Consistent reprocessing and reimaging of 9 narrow azimuth surveys across the Campeche Salt Basin, Mexico

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Abstract

The Campeche Salt Basin represents a proven hydrocarbon province with excellent late Jurassic Tithonian source rocks distributed across wide areas, as well as several Mesozoic play types that have been exploited by PEMEX during the previous six decades of exploration. In the shallow waters, Miocene and Pliocene siliciclastic reservoirs have been targeted with considerable success as well, but most discoveries have yielded somewhat smaller resources (Haire, 2016). Recent license rounds offshore Mexico (Rounds 1.4 and 2.1) focused on the Campeche basin, where many 3D programs were acquired for Pemex from 2003-2010. Mexico's National Hydrocarbons Commission (CNH) and Secretary of Energy (SENER) made these legacy data available to help inform evaluation and bidding. Reprocessing existing data with a consistent flow and an optimal set of algorithms has proven to be an extremely cost-effective method for E&P companies to analyze bid round acreage and detailed play and prospect evaluations. Having one contiguous high quality Pre-Stack Depth volume across Campeche Basin will improve the likelihood of having a better understanding of tectonics, stratigraphy as well as depositional system.

Introduction

For evaluation of the earliest rounds in the Campeche basin, ION partnered with Schlumberger to integrate and reimage 20 legacy 3D data sets using advanced processing technologies and workflows. This abstract describes the reimaging and integration of nine of these narrow azimuth data-sets in the Campeche reimaging program North and South sections, covering a contiguous area of more than 66,000 km^2 in deep to shallow water (Figure 1). The data-sets were acquired and processed at different times by multiple companies who employed various processing flows and/or migration algorithms. The reimaging challenge was further complicated by the diverse velocity models, which were driven by different salt interpretation and anisotropy parameters. Those differences result in difficulties creating a complete geological picture and consistency in stratigraphic interpretation, as well as possible reservoir prospects within the area.

The variability of acquisition combined with geological complexity required a consistent and advanced workflow to maximize bandwidth while producing data with strong low frequency content for sub-salt and high-resolution for mini-basins and fold belts. The application of broadband preprocessing followed by high-resolution of steep dip reverse time migration (RTM) and Kirchhoff imaging algorithm will produce ideal data for prospect identification and exploration.

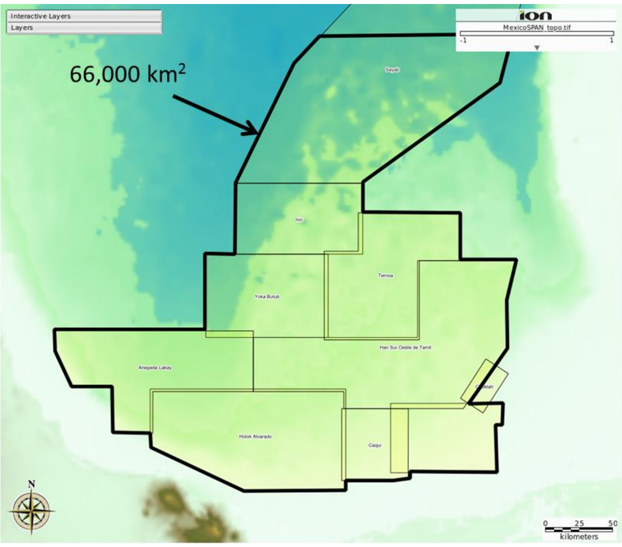

Figure 1 – Bathymetric map of Campeche Reimaging Program North and South areas, which includes 9 narrow azimuth seismic surveys across 66,000 km^2. Data reprocessed and reimaged by ION in partnership with Schlumberger, who holds data licensing rights.

Method

The pre-processing sequence was designed to ensure amplitude, phase and datum consistency throughout the different surveys and imaging inputs. Pre-processing was identical for all the surveys unless acquisition or water depth dictated otherwise. It also enabled accelerated timelines to produce deliverables in advance of the lease sales by outputting quick, but phase consistent intermediate products to allow velocity model building shortly after receipt of data.

Pre-processing for all surveys began with a common starting point, the raw nav-merged gathers. Bubble events were removed from the data using ION's debubble filter generation routine, which uses colored noise to prevent instability in the filter that arises at the ghost frequencies & isolates the frequency range within which bubbled events are expected to occur. Swell and other impulsive noise attenuation were conducted using ION's SWDnoise applied in different domains to ensure sufficient randomization of noise against the coherency of signal. This was followed by linear noise attenuation and ION's TauP swell denoise routine.

A series of processes were applied to correct for acqusition effects including local amplitude footprint removal and reciever motion correction. The ampltiude footprint caused by sensivity variations in hydrophones from some vintage surveys can be significant, up to +/- 1.5dB. Correction of these, in an AVO signal preserving manner, can assist in reducing pre-processing transfrom artefacts and correct energy cancelation during migration.

Subsequently ION WiBand^{TM} technology was applied to remove signal distortion due to ghost reflections from the sea surface. Prior to de-ghosting, a reversible correction is made to compensate for angular variations in the ghost period. This step can greatly simplify the design and application process. The de-ghosting method selected for this sequence uses a data-driven search methodology to find the optimum source depth, receiver depth and sea surface reflection co-effecient that produces a linear response in the amplitude and phase spectra. Analysis for operator selection is limited to where the signal-to-noise ratio is greatest and the ghost is most clearly visible in the data to produce the most stable result.

WiBand de-ghosting also assisted in matching vintages of data acquired with different tow depths. Conventional survey matching routines often cannot address angle dependent differences in the wavelet when the ghost notches are positioned at different frequencies due to different delay times from the tow depth to the sea surface. Attenuation of ghosted events by WiBand^{TM} effectively removes first order differences in the wavelet between the surveys, which enables easier subsequent matching that primarily focuses on differences due to the recording system, which are more easily adressed with simple global solutions.

As seen in Figure 2, the de-ghosting process provided a significant increase in bandwidth, much improving the richness of low frequency and the extension of higher frequency bandwidth.

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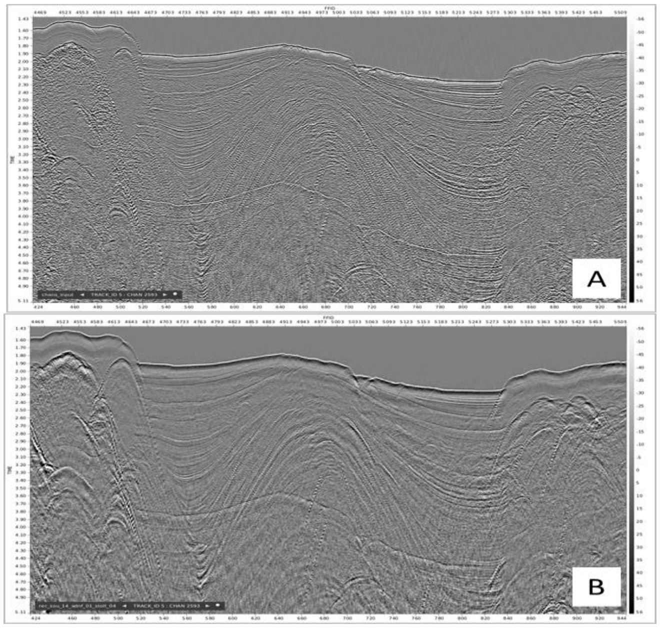

Figure 2 – ION WiBand example: A. input, B. output.

Following WiBand^{TM}, several processes were applied before the demultiple process: residual debubble, zero-phase, as well as amplitude matching between surveys. Depending on the water bottom depth, ION's short period demultiple (SPMA) and 3D-SRME routines were applied in order to the attenuate multiple reflections.

3D-SRME is a two-part processing sequence where the data is used to model the multiple and that modeled multiple is then subtracted from the data. The method is fully data-driven and the only input required is the data to be modeled. As it requires a free-surface to work, it is ideal for the removal of water-bottom multiples. In an area such as the Campeche Basin that contains highly complex salt bodies and a sea floor pockmarked with features, 3D SRME is proven to be very effecitve in removing surface-related multiples, particulary from near offsets (Figure 3.)

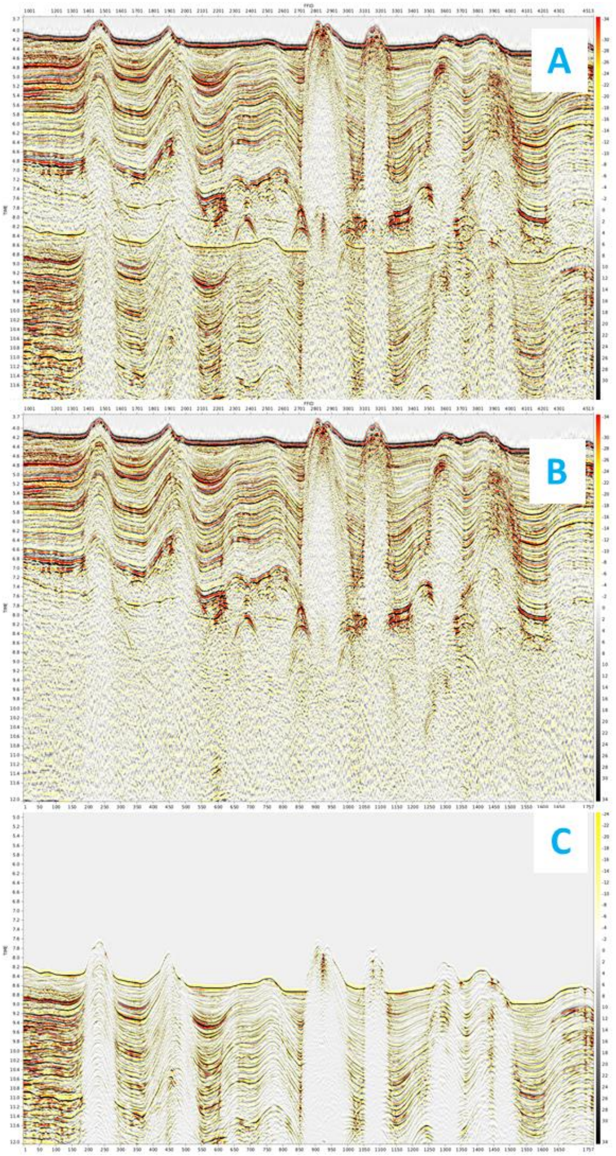

Figure 3 – Sayab 3D-SRME near offset example: A. input, B. 3D-SRME output, C. Difference between output and input of 3D-SRME.

3D SRME was split into 3 steps, data preparation, multiple model prediction, and adaptive subtraction of the model. During data preparation, aperture was included from adjacent surveys, ensuring good attenuation of multiples at all the survey seams. In the subtraction, data was split into complementary frequency bands each adaptively subtracted independently and then recombined. After de-ghosting, the dominant frequency of the data has been shifted towards the lower end of the frequency spectrum. This methodology can prove successful in preserving low frequency signal while still ensuring effective attenuation of the multiple. With more than 66,000 km^2 of data and multiple copies stored on disk at any one time, this was pre-processing on the Peta-byte scale. Timely input of data into velocity model building and imaging was made possible by Perseus™, ION's processing software. It's a distributed application framework for dynamic scientific computing that allows for efficient simultaneous re-organization of multi-terabyte volumes and easy parallelization of CPU intensive processes.

In order to minimize the delivery timeline, velocity model building was performed in parallel with the signal processing. Using the preliminary WiBand deghosted and zero-phased data with fast track demultiple, tomography could be started prior to finalizing all signal processing works. The initial velocity model was built based on the legacy velocity model made available by CNH. The standard of legacy models varied from survey to survey and ranged from time RMS velocity used for pre-stack time migration, to anisotropic depth interval velocity including salt interpretation. The legacy models were converted to isotropic interval velocity, desalted, clipped, merged and smoothed to form a continuous sediment velocity.

Depending on the quality of initial gather flatness for the shallow sediment reflections, the velocity model underwent between 2-5 iterations of tomography. For each iteration of tomography, gathers migrated on a 100x100m grid across the entire Campeche area were analyzed for residual moveout using automatic picking (APK) with general move-out analysis (GMO). Prior to incorporating the finalized demultiple input data, a post-migration Radon filter was typically applied prior to APK to remove any residual multiple. GMO tracked reflection events from near to far offset without any trajectory assumptions (e.g. 2nd and/or 4th order moveout) and was thus able to analyze complex moveouts, which tomography can invert into a more detailed and accurate velocity model.

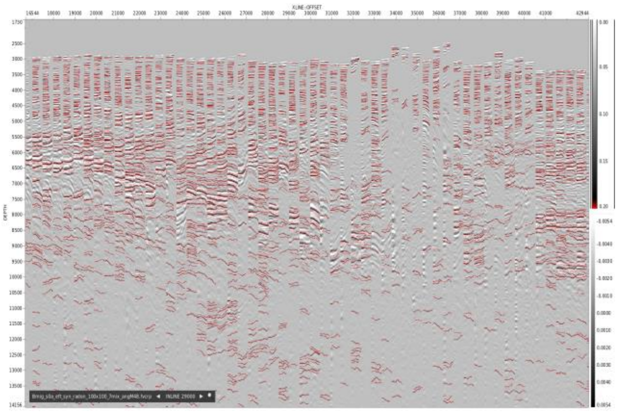

Figure4 – GMO picks on the initial migrated gathers.

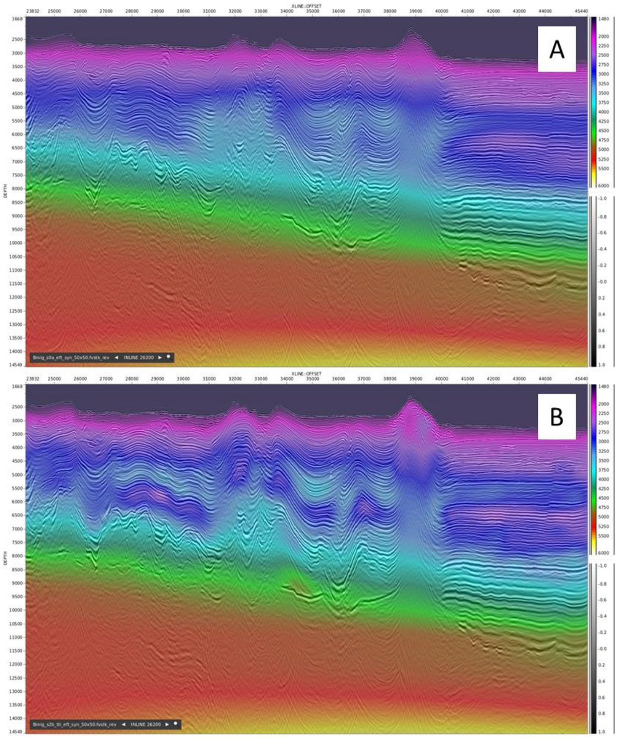

Figure 5 – A. Initial velocity and PSDM stack overlay, B. Second update velocity and PSDM overlay.

All shallow sedimentary velocity updates were performed on beam gathers migrated with TTI anisotropy and anisotropic tomographic inversion. The anisotropic Delta parameter was calculated from the difference between the check-shot velocity and the isotropic-converted migration velocity at well locations. This Delta value was then used for high frequency Kirchhoff PSDM followed by mistie analysis between the formation tops obtained from the wells and the PSDM stack (Figure 6). This analysis was performed on four wells, both in deep and shallow water areas, with one well penetrating to the top salt. With the final Delta function, the measured misties are consistently small, for example 15m at the top of upper cretaceous on the well that penetrated to the top salt.

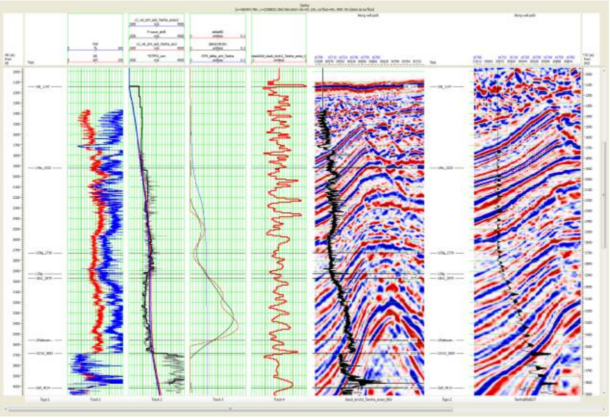

Figure 6 – Mistie analysis

The value for the anisotropic Epsilon parameter was scanned for between 1.5 – 2.25 x Delta, using migrated gathers to determine which value provided the flattest far offsets (Figure 7). The same Delta and Epsilon functions were applied to the whole Campeche area.

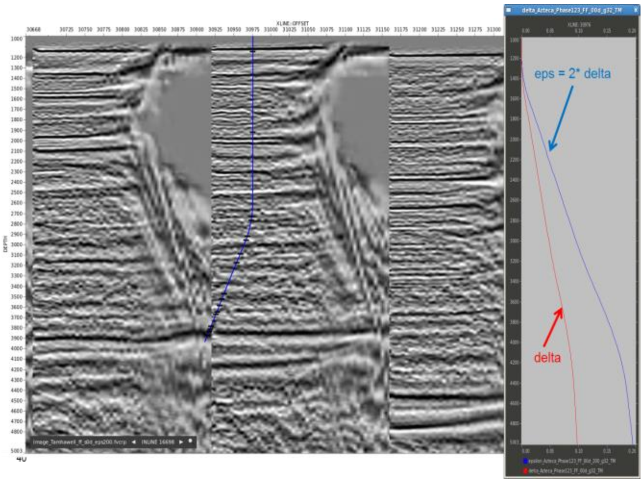

*Figure 7– Epsilon scan example with Epsilon = 2*Delta.*

The salt model was interpreted using RTM images migrated using the final sediment velocity model obtained from the tomography. Top salt was interpreted using a 30Hz RTM, the salt flood model was then built using 4480 m/s salt velocity, followed by a 20 Hz RTM migration on which base salt was picked. The top and base allocthonous salt are interpreted across the entire Campeche region. In the northern part of Campeche, where the salt structures are predominated autochthonous, this deeper top and base salt are also interpreted.

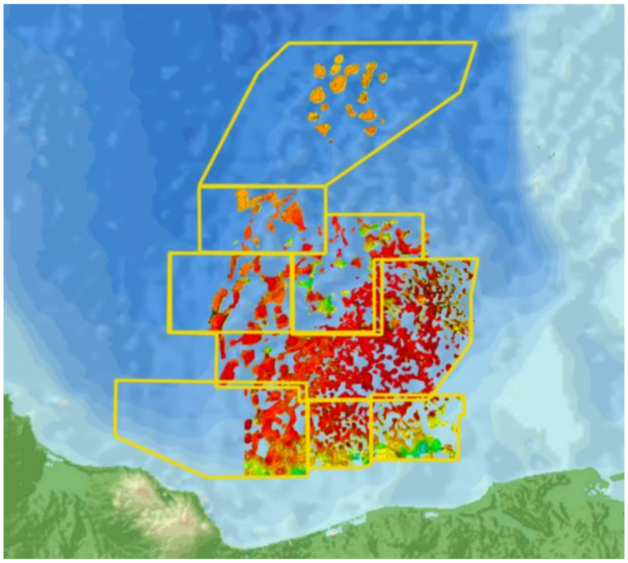

Figure 8 – Salt map across the Campeche basin.

Results

Having consistent preprocessing, velocity model building, salt interpretation and migration has allowed us to build a contiguous Pre-Stack Depth RTM volume throughout the Campeche Salt Basin. In addition to the consistency between surveys, this RTM volume also has much better image quality as a result of an improved velocity model and TTI anisotropy migration. Several examples in Figures 8, 9, 10, 11 and 12 below demonstrate the improvement after reprocessing and reimaging in both individual surveys and at survey boundaries.

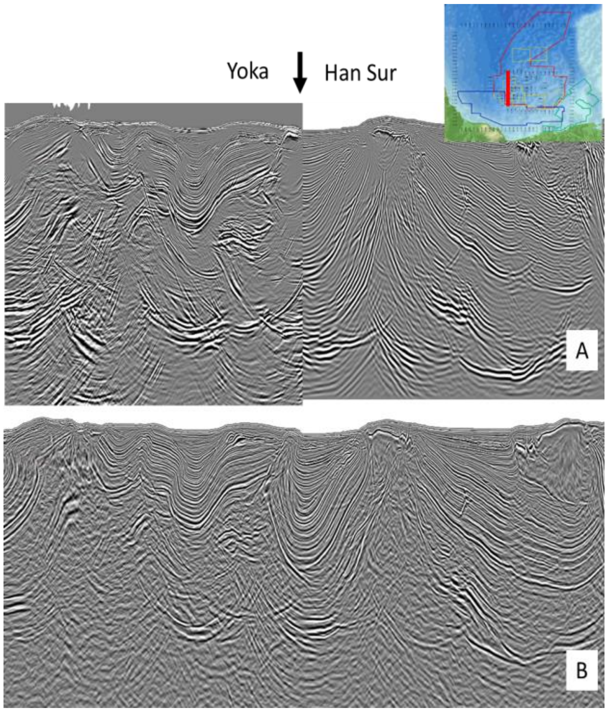

Figure 9 - Intersection of Han Sur oeste de Tamil and Yoka Butub: A. CNH legacy PSDM Stack, B. New, contiguous reprocessing-reimaging PSDM 30 Hz RTM stack. The new reimaged data has much better quality imaging the intersecting surveys.

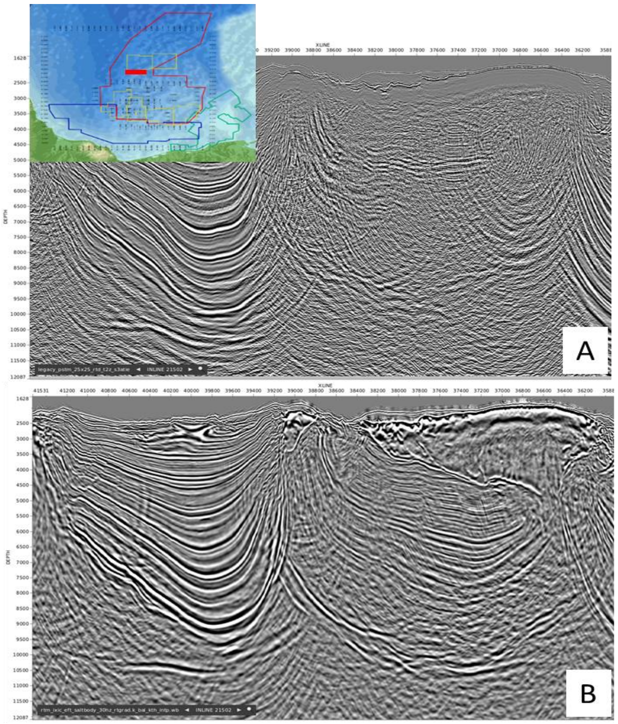

Figure 10 – Ixic example: A. CNH legacy PSTM converted to depth, B. New, contiguous reprocessing-reimaging PSDM 30 Hz RTM stack. The new reimaged data has much better sub-salt image quality.

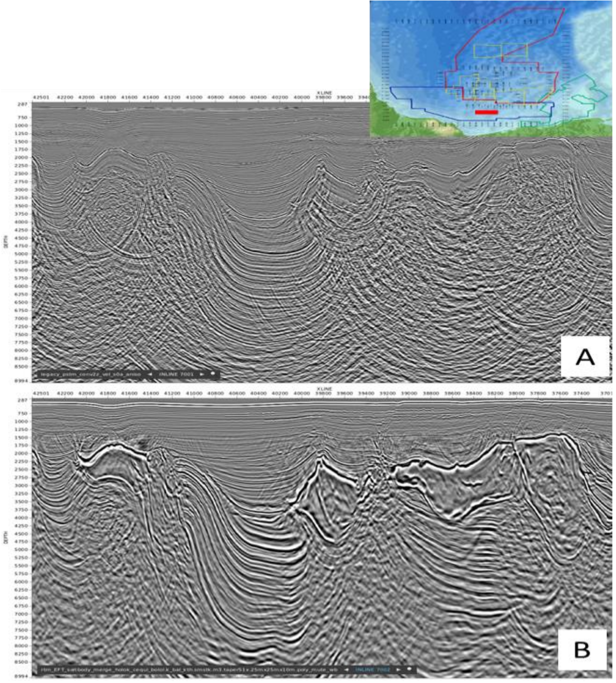

Figure 11 – Shallow water Holok Alvarado example: A. CNH legacy PSTM converted to depth, B. New, contiguous reprocessing-reimaging PSDM 30 Hz RTM stack. The new reimaged data has much better sub-salt image quality.

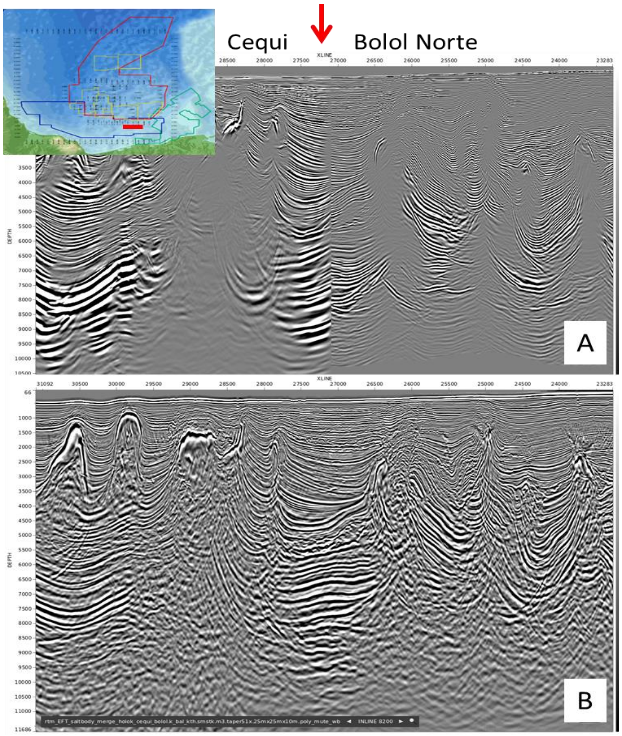

Figure 12 - Intersection of Cequi and Bolol Norte: A. CNH legacy PSDM stack, B. New, contiguous reprocessing-reimaging PSDM 30 Hz RTM stack. The new reimaged data has much better quality imaging the intersecting surveys.

Conclusions

There were two objectives behind the Campeche reimaging project in partnership with Schlumberger. The first was to provide a contiguous, high quality seismic volume to improve understanding of stratigraphy, the depositional system and possible reservoirs. The second was to deliver data in an unprecedented turnaround time in advance of license rounds in the Campeche Basin. In just three to five-months, the team delivered a complete volume with updated seismic velocities and allochthonous salt interpretation for velocity model building, a step-change in turnaround time to deliver key insights before the bid round. The project's scale, complexity and completion timeline would not be possible without the preexisting regional framework understanding and close integration between processing, interpretation and imaging personnel.

Acknowledgments

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5. Marwa Elbadry and Chuck Peng (WesternGeco)

References

Ed Haire, 2016. MexicoSPAN Interpretation Report 63p.