Maximize the value of vintage 3D seismic data through accurate velocity model building and state of art data conditioning and imaging tools- Case studies from Cauvery On-land and KG Offshore Basins

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Abstract

Seismic images provide Geo-scientists a method of mapping the subsurface structure formations and rock properties. High quality subsurface images are critical in petroleum exploration to uncover geological and geophysical aspects of subsurface. The lack of success may have been from the poor imaging quality which led to inaccurate analysis and interpretation. There has been a proliferation of seismic solutions in acquisition and processing techniques to improve the imaging resolution and this coupled with an exponential growth in compute power has led to a major change in the quality of seismic imaging recently. It is important to note that a lot of vintage data were acquired in areas where no recent surveys are available due to exploration restrictions or due to increased logistics, environmental and/or socio-political constraints. Therefore reprocessing of existing data may be the only option in such areas. Leading edge imaging solutions offer new insights to help in exploration and field development by reducing the risks and uncertainty associated with legacy imaging. The data rejuvenation project could benefit from new wells information which would be used for well guided velocity model building and depth calibration. The reprocessing results discussed in this paper has tremendously improved the image quality and increased the confidence of the interpreter by resolving depth issues, fault positioning and reservoir connectivity.

Introduction

The paper presents two case studies of full azimuth angle domain depth imaging, one from Cauvery On-land and the other from KG Offshore Basin.

22 seismic vintages acquired between 1989 to 2013 were used in the land case study, whereas the offshore data was acquired in 2006-07. State of art land time pre-processing such as Surface Wave Attenuation by Modelling and Inversion (SWAMI) applied to generate the input data to depth imaging workflow.

In this work, re-processing of the existing seismic datasets carried with an emphasis on three objectives. First, remove the noises by modeling and adaptive subtraction thus preserving the signal part in the preprocessing stage. Secondly, to derive structural consistent interval velocity unfolding velocity variations that matches with well data. Third objective was to facilitate further prospect delineation through enhanced data resolution, events continuity and fault definitions through diffraction imaging.

Results show a significant improvement in data quality, particularly in the deeper section facilitating the interpreter to generate more accurate geological models. In the onland case, imaging of synrift sequences and Basement improved significantly, especially the deeply situated prospective sediments and steeply dipping Basement flanks. Remarkable improvement in the imaging of faults and continuity of events overall and especially below mass transport complex (MTC) is observed in offshore case. Reliable interval velocity model has been obtained starting from Geologically constrained velocity model incorporating well data and updation using two tomographic approaches: grid tomography and layer-based tomography; both requiring several iterations of the refinement loop, consisting of migration, ray tomography, residual velocity analysis, velocity model update. The updated velocity has accurately captured the velocity inversion below MTC, which in-turn will help while planning for development drilling. Azimuth preserved angle domain depth imaging added further information (e.g., reliable interval velocity model, real geometry and thickness of the main geological units and diffraction image for fault and fracture systems). Applying the up-to-date processing and imaging techniques to vintage data help to enhance their geophysical and geological value.

Case study-I: Cauvery On-land

Geologic background

Full Azimuth Depth imaging of Periyakudi-Vanjiyur area of Cauvery basin is analyzed in this case study. The basin evolved as a result of rift – drift phenomenon giving rise to a series of NE-SW trending horst-graben morphology during late Jurassic to early Cretaceous (Rangaraju et al, 1993). These gave rise to highs and lows in the basin represented by the ridges and depressions. The Andimadam Formation ranging in age from Late Jurassic to Albian, dominantly arenaceous at the top and consists of sand shale alternations in the lower sections, represents the Syrift sediments. The basin witnessed first marine transgression during Late Albian to Cenomanian times resulting in deposition of Sattapadi Shale. The overlying sedimentary unit (early post-rift) is the Bhuvanagiri Formation and is generally characterized by parallel reflections as alternating sand and shale beds affected by prominent unconformity as Late Turonian surface. The basin then witnessed regular cycles of transgressive/ regressive phases from Late Cretaceous to Mio-Plocene. The study area covers Tranquebar and Nagapattinam Sub-Basins separated by Karaikal High (Figure 1).

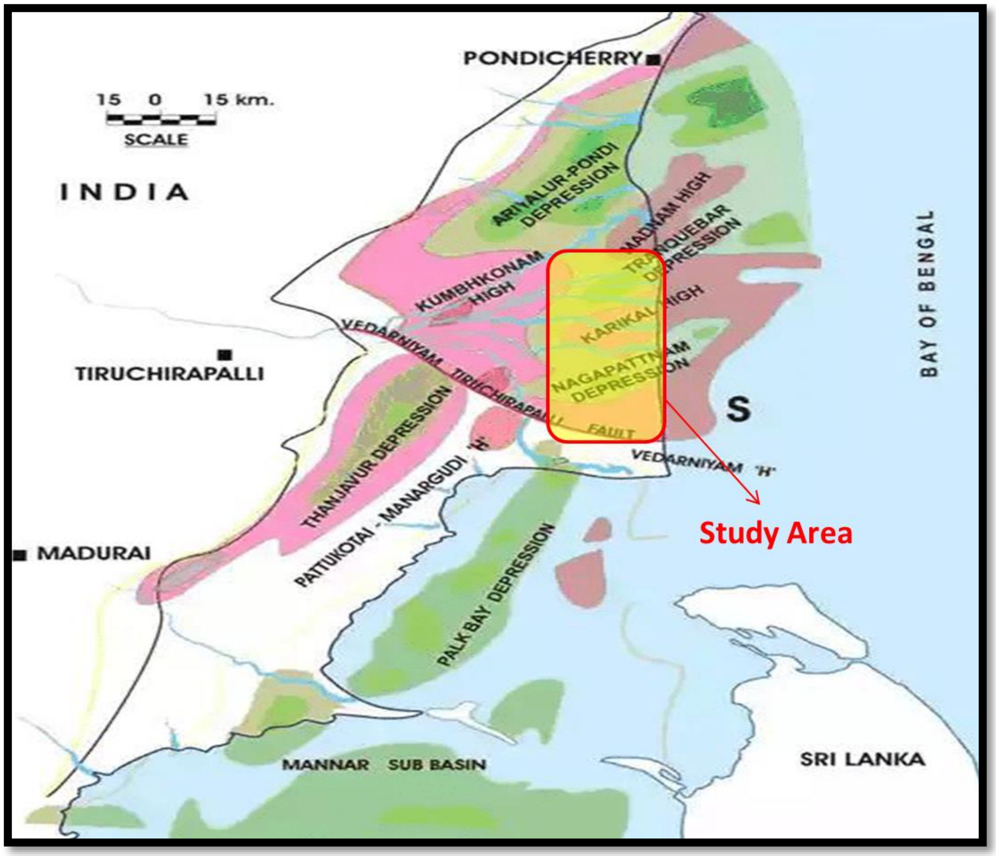

Figure 1: Location map of Case study-I

Reprocessing Approach

Conditioning of Input data: Input data for this study are from 22 vintage seismic investigations acquired through 1991-2013. Utmost care was taken in conditioning the data to obtain the best input for depth imaging workflow. Shot gathers of individual investigations separately underwent several noise attenuation steps to eliminate spikes, ground roll, guided waves, scattered and random noises. State of the art model-based approach referred to as Surface Wave Analysis, Modelling and Inversion (SWAMI) was applied in removing ground roll which adaptively remove ground roll without harming primary energy. This has preserved the low frequency primary reflections and thus helped in better imaging of synrift and Basement (Figure 2). After de-noise, surface consistent deconvolution and amplitude balancing was carried out on shot gathers.. A double iteration of velocity picking and residual statics were computed and applied on CMP gathers which further improved S/N ratio.

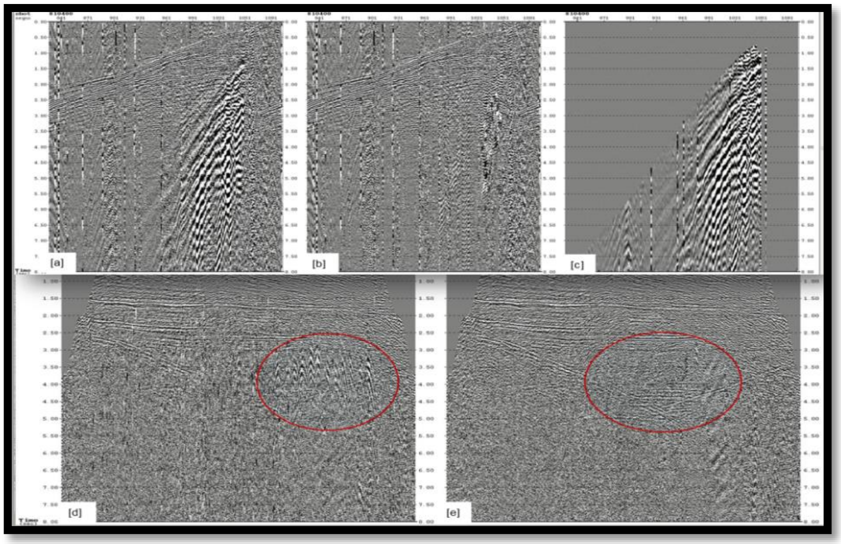

Figure 2: a) Input Gather, b) output after ground roll removal, c) Difference, d) Input stack, e) stack after ground roll removal

Velocity model building: Precise interval velocity model incorporating anisotropy is pre-requisite for accurate imaging and true positioning of seismic events. To estimate the geologically realistic velocity field, an initial model was prepared by combining all the geophysical and geological data available. An abundance of auxiliary information such as well data facilitated to build an initial velocity profile with a high level of geologic consistency. Geo-statistical approach was used in conjunction with data from 51 wells and horizon interpretations to create the starting model for each geologic unit to produce a geologically conformable model. This in turn produced a stable well tie and a robust basis for the computation of initial anisotropy parameters. Iterative processes were adopted for the velocity depth refinement through Model and Grid based tomographies. The final interval velocity derived shows good match with sonic log (Figure 3) which helped in improving the image quality.

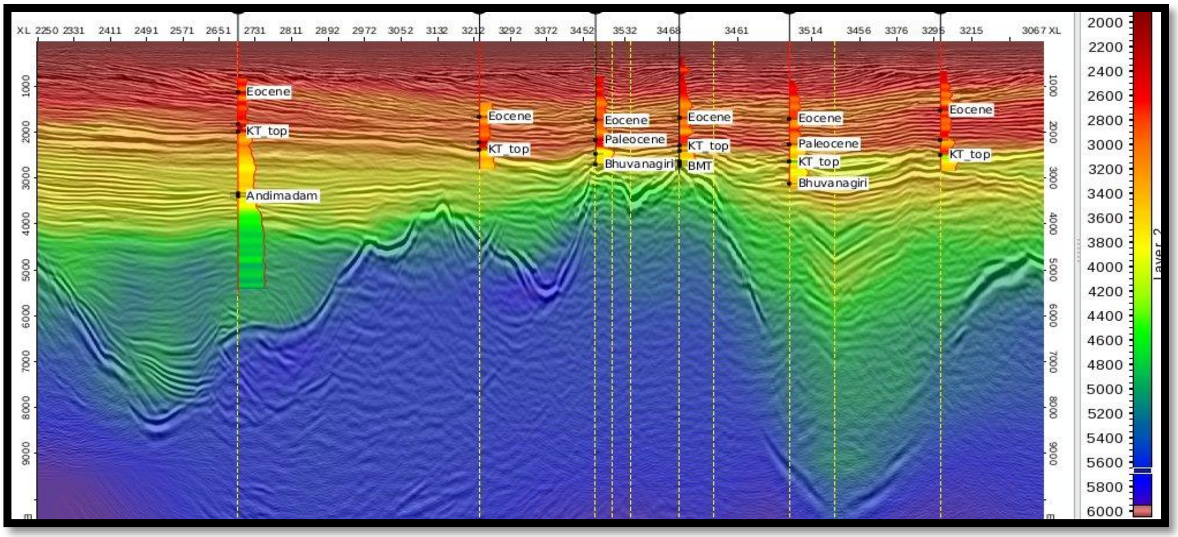

Figure 3: Interval Velocity overlaid by stack

Depth imaging: Conventional Kirchhoff migrations generate surface offset-azimuth/offset domain common image gathers (CIG). In case of complex subsurface, the correlation between the surface offset-azimuths and the actual, in situ, azimuth of the incidence/reflected ray pairs at the image points is relatively poor. Additionally, Kirchhoff migrations do not account for multi-pathing. In order to obtain more reliable information about the subsurface and to estimate fracture distribution at different depth levels, full-azimuth seismic imaging solution was applied. In this method, the input seismic data are first mapped into a full-dimensional decomposition for each imaging point, in four components of the local angle domain (LAD) (Koren & Rave, 2011). A point diffractor ray tracing operator has been designed that shoots rays from the imaging point equally in all directions, and stores the required ray properties for all the rays that succeed in reaching the surface. The permutations of the individual diffracted rays form a system of reflection ray pairs (incident and scattered) that enable the decomposition (binning) of the migrated seismic events into the in situ 4D LAD table at each subsurface point. The in situ 4D LAD table comprises two polar angles representing the directivity of the ray pairs and two additional angles representing the opening angle and opening azimuth between the two slowness vectors at the image points. The imaging system outputs two complementary full-azimuth angle gathers(Reflection and Directional). Reflection gathers are used for reliable velocity analysis and amplitude inversions. Full-azimuth directional angle gathers are organized into dip/azimuth angle bins at the subsurface and can be used to generate specularity enhanced volume to get reflection stack. The specular stack derived from directional angle gathers shows significant improvement in the imaging and increased the degree of traceability of layers including Basement in comparison to Kirchhoff PSTM stack (Figure 4 & 5). Additionally, directional angle gathers are used to generate diffraction enhanced volume, which will help in generating finer seismic attributes. Diffraction depth slice shows a significant additional amount of high-resolution details (Figure 6).

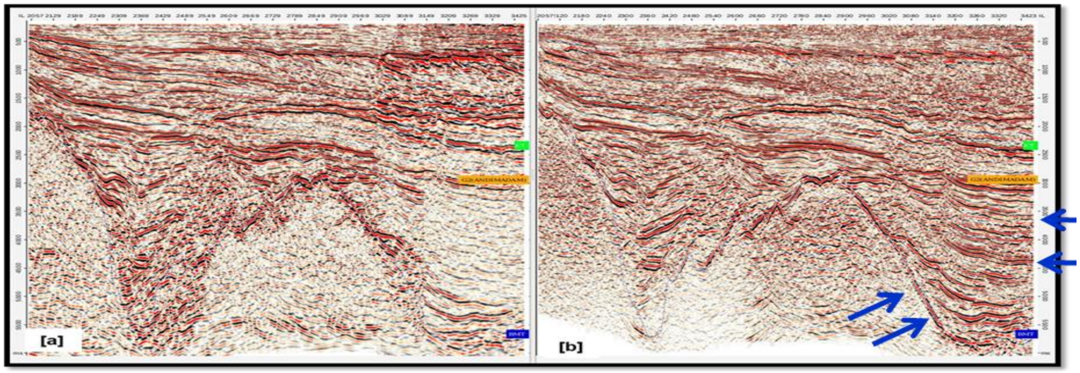

Figure 4: a) PSTM stack, b) specular enhanced stack scaled to time

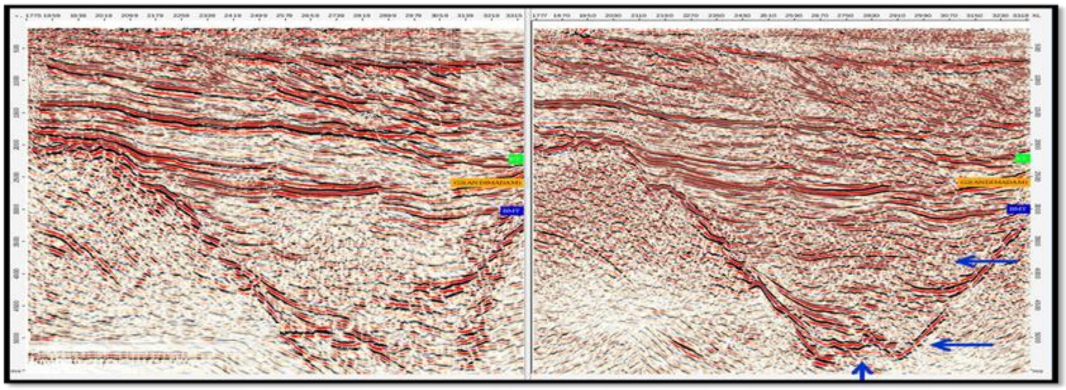

Figure 5: a) PSTM stack, b) specular enhanced stack scaled to time

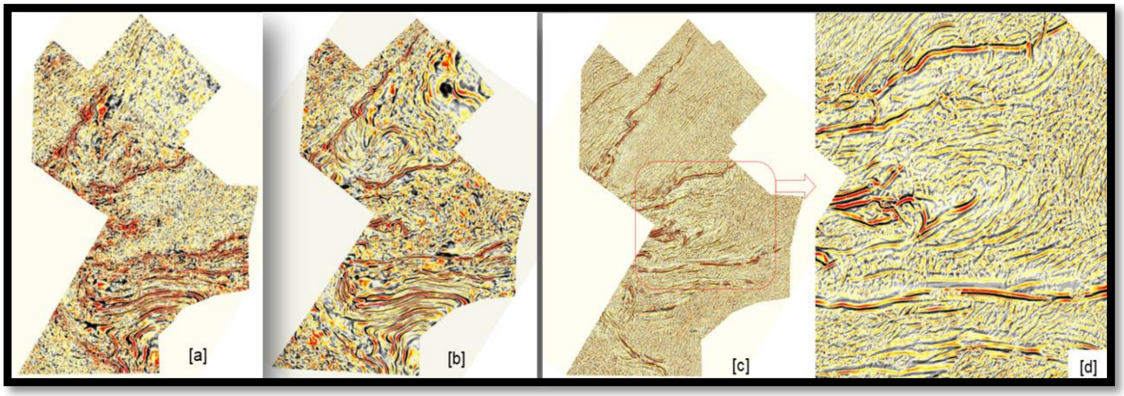

Figure 6: Time Slice at 3500 ms (a) PSTM, b) specular enhanced stack scaled to time, c) Diffraction enhanced stack scaled to time d) Diffraction enhanced stack (zoomed)

Case study-II: KG Offshore

Geologic background

Full azimuth Depth imaging of area from KG Offshore (Figure 7) is analyzed in this case study. Krishna-Godavari Basin is a major intra-cratonic basin (Rao, G. N., 2001) within the greater Gondwanaland land mass during late Carboniferous, Permian and Triassic. Late Jurassic – Early Cretaceous saw development of syn-rift basin. Since Late Cretaceous, the basin became a passive margin basin. In Paleogene, proximal areas of the basin received maximum sands. From Mid-Oligocene onwards, increase in sedimentation rates resulted in sediments piling, which further resulted in growth faults and toe thrusting. Enhancement of these growth faults and toe thrusts was a key objective of this project. Most of the hydrocarbon discoveries in the area are within Early Pliocene to Early Pleistocene zone.

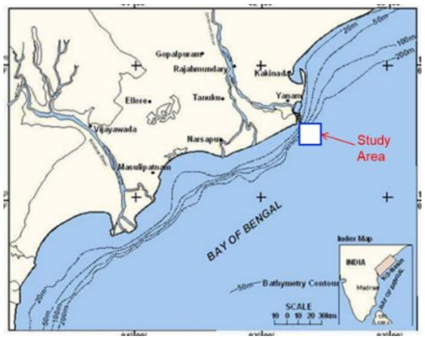

Figure 7: Location map of Case study-II

Reprocessing Approach

Conditioning of Input data: Input data for this study is acquired in the year 2006–07. Conditioned gather from previous reprocessing was taken as input for depth migration. *Velocity model building and depth imaging:* Same approach as discussed in Case study-I was adopted for velocity field estimation and depth imaging here also. The final updated interval velocity showed good correlation with well log and has clearly captured the inversion below MTC (Figure 8).

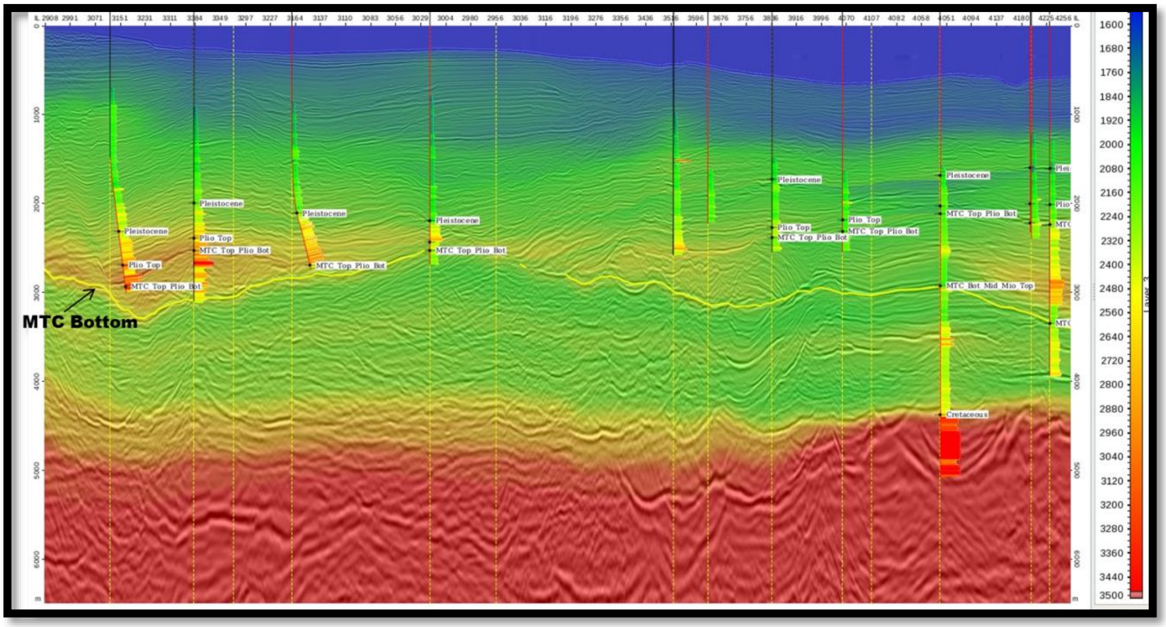

Figure 8: Interval Velocity model overlaid by stack

The visual comparison (Figure 9 & 10) revealed a higher quality of image and detailed reflections from the target and deeper horizons. Imaging of Plio – Pleistocene sequences and growth faults improved significantly. There was also less migration noise and a more accurate focus, helping to resolve a complex zone below MTC. The high resolution diffraction stack (Figure 11) generated from directional gathers enable interpreter in identifying faults and fracture system.

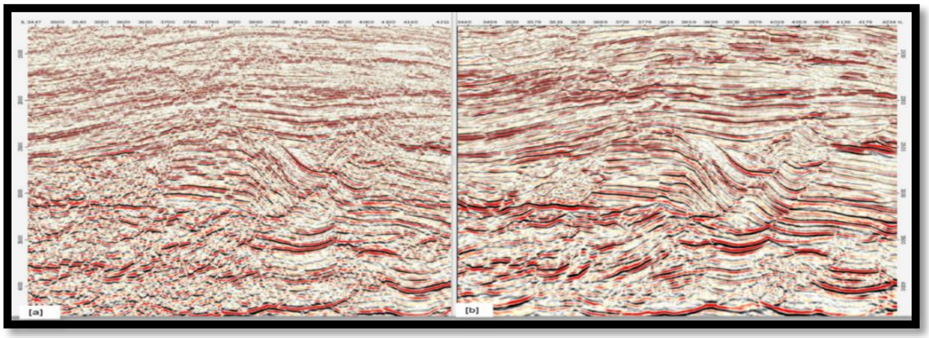

Figure 9: a) PSTM stack, b) specular enhanced stack scaled to time

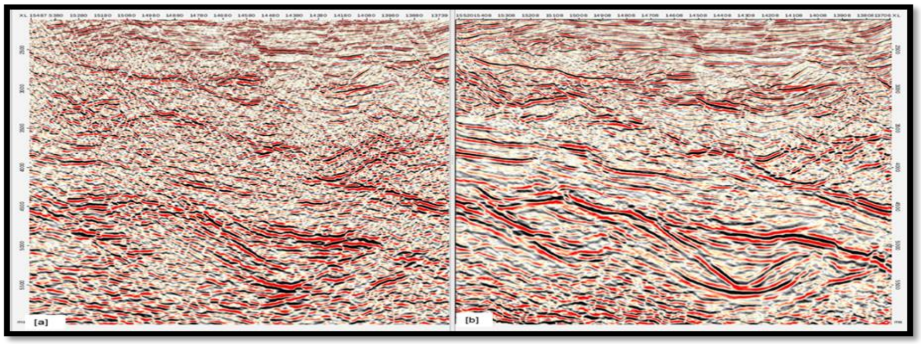

Figure 10: a) PSTM stack, b) specular enhanced stack scaled to time

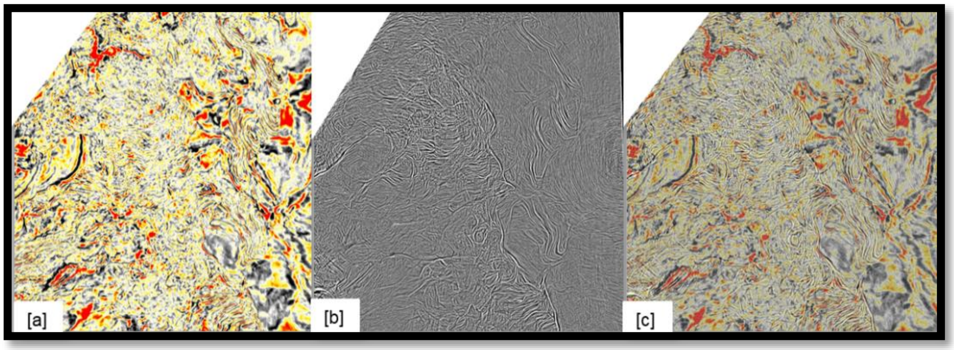

Figure 11: Depth slice at 2800m (a) specular enhanced stack, b) Diffraction enhanced stack c) a & b overlaid

Conclusions

The case studies presented here demonstrate that the state of art conditioning and full azimuth imaging in combination with accurate velocity model building approach produce substantial improvement in imaging quality which offer new insights to help with field development and reduce the risks and uncertainty associated with legacy imaging. This study confirms that applying the up-to-date processing and imaging techniques to vintage data, their geophysical and geological value is enhanced and renewed at a relatively low cost.

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