Semi-Automated Relative Geological Time modeling towards geological prospect identification: case study, Neuquén Basin, Argentina

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Summary

The following paper aims at applying a semi-automated method for comprehensive seismic interpretation on a Neuquén Basin case study, onshore Argentina.
The performed workflow is based on the creation of a signal driven Relative Geological Time (RGT) model (Pauget et al, 2009). RGT model outputs such as Thinning attribute, Wheeler diagram and isochrones enable to emphasize two prograding systems in the Cuyo Group and Quintuco-Vaca Muerta Formation.
A 3D stratigraphic framework is built from boundary delineation with bedset termination management, and unit modeling with sedimentary dynamics assignment. This interpretation of depositional settings then leads to a dynamic analysis of isochrones through a stratal slicing performed at a sub-seismic sample scale.
The analysis of seismic amplitudes, spectral decomposition results and RGT attributes finally reveals the presence of Cuyo sub-marine canyons interpreted as turbidite systems.

Introduction

The Neuquén Basin is one of the major hydrocarbon producers in Argentina. The geological history of the Neuquén Basin is influenced by relative sea level cycles and characterized by sedimentary dynamics changes between submarine and subaerial environments. Sequence stratigraphy concepts have thus been used during the comprehensive seismic interpretation workflow applied on this Neuquén Basin study.
The approach is based on a semi-automated process which stratigraphically organizes the seismic reflectors. This signal-driven method delivers a Relative Geological Time (RGT) model (Pauget et al., 2009). Continuous surfaces can be computed anywhere inside the RGT model without being limited by the seismic polarity changes, whereas other techniques are limited to 2D analysis and/or a limited number of horizons.
Based on an a priori geological knowledge of the Neuquén Basin (Brinkworth et al., 2018), RGT modeling aims at enhancing regional scale stratigraphic features towards the detection of sedimentary structures at a reservoir scale.

Geological Context

The Neuquén Basin provides many high-quality case studies which integrate different basin evolution aspects and sequence stratigraphy models. Thanks to 4,000 meters of sedimentary deposition and complex geology, this basin has produced hydrocarbon for more than 100 years.
The Neuquén Basin is located eastern of the Andes Mountains, between 32 and 40 degrees south latitude, and has a triangular form. Largely limited by cratons, by Patagonian massif in the south and San Rafael massif in the north, the basin was filled between tectonostratigraphic and accreted terranes. The structural history registered the extension during late Triassic rifting, the thermal subsidence from the Jurassic to the early Cretaceous, the middle Cretaceous foreland basin subsidence, and the Andean compression (Howell et al, 2004).
The basin is divided in different main areas: Neuquén Andes in the west, composed by N-S strike foreland fold and thrust belt, and outcrops of the Mesozoic succession; Neuquén Embayment in the east, where the Mesozoic sediments are found in the subsurface (with lower relative deformation) and where most of the hydrocarbon deposits are located.
From the Triassic to the late Cenozoic the successive infillings consist of clastic and pyroclastic rocks, deep-water turbidite systems, pelagic and hemipelagic systems, proximal clastic rocks and carbonates, fluviatile systems and many evaporitic and aeolian system periods. The continental and marine sediment accumulations happened in different basin types which are the testimony of drastic relative sea level changes.
The studied seismic cube geographically covers a sub-area of the Neuquén Embayment and stratigraphically covers a vertical succession of deep-water, platform and fluvial deposits from base to top.

Semi-automated seismic interpretation method

The RGT modeling workflow is composed of two steps. The first step consists in computing a geotime Model Grid using a cost function minimization algorithm, which merges seismic points according to the similarity of the wavelets and their relative distance. This process automatically tracks every horizon within the seismic volume and a relative

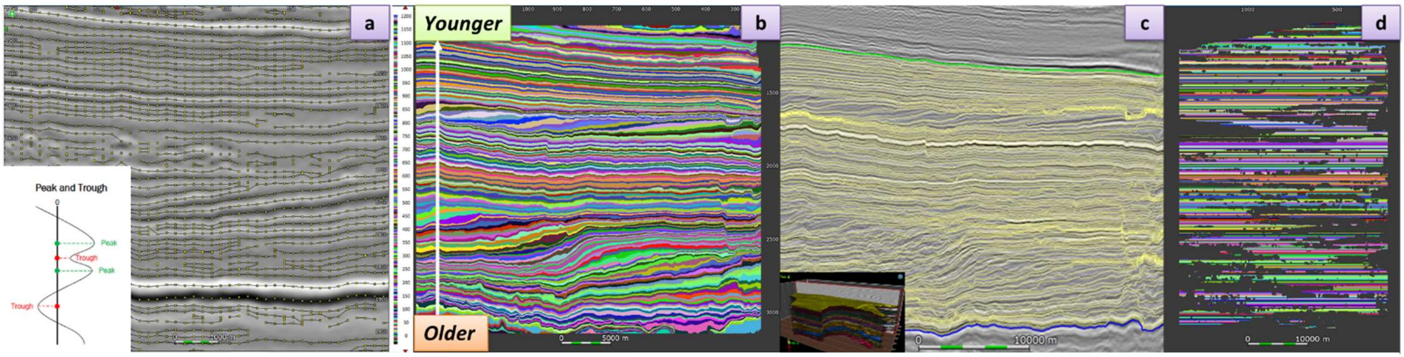

Figure 1- Vertical section of the 3D cube with: a) 3D Model-Grid display; b) 3D RGT Model; c) 3D Horizon Stack intersections; d) Comprehensively flattened 3D RGT model - Wheeler diagram.

geological time is computed for every point (Figure 1, a). The interpreter still uses computer-aided tools to automatically detect potential wrong correlations within the Model-Grid before correcting them. The Relative Geological Time model is finally computed from the vertical interpolation with 3D Gaussian smoothing of the Model-Grid (Figure 1, b) and a relative geological age is assigned to each voxel of the volume (Pauget et al., 2009).

Since the 3D RGT model is both vertically and spatially continuous, an unlimited number of chronostratigraphic surfaces can be generated. These depositional time surfaces can be extracted as dynamic series called Horizon Stacks (Figure 1, c). The Horizon Stack enables an interactive stratal slicing through the seismic volume where sedimentary as well as structural features can be highlighted with a strong accuracy.

A comprehensive flattening can be applied to all the RGT values in order to build a 3D Wheeler diagram (Figure 1, d).

Depositional Sequences

The Thinning attribute (vertical derivative of the RGT model) enables to emphasize the relative maxima of isochrone convergence within a pre-defined window (Figure 2, a). The sample rate of the input seismic data allows

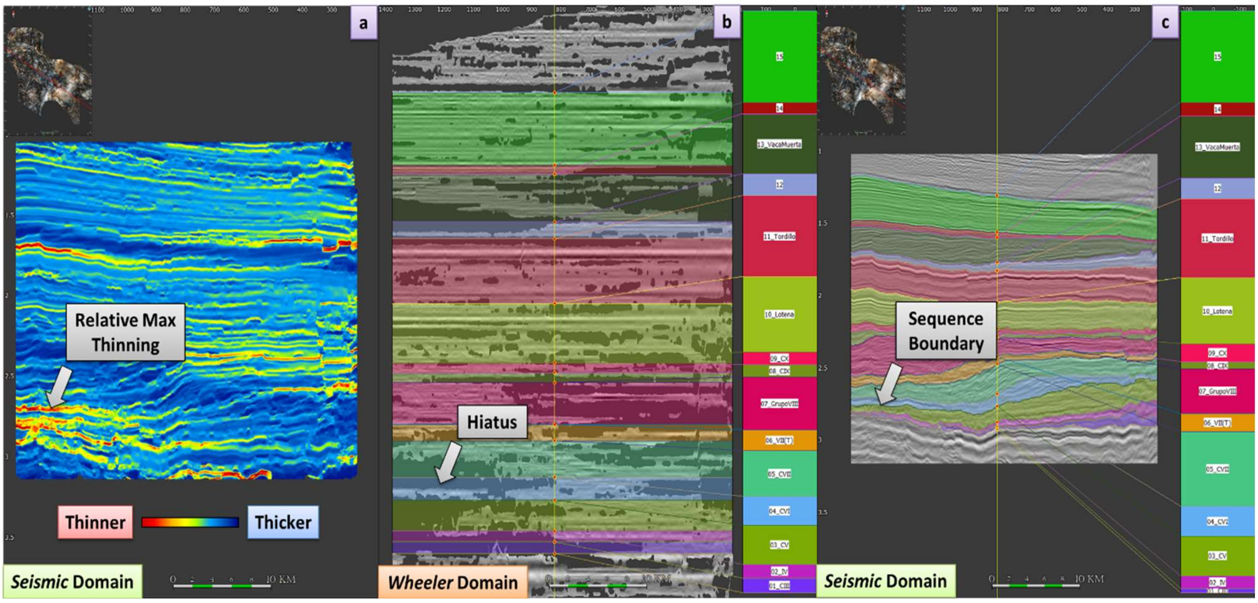

Figure 2- Vertical section of the 3D cube with: a) Thinning attributes; Regional Lithostratigraphic Chart correlated with, b) 3D Wheeler transformed seismic data, c) Seismic data.

controlling this vertical window size. Relative maxima of thinning attribute are interpreted as proxies of minimum accommodation space (Figure 2, a) and correlated to Wheeler diagram hiatuses (Figure 2, b). The Wheeler diagram is controlled by a comprehensive flattening of the whole series of RGT values and hiatuses are dynamically enhanced according to a ratio of mitigation. Any depositional time surface provided by the RGT model can be selected to delineate subtle stratigraphic boundaries and create sequences (Figure 2, b and c).

Based on the quick semi-automated and signal driven RGT modeling, a lithostratigraphic chart of the area can be easily built in order to roughly correlate the main layers, members and formations of the different Neuquén Basin groups – Cuyo, Lotena and Mendoza coming from the literature (Brinkworth et al., 2018) – with the main stratigraphic units of the seismic data (Figure 2, b and c).
A data reconnaissance stratal slicing of the Cuyo Group leads to the identification of seismic and time-frequency signatures in a mostly prograding system correlated to Los Molles formation. Following the above workflow, i.e. Thinning attribute combined with seismic pattern and real time Wheeler diagram, a depositional sequencing is performed (Figure 3, c). The bedset terminations of each stratigraphic boundary are managed while analyzing hiatuses, the Thinning attribute in stratal slicing for relative sedimentary dynamics understanding (Figure 3, a) and clinothem isochore computation for vertical thickness computation (Figure 3, b). The stratigraphic model is editable, and the sub-layering method of each system tract is adapted to the sedimentary dynamics: progradation, aggradation or retrogradation (Figure 3, d). An optimum reliability should nevertheless be obtained by first refining the input RGT model, then integrating well markers in the sequence stratigraphy analysis.
The stratigraphic model can finally be converted to a corner point grid for reservoir modeling purpose (Figure 3, e) and towards reservoir simulations.

A detailed stratal slicing of Los Molles formation highlights the presence of submarine canyons within the assumed cycles VII and VIII (Figure 4, 1a). The geometry of those canyons is subtly revealed by the simultaneous analysis of paleo-geomorphology (Z-Value, Figure 4, 1c) and seismic amplitude anomalies. A tailor-made spectral decomposition

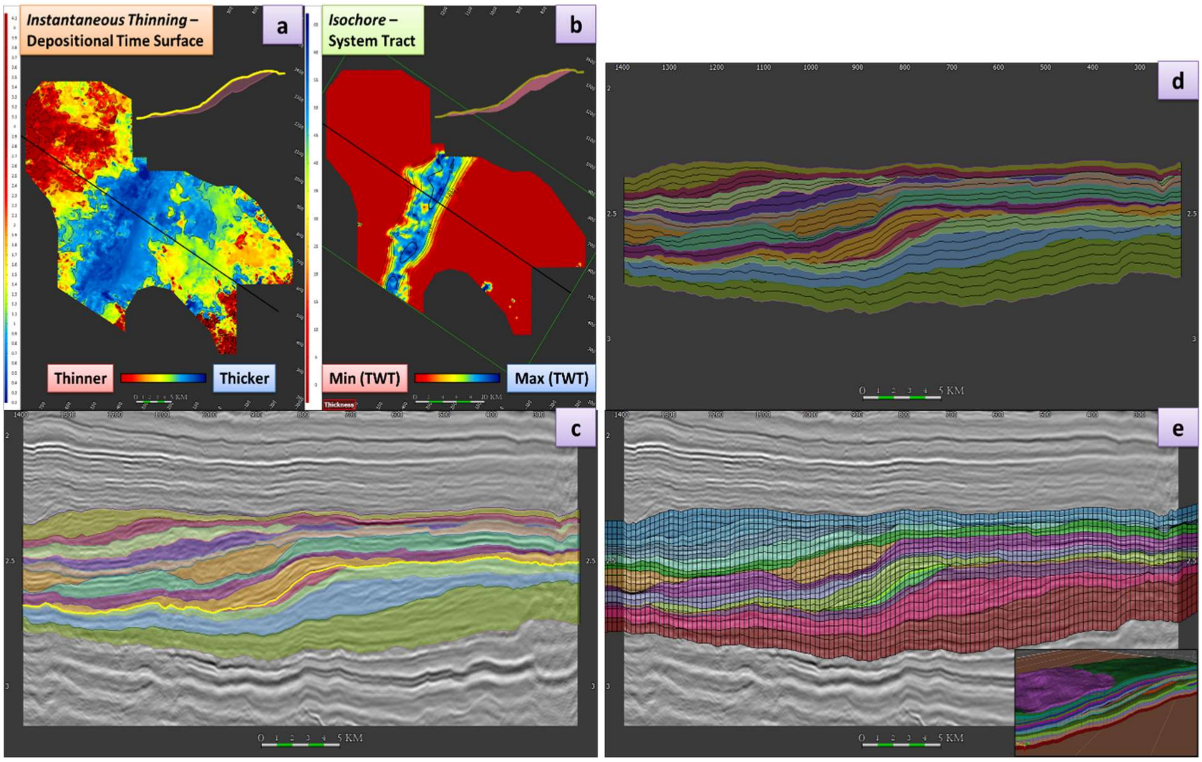

Figure 3- a) Thinning attribute mapped on the yellow boundary overlying the dark red sedimentary unit; b) Isochore data of the dark red sedimentary unit; c) Detailed stratigraphic sequencing of the Los Molles fm.; d) Sub-layering of the different stratigraphic units; e) 3D Geocellular Model, vertical 2D section and 3D view.

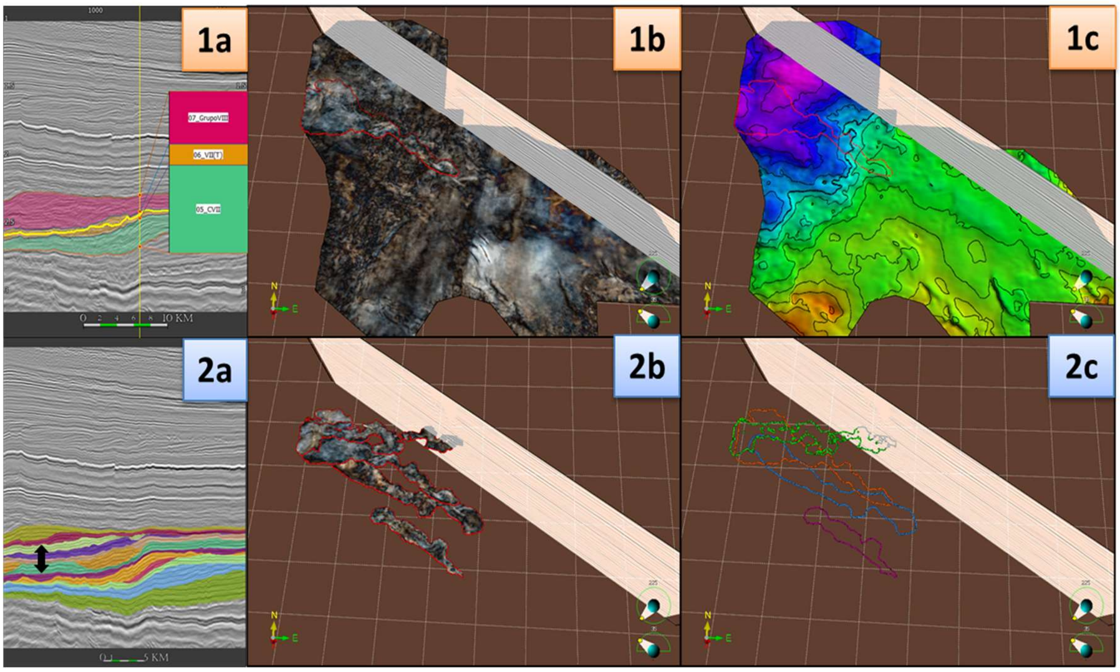

Figure 4- Los Molles fm., 1a) Main stratigraphic units, simplified lithostratigraphic chart and intersection of reference isochrone in yellow; 3D viewers, 1b) RGB blending of spectral decomposition (frequencies: 31Hz, 36Hz and 41Hz) mapped on an intra Los Molles isochrone with turbidite channel outline, 1c) Z-value on same intra Los Molles isochrone with Z-value contouring and turbidite channel outline; 2a) Detailed stratigraphic sequencing of Los Molles fm. with sub-layering adapted to the sedimentary dynamics (the black arrow shows the four stratigraphic units - green, orange, purple, light green - within which turbidite systems are revealed); 3D viewers, vertical superposition of 4 turbidite channels, 2b) Geobody outlines with RGB blending of spectral decomposition, 2c) Geobody outlines.

process is performed for each of the four relevant events whereas an average spectral decomposition enables to correlate them in a dynamic kinematics. The stratal slicing kinematics is based on a 38 ms Short Time Fourier Transform spectral decomposition with the following frequencies: 31 Hz, 36 Hz and 41 Hz (Figure 4, 1b). The RGB blending of those frequencies emphasizes the detection of turbidite channels, afterwards delineated and modeled as geobodies (Figure 4, 2b and 2c). Those turbidite channels can be correlated to the previously built stratigraphic model and may help refining it.

Conclusions

A comprehensive approach, based on a semi-automated seismic interpretation workflow, enables to build a fast stratigraphic framework on this Neuquén Basin case study, highlighting two prograding systems in the Cuyo Group and Quintuco-Vaca Muerta Formation.
A regional lithostratigraphic chart can be easily built from the data driven RGT model correlated with the main geological groups provided by the literature.

Deliverables coming from the RGT modeling (Thinning attribute, Wheeler diagram, sub-seismic sample stratal slicing) allows performing a preliminary discrimination of system tracts in Los Molles Formation (Cuyo Group). A spectral decomposition performed in Los Molles Formation and combined with a reservoir scale stratal slicing then reveals the presence of submarine canyons interpreted as a series of turbidite channels.

A high-confidence stratigraphic model could be obtained with the integration of field data (well logs, stratigraphic markers) in order to constrain the workflow at different stages: during the Model-Grid QC to refine the geological correlations, during the sequence boundary delineation, bedset termination and sedimentary dynamics management steps. The series of modeled geobodies could as well be increased and classified towards its integration in further reservoir scale facies modeling process.
The same approach could be applied on other geographic zones of the Neuquén Basin towards the correlation of sedimentary units from a regional to a basin scale.