



Improved seismic imaging in Gandhar Area through Full-Azimuth depth migration in the Local Angle Domain

Mithai Lal*, Rajesh Madan,
Oil & Natural Gas Corporation Limited, Vadodara

Email: lal_mithai@ongc.co.in

Keywords: Earth Study 360, Full-Azimuth Angle-Domain, Specular and Diffraction Imaging

Abstract

The Earth Study 360 (ES-360) Imager a new subsurface angle-domain seismic imaging system for generating and extracting high-resolution information about subsurface angle-dependent reflectivity. The system enables geophysicists to use all recorded seismic data in a continuous fashion directly in the subsurface local angle domain (LAD), resulting full-azimuth, common-image angle gathers namely: directional and reflection gathers. The complete set of information from both types of angle gathers leads to accurate high-resolution, reliable velocity model determination and reservoir characterization. The directional angle decomposition enables the implementation of specular and diffraction imaging in real 3D isotropic/anisotropic geological models, leading to simultaneous emphasis on continuous structural surfaces and discontinuous objects such as faults and small-scale fractures. Structural attributes at each subsurface point, e.g., dip, azimuth and continuity, can be derived directly from the directional angle gathers. The reflection-angle gathers display reflectivity as a function of the opening angle and opening azimuth. The reflection-angle gathers are used for automatic picking of full-azimuth angle-domain residual moveouts (RMO) which, together with the derived background orientations of the subsurface reflection horizons, provide a complete set of input data to isotropic/anisotropic tomography. The full-azimuth, angle-dependent amplitude variations are used for reliable and accurate amplitude versus angle and azimuth (AVAZ) analysis and reservoir characterization. This paper discusses the application of a new seismic data imaging method *full-azimuth angle domain depth imaging*, which is particularly useful when working with rich-azimuth seismic data. This innovative technology was applied to improve the accuracy and resolution of the available seismic images.

Introduction

Conventional seismic depth imaging tools, such as ray-based or beam-based Kirchhoff migrations, applied to narrow azimuth seismic data, normally generate multi-azimuth offset-domain common image gathers (CIGs). These are further used for anisotropic velocity model determination and for the characterization of reservoir properties, such as

fracture networks. In these types of migrations, the input data is first binned into specific surface offset/azimuth geometrical groups, such as offset vector tiles (OVT), azimuthal sectors or planner spirals, depending on the acquisition pattern. Each set of binned data is then independently migrated, with the final CIGs being simply a collection of individual images. However, in many cases, particularly when studying hydrocarbon reservoirs below complex geological areas and along steep inclined layers, the offset/azimuth CIGs do not provide the required information (in terms of accuracy and resolution, for example) to achieve the above mentioned goals. Unlike subsurface imaged events along the angle domain CIGs, which indicate 'true' local reflectivities, the reflection image events along the offset domain CIGs can be only considered a rough approximation of the 'true' reflectivities. Obviously, the accuracy and reliability of the offset domain CIGs are strongly compromised when imaging below complex geological areas with complex wave phenomena. One of the main drawbacks of offset domain imaging, especially in complex geological areas, is its inability to deal with the actual multi-pathing waves which are naturally handled within angle domain imaging. Moreover, the surface azimuths of the offset domain CIGs represent the directions between sources and receivers along the acquisition surface, which can be considerably different from the actual in-situ azimuth along the inclined reflectors.

In this work we use an alternative imaging technique, the Earth Study 360 Imager (Koren and Ravve, 2011), which provides much richer information on the subsurface image points compared to any other available seismic imaging/migration system. In this imaging system, the surface recorded seismic data are simultaneously mapped (downward propagated using an advanced ray-based solution) to the subsurface and binned into high-resolution, multi-dimensional tables at each subsurface grid point. Each bin is characterized by the spatial location coordinates of a given subsurface image point and by a given central ray pair (incident/scattered slowness vectors), arriving to the image point from a given source and scattered up to a given receiver, forming a local four-dimensional angle system, referred to as the local angle domain (LAD). Two of the four LAD angles indicate the apparent directivity (dip and azimuth) of the given ray pair,

while the other two indicate the opening angle and azimuth between the ray pair. The imaged amplitudes of the directivity components within the LAD (directional) gathers provide the ability to decompose the imaged data into specular (most energetic) components (associated with the specular direction/s) and non-specular (different types of diffraction) components. Specular energy is mainly used to enhance subsurface image/structural continuity, while non-specular (diffraction) components are used to enhance discontinuous objects, such as small faults, edges and tips, and even small fracture networks. The imaged amplitudes of the reflectivity components (specular energy) within the LAD gathers (full-azimuth reflection angle gathers), provide rich information about the in-situ full-azimuth angle domain residual moveouts (translated to traveltimes errors along the central ray pairs) to be used for updating/refining the background depth velocity model (e.g., anisotropic tomography). Once the velocity model is updated and the seismic events along the image gathers are relatively flat (from all azimuths and angles), the amplitude preserved image events along the full-azimuth reflection gathers are used for azimuthally varying amplitude analysis vs. angles (AVAZ) and amplitude inversion to obtain impedances and rock properties.

The previous seismic prospect in this area was based on conventional seismic imaging technology mainly obtained by iterative procedures using offset-domain pre-stack time and depth Kirchhoff migrations (PSTM and PSDM). The acquisition details of Gandhar area i.e. acquisition parameters, azimuth and offset distribution are shown in Figure 1. In order to improve the accuracy and resolution of the available seismic images, a new seismic imaging technology was selected: Earth Study 360. Using this technology, we were able to better predict structural-tectonic inhomogeneities in the target geological environment, including fracture detection and characterization.

Methodology:

The proposed method follows the concept of imaging and analysis in the local angle domain (LAD) in isotropy/anisotropy subsurface models. Imaging systems involve the interaction of two wavefields at the image points: incident and scattered (reflected/diffracted). Each wavefield can be decomposed into local plane waves (or rays), indicating the direction of propagation. The direction of the incident and scattered rays can be described conventionally by their respective polar angles. Each polar angle includes two components-dip and azimuth.

The imaging stage involves combining a huge number of ray pairs representing the incident and scattered rays. Each ray pair maps the seismic data recorded on the acquisition surface into the 4D LAD space.

The ability to decompose the specular and diffraction energy from the total scattered field obtained within the full-azimuth directional angle gathers is the core component of our proposed imaging system. It is based on estimating a directivity-dependent specularly attribute which measures the energy within calculated local Fresnel zones along the 3D directional gather. The directivity-dependent Fresnel zones are estimated using precomputed diffraction ray attributes, such as travel times, surface locations and slowness vectors. In practice, a specularly directional gather is computed for the corresponding seismic directional gather that also allows the extraction of structural subsurface attributes (e.g., dip, azimuth, and specularly/continuity) of the local reflecting/diffracting surfaces. The energy (or specularly measurement) computed along the directional angle gather values also is used as a weighted stack operator. Two types of images are constructed: specular weighted stacks for emphasizing subsurface structure continuity, and diffraction weighted stacks, which emphasize discontinuities of small-scale objects such as faults, channels and fracture systems. Note that full-azimuth directional angle decomposition does not necessarily require a wide-azimuth acquisition geometry system; rather, a large migration aperture is needed to allow information from all directions. Moreover, in many cases it is sufficient to use small offsets to create directional angle gathers.

Once background directivity is derived, full-azimuth reflection angle gathers are created by integrating all the dip/azimuth angles around that direction. Note that if the certainty about the background directivity is high (measured by the specularly criteria), only a small dip-angle range around the background direction (estimated from the angle-dependent Fresnel zone) is required to capture the specular energy. The specularly criterion is a measure of the energy concentration along the directional angle gathers. The seismic data reflected/ diffracted from the image points are decomposed/binning into common opening (reflection/diffraction) angles and opening azimuth angles. The full-azimuth reflection-angle gathers are used to extract residual moveouts (RMO), which measure the accuracy of the background velocity model used. The full-azimuth RMO, together with the directivity information, comprises the required set of input data for velocity model determination via tomographic solutions. In addition, the true amplitude,

full-azimuth, reflection-angle gathers serve as optimal data for amplitude analysis (AVAZ), and for the extraction of high-resolution elastic properties. For these kinematic and dynamic types of analysis, long offsets and rich azimuths are particularly effective.

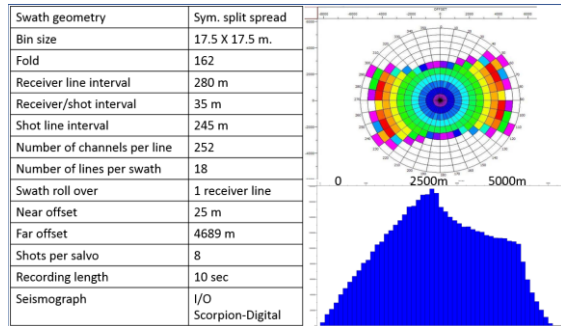


Figure 1: Show the Acquisition parameters, Azimuth and Offset distribution of the Area.

The full-azimuth angle-domain decomposition stage involves forming a combination of ray pairs indicating incident and reflected/diffracted rays. Each ray pair maps a specific seismic data event, recorded on the acquisition surface, into a 4D local angle-domain space in the subsurface—dip and azimuth of the ray pair normal, opening angle and opening azimuth (Dr Zvi Koren -Figure 2).

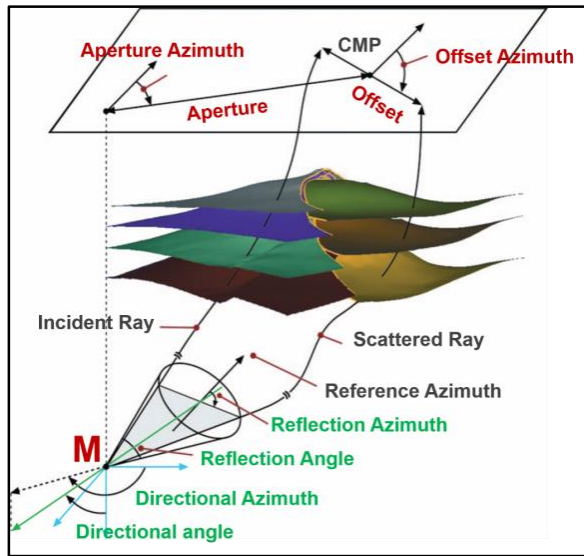


Figure 2: Subsurface-to-surface and surface-to-subsurface ray based mapping. Each ray pair maps a specific seismic data event recorded on the acquisition surface, into a 4D local angle-domain space in the subsurface - dip and azimuth of the ray pair normal, opening angle and opening azimuth.

Results:

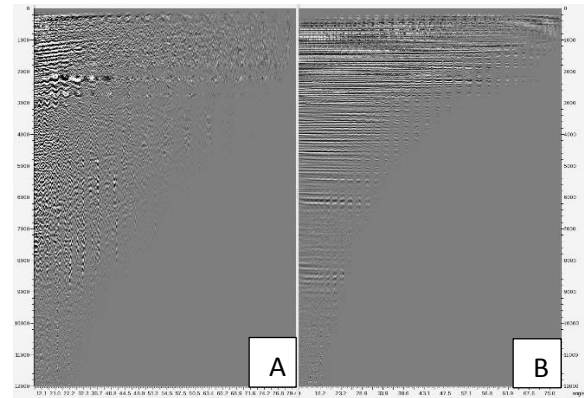


Figure 3: Show a Directional gather (A) and Reflection gather (B).

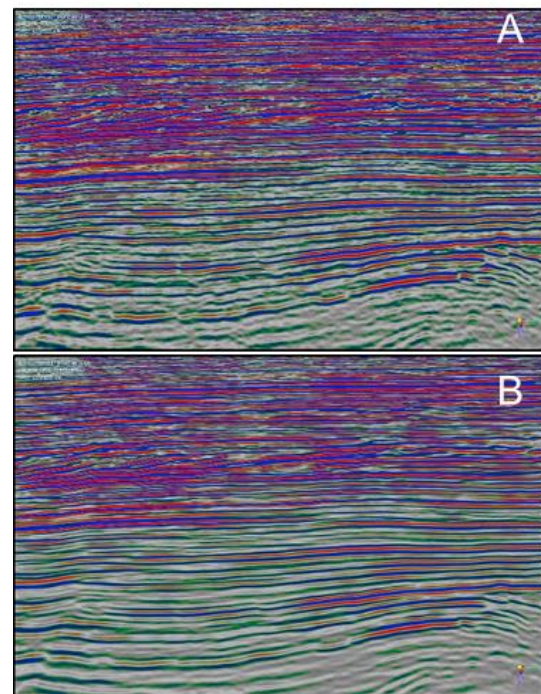


Figure 4: Comparison of Regular Stack (A) and Specular Enhanced Stack (B). Specular section (B) depicts better continuity and amplitude standout after elimination of random noise.

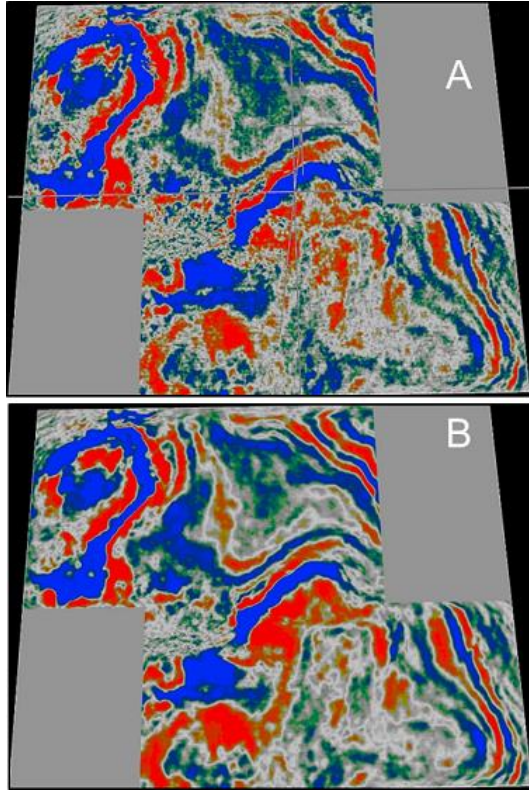


Figure 5: Shows comparison of depth slices of Regular stack Image (A) and Specular enhanced image (B). Specularity section (B) depicts improved resolution and continuity.

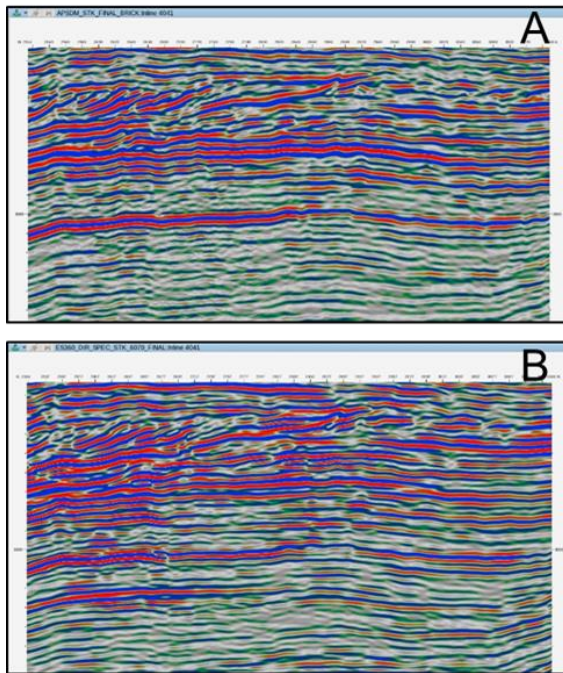


Figure 6: Shows comparison of inline section of APSDM (A) and ES360 image (B). ES360 image depicts improvement at shallow and deeper levels.

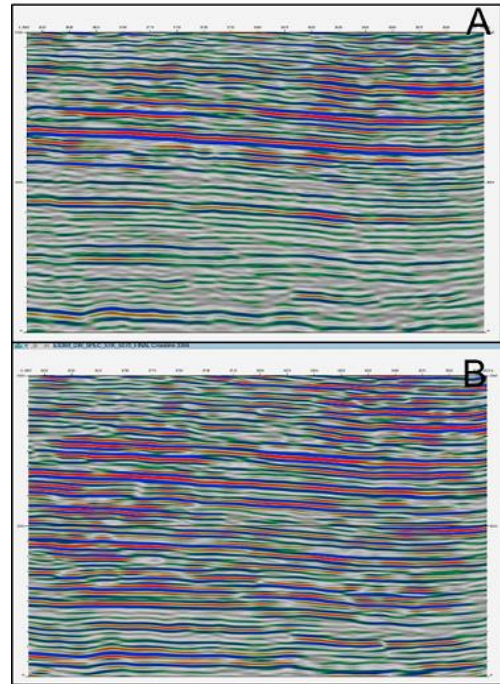


Figure 7: Shows comparison of Crossline section of APSDM (A) and ES360 image (B). ES360 image depicts improvement at shallow and deeper levels.

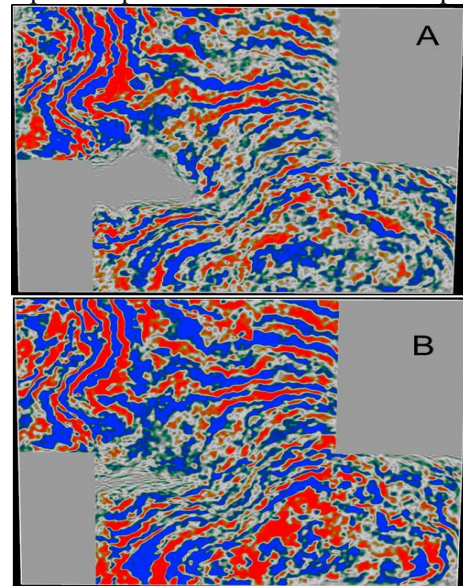


Figure 8: Shows comparison of inline depth slice of APSDM (A) and ES360 image (B). ES360 image depicts improvement.

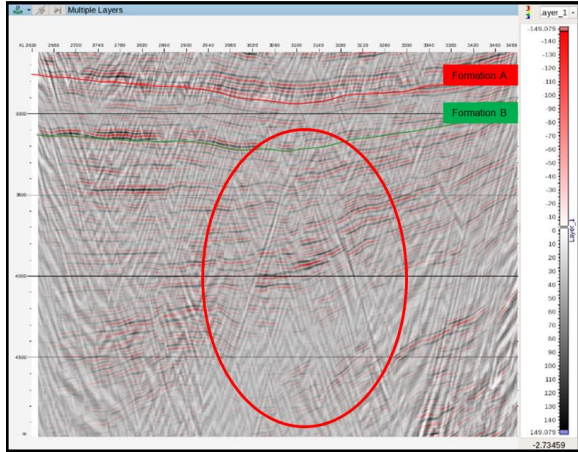


Figure 9: shows Diffraction stack overlain specular stack.

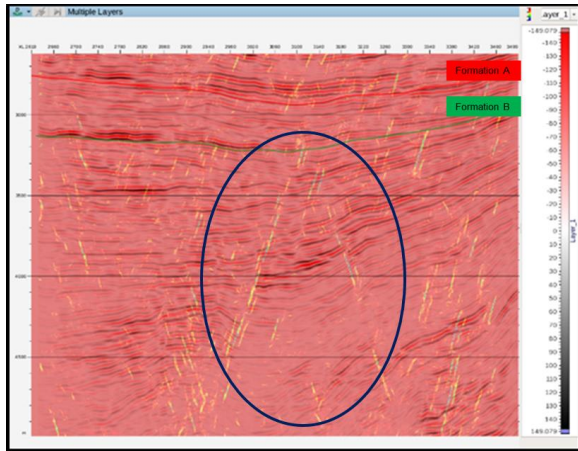


Figure 10: shows AFE from diffraction stack overlain specular stack.

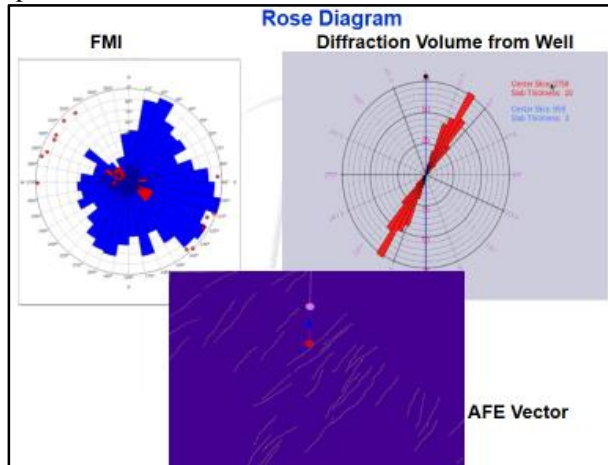


Figure 11: Shows Rose diagram from FMI log, diffraction volume and AFE vector. Fracture direction is matches with Rose diagram of FMI log and diffraction volume. Vector maps that regionally indicate the local orientation and intensity magnitudes of the fracture networks.

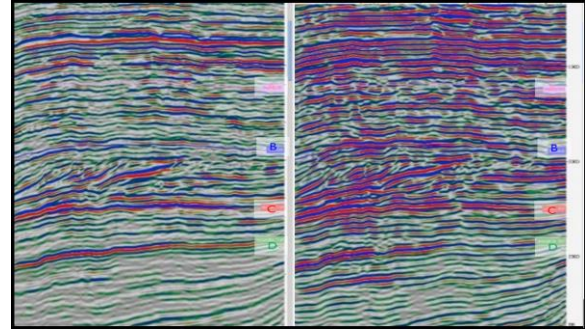


Figure 12: Shows comparison of inline section of Earlier PSTM (A) and ES360 images scale back to time (B). ES360 image depicts improvement at shallow and deeper levels.

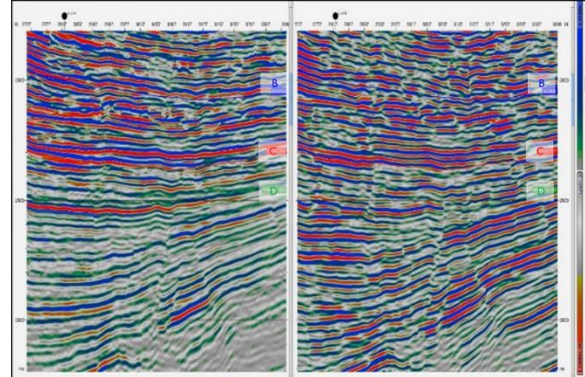


Figure 13: Shows comparison of inline section of Earlier PSTM (A) and ES360 images scale back to time (B). ES360 image depicts improved seismic imaging.

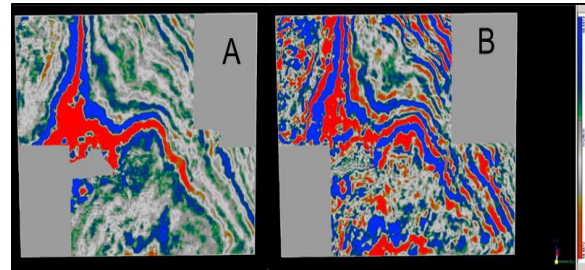


Figure 14: Shows comparison of Time slice of Earlier PSTM (A) and ES360 images scale back to time (B). ES360 image depicts marked improvement.

Conclusion

This paper presents a new imaging technique (ES-360) for generating continuous, full-azimuth, angle-domain image gathers (Directional and Reflection gather), deliver high-resolution information about the subsurface model. The full azimuth imaging data had a higher resolution and greater detail than those produced using the Kirchhoff migration. Using directional image gathers, we were able to clearly decompose the full image data into specular energy, which enhances the structural continuity, as well as



diffraction energy, for enhancing small and discontinuous subsurface objects, in particular fault, channels and fracture networks. The specular weighted full-azimuth opening (reflection) angle gathers were optimally used for highly accurate, high-resolution VVAZ and AVAZ analysis, mainly to further characterize the azimuthally anisotropic effects associated with the target fracture networks.

Acknowledgements:

Authors are thankful to Shri R.K. Srivastava ,Director (Exploration) and Shri H. Madhavan, GGM , Basin Manager, WON, ONGC for providing the opportunity to work on this data. Thanks are also due to Shri K.V. Krishnan, ED-CGS and Shri Matibar Singh, GGM (GP)-HGS for his valuable suggestions. Authors express their gratefulness to all the colleagues at RCC, ONGC for their involvement in study to make the project a success.

Views expressed in this paper are that of the author(s) only and may not necessarily be of ONGC.

References:

Koren Z. and Rave I. [2011]. Full azimuth subsurface angle domain wavefield decomposition and imaging Part 1 and 2. *Geophysics*, 76 (part 1 and 2).

Kowalski, H., Godlewski, P., Kobusinski, W., Makarewicz, J., Podolak, M., Nowicka, A. and Koren, Z. [2014]. Imaging and characterization of a shale reservoir onshore Poland, using full-azimuth seismic depth imaging. *First Break*, 32, 101-109.

Inozemtsev, A., Koren, Z. and Galkin, A. [2015]. Noise suppression and multiple attenuation using full-azimuth angle domain imaging: case studies. *First Break*, 33, 81-86.

Kowalski, H. [2014] Full-azimuth migration. Innovative tool of seismic prospection. *3rd Technology Workshop GT-PGNIg*, Torun.

David Chase, Yuval Serfaty, Igor Belfer and Zvi Koren [2015] Approach Enhance Seismic Imaging , The American oil & gas reporter

Inozemtsev, A., Koren, Z. and Galkin, A. [2017]. Applying full-azimuth depth imaging in the local angle domain to delineate hard to recover hydrocarbon reserves. *First Break*, 35.

Koren, Z. and Ravve, I. [2011]. Full-azimuth Subsurface Angle Domain Wavefield Decomposition and Imaging. *Geophysics*, 76(1), S1-S13.

Kozlov, E.A., Koren, Z., Tverdohlebov, D.N. and Badeikin, A.N. [2009]. Corner reflectors a new concept of imaging vertical boundaries. 71ST EAGE Conference and Exhibition, Extended Abstracts Z039.

Olneva, T. , Semin, D., Inozemtsev, A. , Bogatyrev, I., Ezhov, K., Kharyba, E. and Koren, Z. [2019]. Improved seismic images through full-azimuth depth migration: updating the seismic geological model of an oil field in the pre-neogene base of the Pannonian Basin. *First Break* 37.