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Prospectivity Insights from Simultaneous Velocity and Reflectivity Inversion, Offshore Newfoundland and Labrador, Canada

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Summary

Implementing advanced geophysical processing techniques for valuable interpretation insights in frontier environments and challenging data environments.

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Introduction

The Atlantic continental margin and associated offshore basins of Newfoundland and Labrador are predominantly frontier exploration environments. From 2011 to 2021, the Oil and Gas Company of Newfoundland and Labrador (Oilco) in partnership with TGS and PGS have systematically acquired seismic data to better understand the prospectivity within these basins. As a result of the program over 49,000 km^2 of modern broadband 3D multi-client data has been acquired over prospective acreage in the region. Interpretation of these datasets has revealed leads with intriguing geological, structural and AVO characteristics. Several areas within these datasets have been high graded for more in depth analysis with modern processing techniques in an attempt to gain a better geologic understanding and assist de-risking new prospects. Simultaneous velocity and reflectivity inversion has several inherent properties that add value when analysing seismic data in frontier and challenging data environments. Specifically, high resolution velocity data are obtained, true vector reflectivity volumes are generated and relative impedance and density can be estimated directly from the velocity and reflectivity products. Results to date show that analysis of Ultima products when compared to conventional seismic analysis has the ability to provide additional information in the form of image quality as well as property constraints that reduces uncertainty of interpretations where well data is limited.

This study reviews results from two areas with unique characteristics that test the performance of the simultaneous inversion in different geological settings. Area 1 (Blomidon 3D), is located on the shelf to slope transition in the Orphan Basin. This study area is characterized by a shallow and high impedance water bottom that generates significant multiple contamination throughout the conventional dataset limiting interpretability of the shallow Cenozoic section. The Cenozoic section is of importance in this region as it encompasses a large passive margin fan play requiring better definition. Simultaneous inversion was run in multi-frequency stages up to 20Hz for Area 1. Area 2, is located in the Salar basin (South Bank 3D survey), this area has high quality 3D data and is shot over an extensive Cenozoic fan complex that is over 800m thick. The inversion tests in this location were run to ascertain what additional constraints on prospectivity and rock properties can be determined by applying the technology. The inversion was run to 25Hz for Area 2.

Simultaneous Inversion/Ultima Methodology

Simultaneous inversion for velocity and reflectivity (Yang et al., 2021) combines two separate processes – Full Wavefrom Inversion (FWI) and Least-squares Reverse Time Migration (LS-RTM) into a joint workflow based on a new wave equation parametrized in terms of velocity and vector reflectivity (Whitmore et al., 2020. Since there are no approximations in the reformulation, the modelling engine is able to generate the entire acoustic wavefield including refracted and reflected energy, as well as all orders of multiples. The simultaneous inversion is an iterative process that minimizes data misfits between modeled and recorded data The simultaneous aspect of the inversion has advantages over the traditional approach of running FWI and LS-RTM separately by enabling a simultaneous inversion of velocity and reflectivity. Specifically, simultaneous inversion simplifies the workflow and minimizes crosstalk between the two properties by separating the low- and high-wavenumber components of the earth model, providing more reliable velocity and reflectivity models. The iterative inversion also compensates for incomplete acquisitions and varying illumination in the subsurface to provide true-amplitude earth reflectivity. The high-fidelity velocity and reflectivity models are then readily available for Quantitative Interpretation (QI). Moreover, they are employed to derive additional earth attributes, mainly relative impedance and density for prospectivity assessment.

Area 1 – Challenged Data Quality Analysis – Blomidon 3D

A significant amount of the prospectivity within the Blomidon 3D resides below the present day shelf. Multiple contamination in this area negatively impacts interpretability as well as amplitude and velocity fidelity. In unconsolidated environments, confidently interpreting amplitude and depth conformance are paramount for de-risking. The simultaneous inversion was applied in this location with the objective of obtaining better interpretability within the shallow section, better amplitude fidelity and a more detailed velocity model to better constrain the structure. Results from the 20 Hz simultaneous inversion were encouraging. Despite a lower bandwidth in comparison to the conventional outputs, the reflectivity results showed much better amplitude fidelity. Regional markers maintained consistent amplitudes moving across the section covering the present day shelf to deep water transition. The enhanced removal of multiple energy allowed for the interpretation of regional markers throughout the Cenozoic section with increased confidence. 3D mapping and prospect analysis provided important insights as well. A large passive margin fan identified within the dataset that manifests as a Class IIn anomaly showed significant uplift. Specifically, geomorphological events were more clearly defined in the simultaneous inversion product. Feeders channels, bypass channels and lobes were interpretable due to the better conformance of amplitudes to lithological boundaries and local structures (Figure 1).

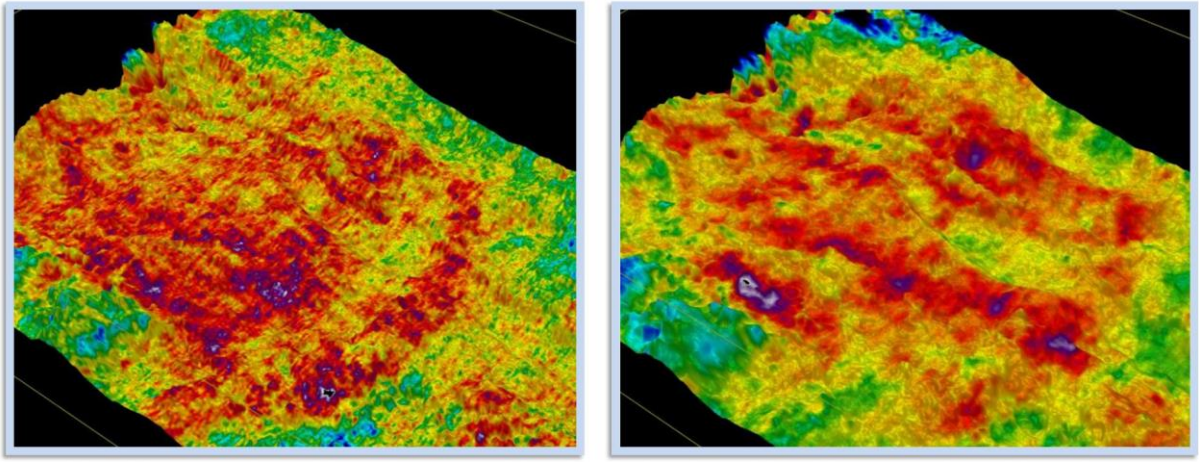

Figure 1 *Left image illustrates a Relative Ip amplitude extraction over fan from conventional PSTM processing result. Right image illustrates the amplitude extraction performed on the simultaneous inversion result. Amplitude anomalies are confined to the fan outline in the updated result and geomorphological events can be interpreted.*

An analysis of the initial model identified a low velocity zone in a region below the shelf that loosely correlated with the areal extent and depth of the fan complex. Given the data quality issues it was not clear whether or not the velocity anomaly was related to poor tomographic results due to data quality or to the large scale fan complex itself. The simultaneous inversion results (Yang et al., 2022) confirmed that the low velocity anomaly was in fact inaccurate resulting in a false positive around the lead. The enhanced velocity model appears to not only more accurately reflect the earth model in higher detail, but also, as a function of the more accurate and detailed velocity model, a more accurate depth structure is obtained. These results were critical in the analysis of this area as significant structural changes were observed using the updated velocity model, including changes in dips on regional beds. The results also show better correlation of amplitude anomalies to closures within the fan complex.

Area 2 – Insights from Simultaneous Inversion in areas with high quality conventional processing results

The Salar basin is characterized as a rift basin with passive margin fill throughout the Cenozoic. Data analysis to date suggests prospectivity primarily lies within an Oligocene stacked fan complex with a combined thickness of 800 m. The Salar basin is a true frontier environment with no exploratory drilling to date in the slope to deep water environment. The lack of well data means that rock

properties are unconstrained and many uncertainties exist when interpreting reflectivity anomalies within the basin. Conventional Kirchhoff migration results in the area however are high signal to noise and show many intriguing amplitude anomalies within the zone of interest. Low seismic velocities and depth below mudline of the complex (1200-2000 m) are suggestive of an unconsolidated environment. Simultaneous inversion was performed in an effort to better constrain uncertainties that exist due to the aforementioned lack of well data and to better characterize the fan complex. The inversion was run to 25 Hz in this area.

Results to date have provided valuable information to the interpretation of the fan complex. Firstly, while the Kirchhoff migration dataset shows high quality imaging results, comparisons of the conventional and new velocity model are very insightful. Subsurface velocity compaction trends are clearly defined in the new productions and it is easily identifiable how they change moving distally away from the shelf from sandier to shalier environments. Additionally the increased resolution of the model creates a situation where velocities are constrained to individual lithologic layers giving insights and constraints on rock properties at specific target intervals (Figure 2). In fact, it appears as though sand and shale compaction trends can start to be identified directly from the seismic data in this particular case as multiple sandy and shaley intervals are interpreted over a large depth range. At the top of the fan complex the interpreted sands have a significantly lower velocity than the shales, moving down through the complex the sand and shale velocities move closer together suggesting the base of the complex is nearing the velocity crossover point of sands and shales (Figure 3).

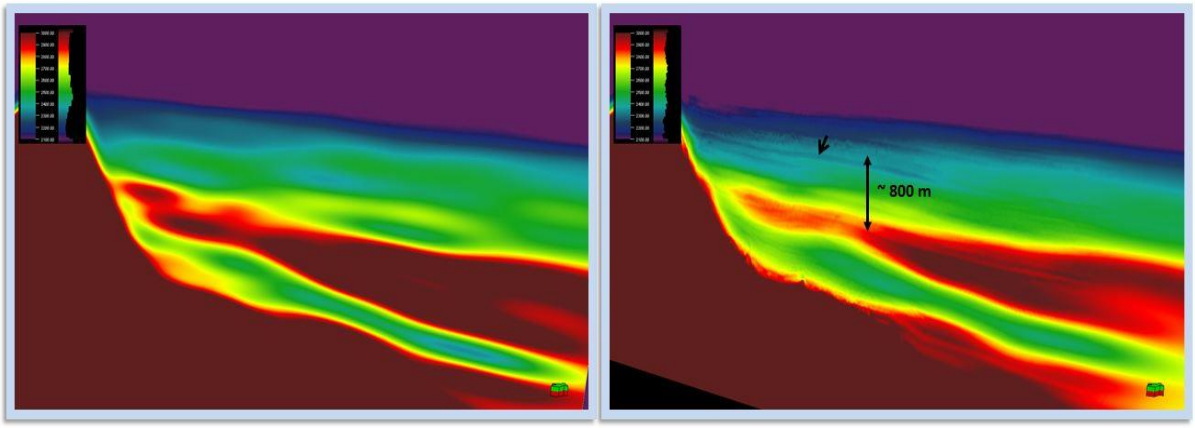

Figure 2 *Left image shows final PSTM velocity model over a section of the 3D dataset. Right image illustrates the simultaneous inversion results. Note the updated compaction trends in the top half of the volumes. The small black arrow points to the top of an interpreted love near the top of the fan complex. This figure shows the velocities constraining to the lobe interval and that it appears to be a lower velocity than its bounding stratigraphy.*

The reflectivity outputs here also show consistency with the conventional datasets. Extractions at top of lobes show that depth and lithology related changes in amplitude are reflected on both conventional dataset as well as the simultaneous inversion outputs giving confidence in the results of the newer technology. It should be noted however that higher frequencies are required to better resolve thinner lobes and resolution analysis must considered when designing the workflow.

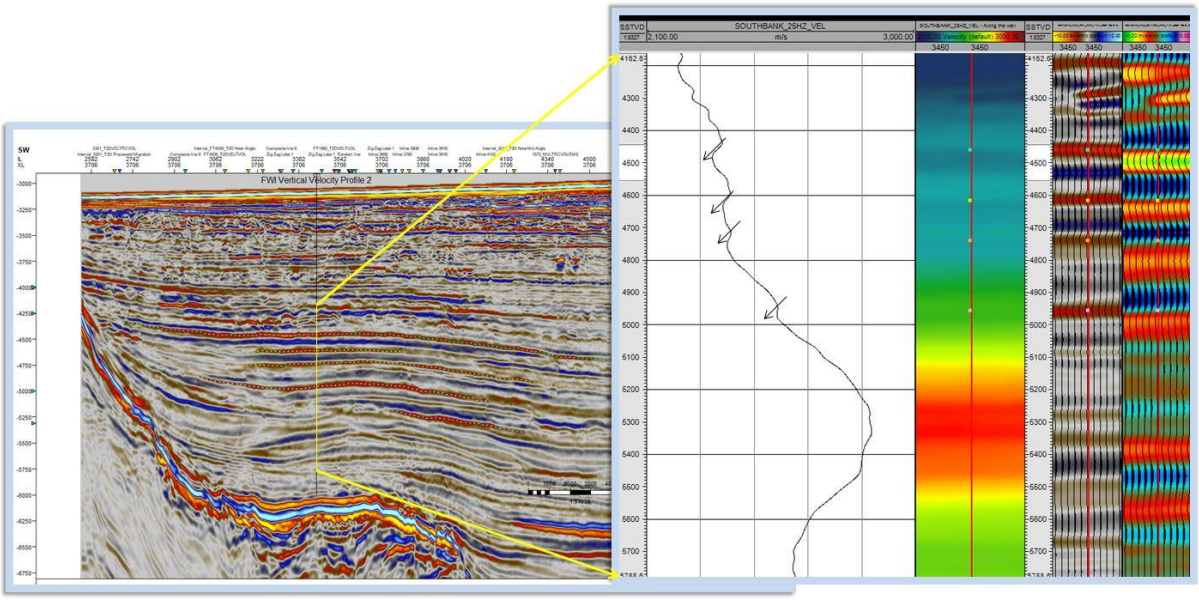

Figure 3 *Pseudo well shows a velocity trace extraction through the fan complex. Arrows in track one denote the drop in velocity moving into the interpreted sandy lobes. Track 2 shows the velocity in colour. Track 3 and 4 are respectively, the Simultaneous inversion reflectivity and relative density extractions at the pseudo well location denoted on seismic image to the left.*

Conclusions

Applications of simultaneous inversions have provided some new and key insights into prospectivity in targeted areas across the Newfoundland and Labrador margin. Its applicability in unique geologic scenarios has worked to solve multiple objectives in the datasets. On the shelf the inversions to reflectivity and velocity are showing significant uplift to conventional data signal to noise levels in data challenged areas increasing confidence levels in structural and amplitude supported leads. The velocity outputs in both study areas have refined and increased knowledge related to compaction trends, questionable velocity anomalies and rock properties. The more detailed results better constrain velocities and relative velocity changes in lithologies and at lithologic boundaries resulting in higher confidence quantitative geophysical and geological interpretations. In comparative studies in high quality data areas, conventionally processed datasets and simultaneous inversion results show consistency in reflectivity on a prospect level. Currently, work is being undertaken to increase the bandwidth over these datasets as well as investigating an additional area within the region to further the understanding of the technological capabilities with regards to prospectivity analysis, illumination and depth of investigation.

References

Whitmore, N.D., Ramos-Martinez, J., Yang, Y. and Valenciano, A.A. [2020]. Full wave field modeling with vector-reflectivity. 82nd EAGE Conference & Exhibition, Extended Abstracts, 1-5

Yang, Y., Ramos-Martinez, J., Whitmore, D., Guanghui, H. and Chemingui, N. [2021] Simultaneous inversion of velocity and reflectivity. First Break, 39(12), 55-59

Yang, Y., Arasanipalai S., Chemingui, N., Montevecchi, N. [2022]. Estimating reliable earth properties from simultaneous velocity and reflectivity inversion. First Break, 40, 65-70