Attenuation of surface related multiple and Local Angle Domain imaging for enhanced subsurface delineation of Nagayalanka area, KG Basin, India

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Keywords
Surface Related Multiple Attenuation, Data Regularization, Full Angle Azimuth Reflection Grid Tomography, LAD imaging.

Summary
The study area, Nagayalanka, KG Basin is geologically complex and the earlier processed outputs were not able to fulfil the interpreter’s needs in terms of reflector continuity and structural interpretation. The imaging objective is to map stratigraphic features from Raghavapuram to Basement formations where alteration of thin shale and sandstone is observed. Some portion of the study area resides in the backwater zone of Bay of Bengal where the coupling of geophones is poor that in turn reflected in the seismic data. Very strong multiple reflections from shallow limestone layer are present. In this work apart from standard processing workflow, surface related multiple attenuation is performed to attenuate multiples, 4D data regularization is carried out to get uniform offset distribution and pre-stack depth imaging is done for structural imaging. Local angle domain depth imaging is utilized for structural continuity enhancement. Newly processed data shows enhanced frequency and improved continuity of the deeper reflector with better fault delineation. Sequences from Raghavapuram to Basement are imaged very clearly as compared to vintage data.

Introduction
Nagayalanka is located on the edge of the Indian peninsula, in the central part of the eastern coast of Andhra Pradesh state of India (Figure 1). This area is located mostly in backwater zone and comprising of 255 Sq. Km area. Slanted geometry is used for acquisition with receiver interval 30m, shot interval 60m, bearing of shot line with receiver line is 38.17 degree and a nominal fold of 30. Due to presence of backwater zone, coupling of geophone was an issue and this indeed reflects in the shot gathers. Shallow limestone layer present here acts as a strong multiple generating surface. Different mode of multiple reflections are seen and sometimes they are even stronger than primary reflections that can mislead in structural interpretation. Now the data is processed in orthogonal geometry with the inline direction parallel to the receiver line and a bin size of 15m X 15m as per interpretation requirement. Signal processing were done as per standard operating procedures to increase signal to noise ratio. Surface related multiple attenuation is performed for multiple removal. Since the processing geometry is different than the acquisition geometry, 4D offset regularization is performed. It shows improvement in shallower reflection and also reduces acquisition footprints. RMS velocity analysis is carried out follower by initial depth interval velocity volume generation. This depth interval velocity model is then updated using full angle azimuth grid tomography and Local angle domain (LAD) imaging is then performed. In this imaging, the migrated energy is decomposed in reflection and diffraction energy there by generation of specular stack and diffraction stack respectively. Specular stack shows enhanced subsurface reflector continuity from Raghavapuram formation to Basement with improved fault position. Suppression of multiples and improvement of continuity is seen in latest outputs.

Figure 1. Location Map of the study area
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Geology of the study area

The study area is located in a south-west graben of the West Godavari sub basin of Krishna-Godavari (KG) basin and is characterized by the presence of a prospective late syn-rift Cretaceous sequence that formed in response to rifting of India from Antarctica during the breakup of Gondwana. The dominant tectonic grain across the area is approximately NE-SW. In the Cretaceous, the basin became a peri-cratonic rift in which thick deposits of marine to fluvial sediments accumulated within the graben areas associated with basement block faulting due to the reactivation of NE-SW trending Precambrian faults. The Gollapalli Formation comprises a series of stacked micaceous and gritty sandstones containing abundant plant fossils that date it as Neocomian, interpreted to represent fluvial deposits draining into marine embayment defined by the graben and horst structures. The overlying Raghavapuram Shale represents the first significant marine transgression and contains a rich fauna of ammonites, brachiopods and foraminifera that indicate a Barremian to early Aptian age. This shale thins westwards and onto the structural highs in the basin, where significant sandstones, including the Raghavapuram Sandstone and Tirupati Sandstone, that are derived from the west and northwest, and area considered as Upper Cretaceous in age.

Methodology

Seismic land data contains different types of coherent and non-coherent noises and the initial step in processing is to identify and remove it. Apart from geometry merging, noise removal and static application, multiple attenuation is also a major step for this data. Processing workflow is shown in Figure 2. This paper mainly describes the key processes on: Multiple attenuation, Data regularization, Depth interval velocity modelling and LAD imaging.

Multiple attenuation:
Multiple reflections and reverberations are mainly attenuated using techniques based on their periodicity or differences in moveout velocity between multiples and primaries. Parabolic radon-demultiple is tried but the results are not satisfactory in this data. So 2D surface related multiple attenuation (SRMA) is performed and it gives satisfactory result. SRMA is a model based multiple attenuation technique that attenuate the multiples in a two-step fashion. During the first step, surface-related multiples are predicted kinematically. The predicted multiples have about the same traveltimes as the multiples recorded in seismic data but different amplitudes and wavelet shapes. In the second step, the surface-related multiples present in the seismic data are attenuated using these predicted multiples by adoptive subtraction.
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In Figure 3 very strong multiple reflection (shown with red color arrows) from shallow limestone layer is noticeably observed which has to be removed or attenuated else that can mislead in structural interpretation. 2D SRMA technique applied to the data resulted in attenuation of the multiples and reverberations is shown in Figure 4.

Data regularization:
Many seismic processing techniques require regular spatial distribution of traces. As a consequence, datasets that do not fulfil this requirement will suffer from poor processing results. So 4D data regularization is carried out. The reconstruction process of 4D data regularization aims at filling gaps in acquisition geometry, regularizing data to bin centre on a regular grid and improving offset distribution. De-aliased Fourier reconstruction algorithm is used for data regularization. It takes the irregular input data in f-Kx-Ky domain at small spatio-temporal blocks. The data in f-Kx-Ky domain is then brought back in t-X-Y domain at a periodic offset interval.

The data gaps at shallow level due to the non-availability of near offset in data acquisition are taken care by 4D data regularization which is shown in Figure 5. Also the acquisition footprints are greatly minimized even at deeper level with this technique. In Figure 6 the time slice at 2815 ms shows the slanted geometry acquisition foot prints which is minimized after regularization (Figure 7). Hence application of 4D data regularization to this data enhances the data quality by removal of acquisition foot prints and improved offset distribution.
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Depth Interval velocity modeling & LAD Imaging:
Initial depth interval velocity volume is generated by CVI (Constrained Velocity Inversion) (Koren and Ravve, 2006) technique. Unlike Dix inversion technique, CVI is constraint Dix inversion technique and the crucial parameters like data, trend and damper gives more confidence in the velocity. This velocity is further refined by full angle-azimuth grid tomography that utilizes 3D LAD angle-azimuth gathers.

Local Angle Domain (LAD) imaging provides rich information on the subsurface image points and handles multi arrivals. The surface recorded seismic data are downward propagated using an advanced ray based solution to the subsurface and binned into high resolution, multi-dimensional tables at each sub surface grid point. Each bin is characterized by the spatial location coordinates of a given subsurface image point and by a given central ray pair, arriving to the image point from a given source and scattered up to a given receiver forming local four- dimensional angle system, referred to as LAD. Two of four LAD angles indicate the apparent directivity (dip and azimuth) of the given ray pair, while the other two indicate opening angle and azimuth between the ray pair. Hence the output consists of 5D LAD image gathers. (Alexander Inozemtsev, Zvi koren and Alexander Galkin). The vertical axis of these image gathers indicates the fine grid depth locations, and the other four axes indicates directivity (directional dip & azimuth) and reflectivity (opening angle and azimuth) LAD angles. The outputs of LAD imaging are Reflection angle azimuth gathers. Specular energy is mainly used to enhance subsurface image structure continuity while non-specular (diffraction) components are used to enhance discontinuous objects such as faults, edges and fine fracture systems.

Target line LAD imaging is performed with the initial interval velocity volume and the resulted angle azimuth reflection grid tomography is run on the data at the cell dimensions of 400m x 400m x 300m.

Figure 9 shows the initial interval velocity in cross view with the three major horizons. Figure 10 shows the final interval velocity in cross view. Figure 11 shows the final interval velocity blended with specular stack (Depth) in the cross view. Structural consistency of geological sequences with final interval velocity is seen.
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Figure 10. Final Interval velocity volume (cross view)

Figure 11. Final Interval velocity volume blend with specular stack (cross view)

Figure 12 & Figure 14 shows comparison of vintage data (PSTM stack) to the LAD imaging specular stack scaled back to time in Inline and Xline direction respectively. Figure 15 shows comparison of vintage data (Anisotropic PSDM stack) with LAD imaging (Isotropic) specular stack (Depth). The outputs of the recent study shows enhanced frequency content and reflection continuity thereby brought major marine transgression sequences within Raghavapuram formation to Basement as compared to vintage data (zone of interest is shown in red box). Auto-correlation is computed for both vintage data and recent study in a window shown in blue box in Figure 12 to confirm the absence of multiples. The auto-correlation spectrum (Figure 13) in vintage data (PSTM stack) shows periodicity (shown with red colour arrows) whereas specular stack scaled back to time shows absence of multiples. So the specular stack scaled back to time is free from multiple and will give more confidence in structural interpretation.

Figure 12. Vintage PSTM stack (Left) vs Recent study LAD imaging specular stack scaled back to time (Right) along Inline

Figure 13. Vintage data (Left) vs recent study (Right) auto-correlation spectrum
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Figure 14. Vintage PSTM stack (Left) vs Recent study LAD imaging specular stack scaled back to time (Right) along Xline

Figure 15. Vintage Anisotropic PSDM stack (Depth) (Left) vs Recent study Isotropic LAD imaging specular stack (Depth) (Right) along Inline

Conclusions

Remnant multiples and acquisition footprints are greatly minimised by the application of 2D SRMA and 4D data regularization respectively. Full angle azimuth reflection grid tomography is used for depth interval velocity modeling which resulted in geologically consistent interval velocity. LAD imaging is performed with the signal conditioned gathers and interval velocity, resulted in the improved subsurface imaging. The imaging brought out by this work in general has shown enhanced frequency, better reflection continuity and subtle stratigraphic features. Sequences from Raghavapuram formation to Basement are clearly imaged. The processed outputs can help in formulating the exploration strategies and identifying hydrocarbon prospect in the study area.

References


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