Sequence Stratigraphic Modelling and Characterization of Sand Fairways, Enabled by an Automation-Assisted and Signal-Driven Relative Geological Time Model: Multi-Source and Small-Scale Turbidite System, Neuquén Basin, Onshore Argentina

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Relative Geological Time, Automation, Sequence Stratigraphy, Turbidite System, Spectral Decomposition

Abstract

The depositional history of the Neuquén Basin (onshore Argentina) was primarily influenced by changes in relative sea-level from the Triassic to the late Jurassic, leading to the occurrence of submarine and subaerial deposits (Brinkworth et al., 2018). Those processes led to the development of several petroleum systems. In the study area, located in the Neuquén Embayment region (eastern half of the Neuquén Basin), the author performs a comprehensive seismic interpretation, focusing on the Cuyo Group. The work illustrates the benefits of using a signal-driven Relative Geological Time (RGT) model (Pauget et al., 2009) to enhance the understanding of regional scale stratigraphic features, ultimately revealing a subtle and complex turbidite system.

Introduction

Many seismic interpretation case studies were conducted in the Neuquén Basin with the focus on basin evolution and sequence stratigraphy. With more than four thousand meters of sedimentary infill and several proven petroleum systems, the natural resources of this basin have been exploited for more than one hundred years.
In this paper, the author concentrates on a sub-zone of the Neuquén Embayment region (Figure 1, eastern half of the Neuquén Basin), covering an area of 700 km². The post stack 3D seismic data has a vertical extension of 5 seconds TWT, a bin size / CDP spacing of 30 meters and a sampling rate of 2 milliseconds. This is a PSTM (Pre-Stack Time Migration) seismic data processed in 2016. Simple data screening facilitates the identification of the key stratigraphic groups, Cuyo and Mendoza, having average depth ranging from 2.25 to 3 seconds TWT, and from 1.6 to 1.9 seconds TWT respectively. The Cuyo Group, which extends from Middle Lias to Late Dogger, a period of some 20 Million Years, is composed of formations that range from deep-water submarine environment to subaerial fluvial environment. The main objective of this study is the characterization of the understudied and not exploited deep-water formation named Los Molles.

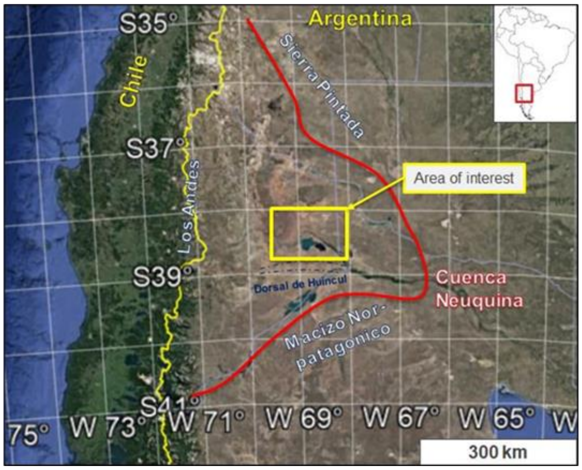

Figure 1: Location of the study area: Neuquén Embayment, onshore Argentina.

Relative Geological Time (RGT) Modelling Method

The signal-driven RGT modelling approach consists of a two-step workflow (Pauget et al, 2009). First, a discrete stratigraphic framework called 'Model-Grid' is computed to convert all the seismic reflections into horizons. Those horizons are stratigraphically sorted, enabling the geoscientist to individually edit and refine as needed. A 3D interpolation of the discrete Model-Grid finally converts each seismic sample into relative geological time and delivers a continuous RGT model (Figure 2).

The RGT model is then used to generate a series of advanced stratigraphic attributes, from which sub-seismic sample stratal slicing can be performed. The Thinning attribute corresponds to the first derivative of the RGT model and emphasizes zones of strata convergence (Figure 3).

Sequence Stratigraphic Modelling, Cuyo Group

Thinning attribute analysis can be combined with a RGT-driven and real-time two-way seismic voxel transformation, enabling the geoscientist to visualize and interpret in both the structural and Wheeler domains. As the RGT model consistently fits the seismic data geometry (structurally and stratigraphically), the RGT-driven Wheeler transform highlights the same hiatuses for both the RGT and seismic reflections. Maxima of Thinning zones can be

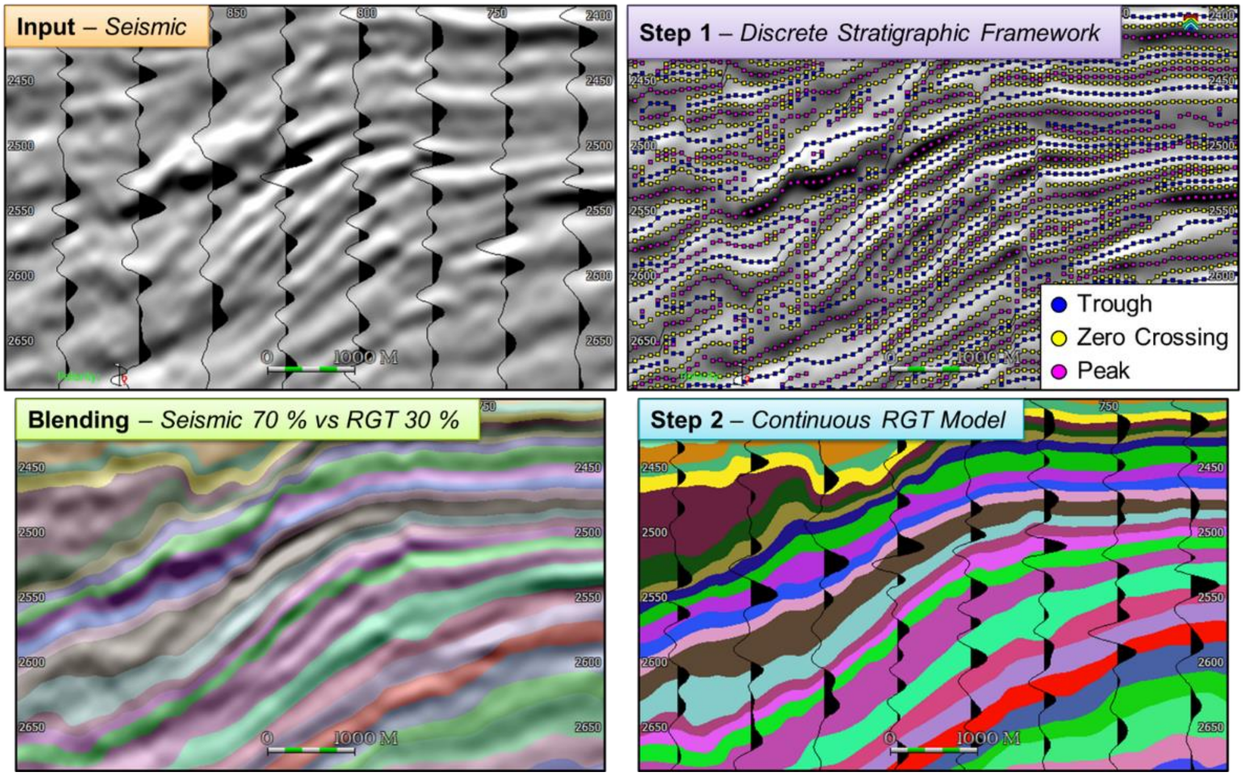

Figure 2: Signal-driven RGT modelling workflow (Pauget et al, 2009).

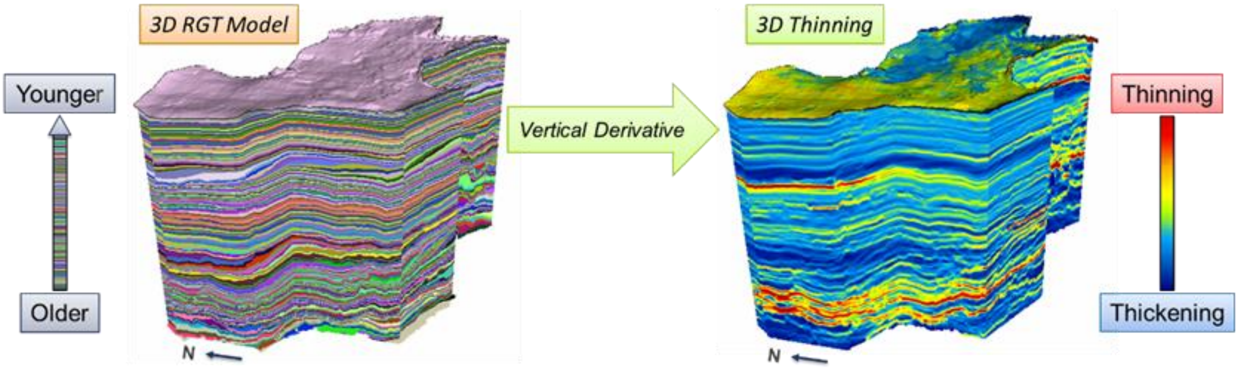

Figure 3: Real time computation of RGT 1st derivative, delivering the Thinning attribute.

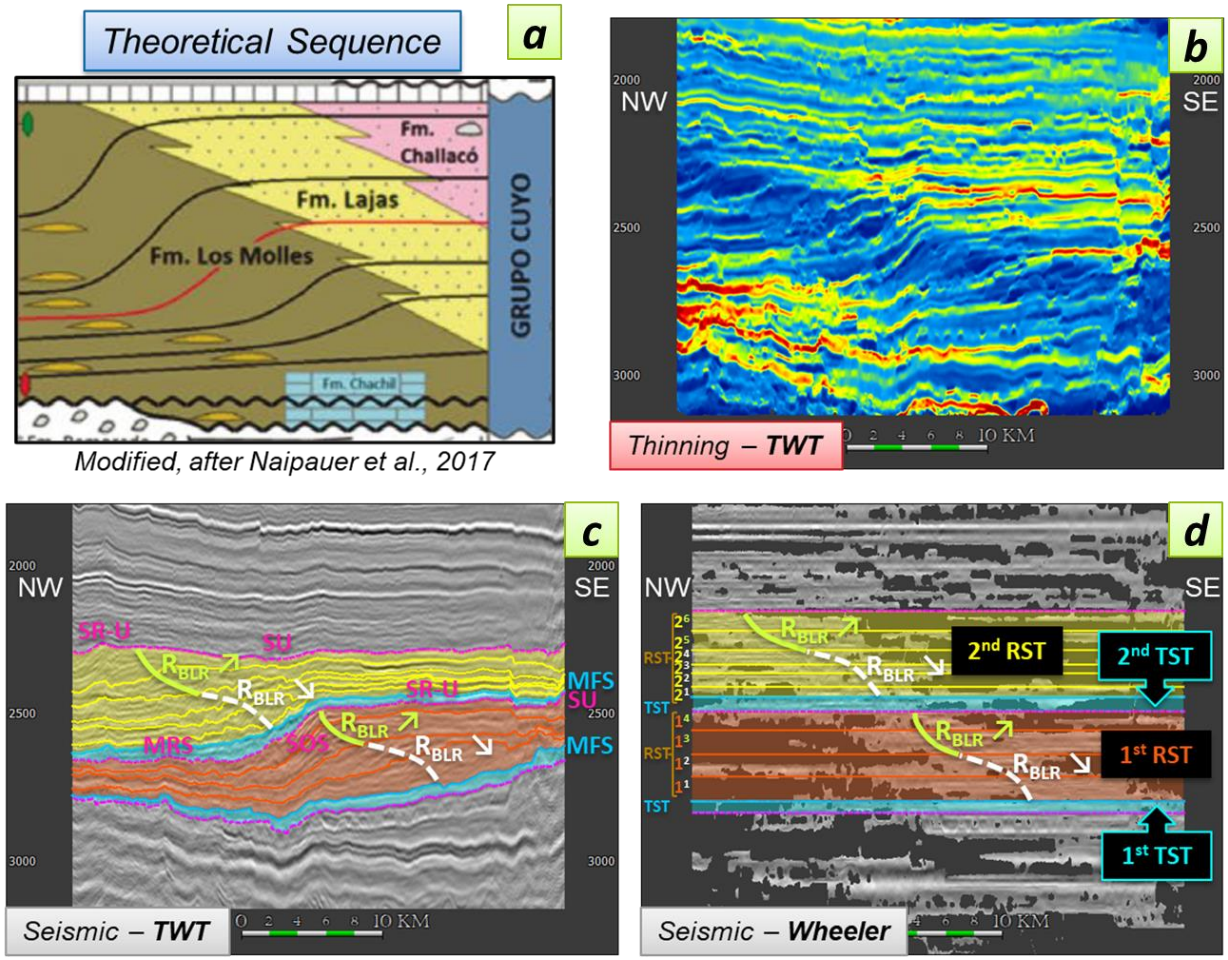

Figure 4: Final Sequence Stratigraphic model of the Cuyo Group. a: Theoretical sequence. b: RGT-derived Thinning attribute. c & d: 3D sequence stratigraphic model based on Ashton Embry's model (i.e. Transgressive-Regressive Depositional Sequence from material-based approach, 2009), composed of two cycles of sea level variations, and displayed in Structural domain (c) and Wheeler domain (d). TST = Transgressive Systems Tract (blue); RST = Regressive Systems Tract (orange and yellow); SU = Subaerial Unconformity; SR-U = Unconformable Shoreline Ravinement; SOS = Slope Onlap Surface; MRS = Maximum Regressive Surface; MFS = Maximum Flooding Surface; R_{BLR} ↘ = speed of initial base level rise rate decreases (dashed white line); R_{BLR} ↗ = speed of initial base level rise rate increases (solid light green line).

correlated to those gaps in the rock record (Figure 4 b & d). Thinning attribute and Wheeler transform emphasize the characterization of stacking patterns and stratigraphic terminations, and therefore ease the accurate delineation of isochronous surfaces, which can be achieved at a sub-seismic sample precision. Clinoform delineation and sequence stratigraphic model building can be performed at different scales of stratigraphic units: large scale depositional sequences and systems tracts, small-scale parasequences, and eventually clinothem stratal slicing. In this study with shelf / slope / basin setting, a Transgressive-Regressive sequence model from Embry (2009) is used to recognize and characterize the boundaries of a material-based depositional sequence (Figure 4 c). Transgressive Systems Tracts (TST) are interpreted on the criterion of a rate of sediment deposition slower than the rate of base-level rise; whereas Regressive Systems Tracts (RST) are interpreted on the criterion of a rate of sediment deposition faster than the base-

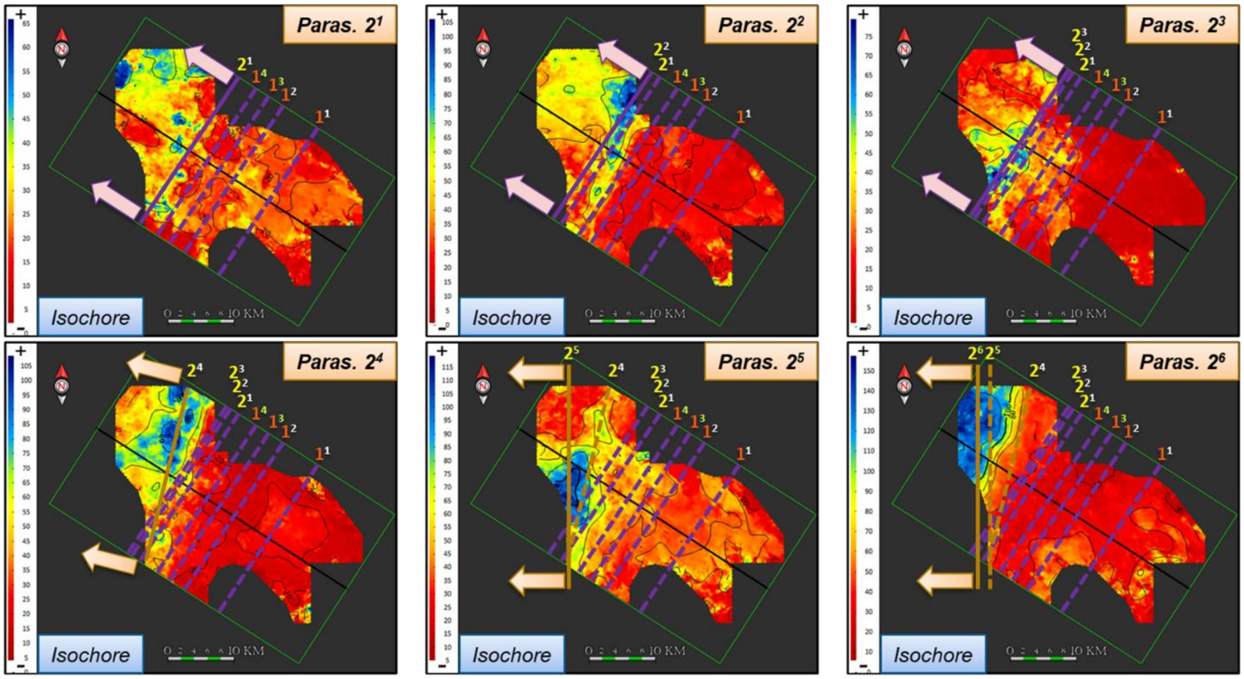

Figure 5: Thickness map (isochore) with axis of maximum deposition for each parasequence of the 2nd Regressive Systems Tract, highlighting the stacking kinematic of Cuyo Group progradational sequence.

level rise, and eventually in a base-level fall configuration.

Two 2nd order cycles of base level variations are identified with a northwestward shift of location of deposition from the base of the first RST to the top of the second one. The stacking pattern of each RST shows an early increasing progradation/aggradation (P/A) ratio and a late decreasing P/A ratio (Figure 4).

The first TST is interpreted as a thin carbonate platform from Pliensbachian stage (Chachil Formation). It is overlain by a first RST that is composed of four parasequences. Parasequences and associated sedimentation, which typically represent changes in the rate of generation of accommodation space during the development of a sea-level cycle, are labelled from 1^1 to 1^4. Parasequences 1^1 and 1^2 show an increasing P/A ratio whereas 1^3 and 1^4 show a decreasing P/A ratio.

The second TST is composed of maximum 3 to 4 reflectors and its recognition is mostly based on the slope onlap depositional pinch-outs. This episode of retrogradation represents a minor sediment deposition rate compared to the previous and the following RST. The Maximum Flooding Surface (MFS) topping the second TST is delineated where the retrogradational stacking pattern changes into a progradational stacking pattern. The second RST is composed of six parasequences, all labelled from 2^1 to 2^6. Parasequences 2^1 to 2^4 show an increasing P/A ratio whereas 2^5 and 2^6 show a decreasing P/A ratio.

The isochore (vertical thickness) is computed for each TST and parasequence, revealing the location of maximum sediment deposition for every clinothem (blue-colored values of the isochore maps). From parasequence 1^1 to 2^3, the progradation has a SE-NW direction (violet-colored foreset axis) whereas parasequence 2^4 has an ESE-WNW direction lately evolving into E-W direction for parasequences 2^5 and 2^6 (brown-colored foreset axis). This 45° counterclockwise rotation of the progradation direction during deposition may highlight changes in the regional tectonic settings, leading to a multi-story, multi-source, multi-directional sedimentary supply and flow (Figure 5).

Based on their scale, geometry, and general depositional setting, clinothems can be classified as shelf-edge scale type, supposed to be contained entirely within the continental shelf, where an intervening slope separates the topset of normal shelf from the bottomset of deeper shelf (Patruno and

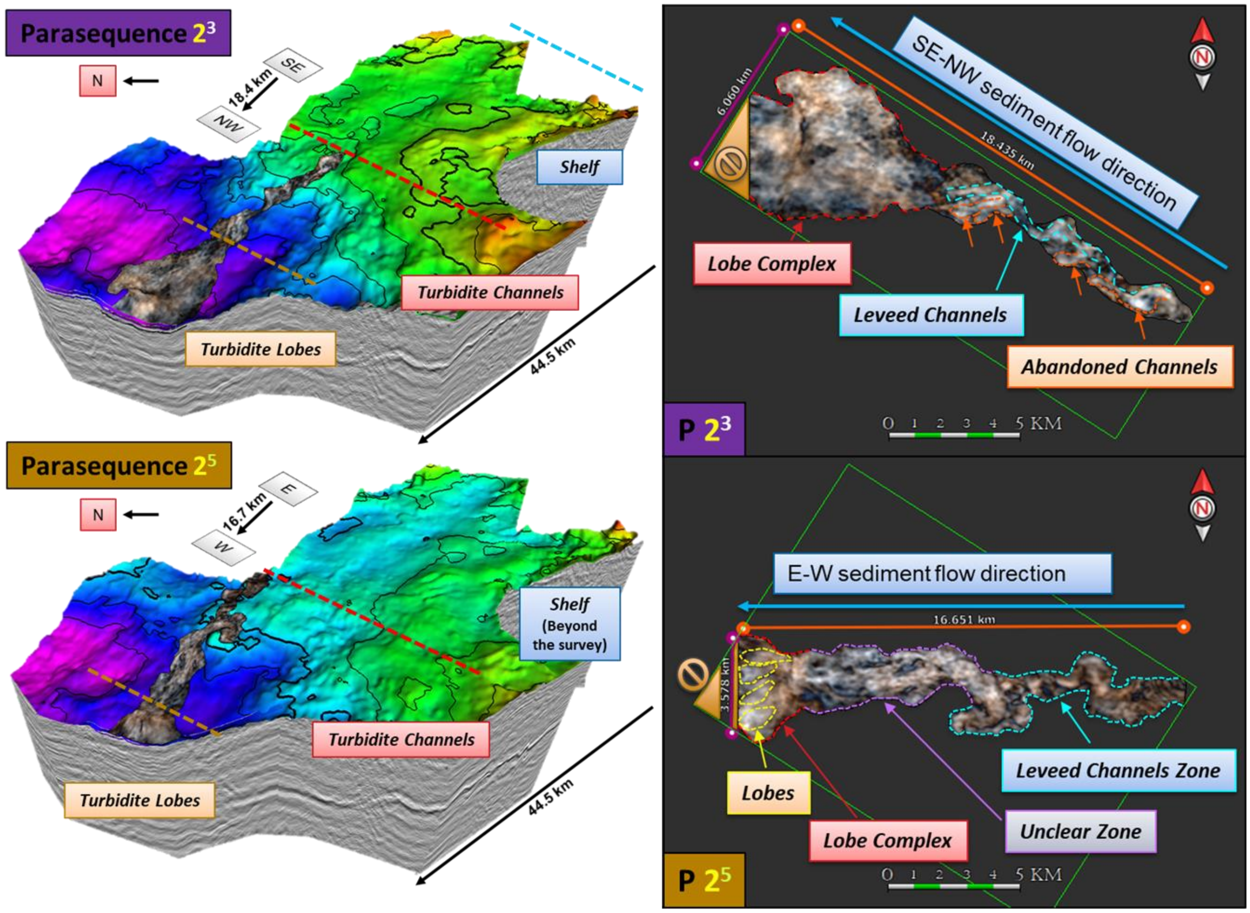

Figure 6: Parasequences 2^3 and 2^5 corresponding to the 2nd and 4th (last) phases of the turbidite system growth kinematic. Left hand side: Key depositional trend surface mapped with topography (i.e. Z-value) and overlayed with RGB-blended magnitude signatures (31Hz, 36Hz, 41Hz) from spectral decomposition. Right hand side: Extraction and description of the revealed morphological elements.

Helland-Hansen, 2018). The observed clinoforms should likely be considered as ‘compound’ because derived from smaller scale merged clinoform elements. Therefore, interpreted parasequences should thus be considered as ‘compound’ too, depending on sediment supply and local sea-level changes. Because the Cuyo Group sequence extends over a period of some 20 Million Years (including condensed sections of TST), those compound parasequences may represent meter-scale to decameter-scale bedsets (thin 3rd to 4th order sequences, each approximately spanning less than 1 Million Year).

Stratal Slicing & Geobody Characterization, Los Molles Formation

Parasequences from the second RST are dynamically stratal-sliced at a sub-sample resolution to reveal subtle seismic expressions related to smaller scale and shorter time span base-level fall-rise cycles. Basic and instantaneous seismic attributes like Root Mean Square and Envelope are used at an early stage to detect sweet spots lately enhanced by a spectral decomposition. A Short-time Fourier transform method is applied with a vertical window of 38 ms. The stratal slices of subsequent magnitude volumes from discrete frequencies (31Hz, 36Hz, 41Hz) are RGB-blended to emphasize a turbidite system in the bottomsets of the second RST. Four growth phases of this turbidite system are identified, with variations in size (length, width, surface area), depocenters location, and subsequent progradation direction. The second and fourth growth phases are here described with several key morphological elements (Figure 6).

Conclusions

This study combines a proven comprehensive method for seismic interpretation (Pauget et al, 2009) with concepts of sequence stratigraphy and deep-water sedimentology. It reveals an unprecedented level of visualization detail from seismic images as applied to a small scale turbidite system (about 25 to 45 km² depending on the stratigraphic level). The development of deep sea fans on the shelf rather than in a basin plain could be explained by the small scale of the Neuquén Basin in comparison with examples from literature used to establish reference models. Such a methodology offers new perspectives and insights in the evaluation of hydrocarbon resource potential in the Neuquén Basin.

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