The direction reflecting maximum energy at a particular image point is known as 'specular direction', geologically it is the true bed dip, and remaining scattered energy at that image point is known as 'non-specular energy'. Non-specular energy mostly include point diffractor and corner waves. Based on the specular direction reflection energy is separated and stacked that gives specular image hence an enhancement in the continuity of reflection events. Remaining scattered energy, mostly dominated by diffraction from structural discontinuities, on stacking gives diffraction image. Due to the absence of non-specular energy in specular stack, it enhances sub-coal structure whereas diffraction stack delineates small-scale subsurface discontinuities and their lateral extent. Specular stack of figure.7 shows enhanced continuity of sub-coal sequences as compared to earlier vintage process data.

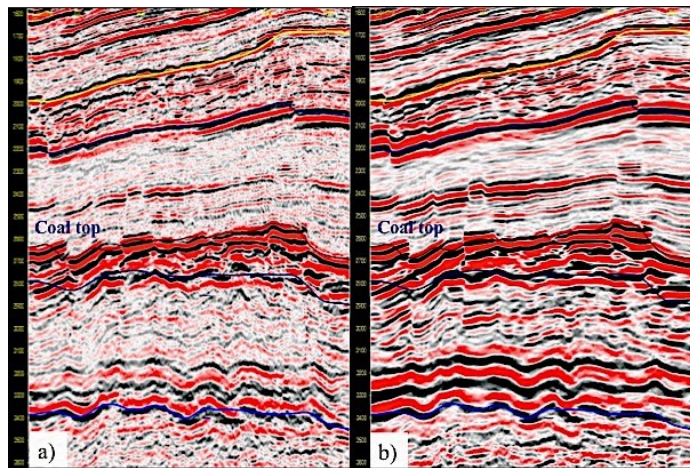


Figure.7 Representative inline a) vintage PSTM data vs b) recent specular stack scaled back to time.

Apart from the LBS sands, imaging of Tura, Sylhet and basement are also improved (figure.8). Extension of faults in sub-coal region is also very clear. Diffraction stack delineates lateral extent of faults in the sub-coal region (figure.9) and lateral consistency is check with specular stack.

In Sonari high velocity zone above coal causes structural change from depth to Time. Structural dips of Barail coal and sub-coal sequences in times migrated (figure10b) section is opposite of actual depth (figure.11b) structure. Depth structure from Tipam to Barail coal are verified with the well marker as shown in figure.5c. Continuity of sub-coal sequences are also improved as compared to vintage PSTM.

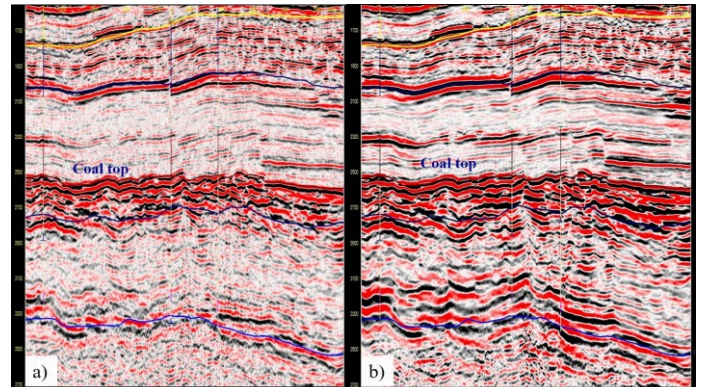


Figure.8 Representative xline a) vintage PSTM data vs b) recent specular stack scaled back to time

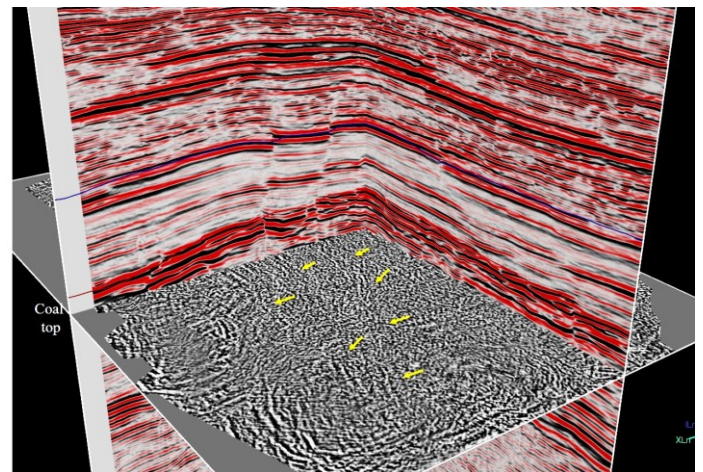


Figure.9 Sub-coal faults networks in diffraction slice and specular stack in section

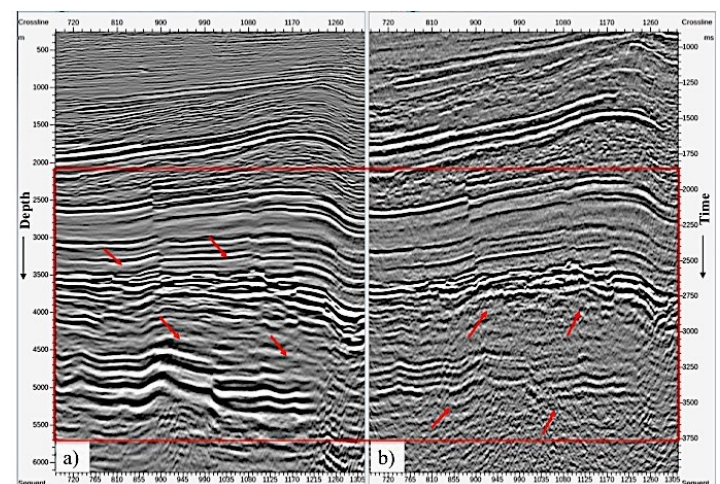


Figure.10 Structural change due to high velocity zone above coal in (left) depth migrated section and (right) time migrated section.



Sub-Coal Imaging of Lakwa-Sonari Field, A&AA Basin, Using Local Angle Domain Wavefield Decomposition

Conclusion

Formation dependent constraint Dix inversion gives a structure consistent starting depth interval velocity model. Grid based full azimuth tomography is able to bring the coal imprints in depth-interval velocity model and also brought out high velocity anomalous zone above coal layer in Sonari field. This velocity anomaly explains coal and below coal structural change in the time and depth. Utilization of slant stacking in shot-receiver fresnel zone helps in improving sub-coal signal to noise ratio. Specular stack enhances structural continuity of sub-coal LBS sequences and Kopili source rock. High resolution diffraction stack separate out non specular energy and delineates major faults. Significant improvement over vintage processed data are seen in terms of sub-coal continuity enhancement and discontinuity delineation. Faithful mapping of continuous reflection events and delineation of large and small scale discontinuities below Barail coal will help in localizing hydrocarbon entrapments and reserve estimation for further exploration in this area.

References

- Dan Kosloff et al., 1996, Velocity and interface depth determination by tomography of depth migrated gathers; *GEOPHYSICS*, VOL. 61, NO.5 (September-October, 1996); P. 1511-1523.
- Zvi Koren and Igor Ravve, 2006, Constrained Dix inversion; *GEOPHYSICS*, VOL. 71, NO.6 (November-December, 2006); P.R113-R130.
- Zvi Koren and Igor Ravve, 2011, Full-azimuth subsurface angle domain wavefield decomposition and imaging Part-I: Directional and reflection image gathers; *GEOPHYSICS*, VOL. 76, NO.1 (January-February, 2011); P.S1-S13.
- Igor Ravve and Zvi Koren, 2011, Full-azimuth subsurface angle domain wavefield decomposition and imaging: Part 2 — Local angle domain; *GEOPHYSICS*, VOL. 76, NO.2 (March-April, 2011); P.S51-S64.
- Zvi Koren, 2014, Local Angle Domain (LAD) Common Image Gathers (CIG) for Reflection Tomography and AVA (Z) in Complex Geological Areas; EAGE/SPE Workshop on Subsalt Imaging, Advance Processing Session, February, 2014.

Acknowledgements

The authors are thankful to Director (Exploration), Oil and Natural Gas Corporation Limited for providing the opportunity to carry out this project. The team is also thankful to HOI-GEOPIC and Head Processing Division, GEOPIC for their valuable suggestions and for providing resources to carry out this work. The authors would like to thank ONGC for giving permission to publish the work.

Views expressed in this paper are those of the authors only and does not refer to any views of ONGC.