Introduction

CO2 storage projects are mostly planned for saline aquifers as they are likely much more prevalent than depleted oil and gas fields. Nevertheless, such hydrocarbon fields stay serious candidates due to their proven seal integrity after millions of years of storage. Given that enhanced recovery processes might be required prior to efficiently storing CO2, a high precision basin correlation framework driving reservoir characterization optimizes site evaluation. This study presents a global approach where seismic samples are stratigraphically correlated through an automation-assisted and amplitude-driven process to deliver a structurally consistent stratigraphic framework called the Relative Geological Time 'RGT' model (Pauget et al., 2009) and combined with Machine Learning (ML) techniques. Results from various sedimentary basins illustrate the consistency of this combined RGT-ML approach for subsurface modeling and characterization in a broad range of tectono-stratigraphic settings.

Method

The RGT modeling workflow (Figure 1) consists of two key steps that can be constrained beforehand by previously interpreted horizons and by an ML-assisted extraction of fault surfaces and intrusive bodies. First, a supervised cost minimization function automatically converts all the seismic reflections into horizons, stratigraphically sorts them, and delivers a discrete stratigraphic framework called 'Model-Grid'. The geoscientist can edit that framework and build different deposition scenarios. Then, a 3D interpolation of the discrete Model-Grid converts each seismic sample into RGT information and delivers a continuous sequence stratigraphic framework. The RGT model is then used to generate Wheeler-transformed seismic sections, sub-seismic sample stratal slices, advanced stratigraphic and structural attributes, waveform-based facies classes, optimized spectral decomposition, and drive quantitative interpretation workflows.

Examples

Results from onshore, offshore and analogue-based synthetic seismic datasets (courtesy of YPF, PAE, ANP, NZPAM, TNO, USGS and SeisMomentum Limited) are gathered in a catalogue format. Various scales and stratigraphic orders are described for siliciclastic depositional sequences, from thick units with stacked turbidite channels (Taranaki basin, Mount Messenger Formation, oil and gas reservoirs), to short time span progradational mesothems (Neuquén basin, low-amplitude deepwater system from Los Molles Formation, both conventional and unconventional gas reservoirs) and faulted, pre-salt retrogradational cyclothems (Northern Europe Carboniferous basin, thin aeolian beds from Upper Rotliegend Group, gas reservoirs).

Low-resolution fluvial channels (San Jorge Gulf Basin, Castillo Formation, oil reservoirs) are described within a regional anticline that hosts a complex network of normal and reverse faults (Figure 2, top left). The high-resolution RGT-driven stratal slicing enables to compensate for the weak amplitude anomalies (Figure 2, top right: yellow contour) and to detect leads despite the low contrasts. RGB-blended magnitudes from spectral decomposition ultimately spotlight meandering fairways (Figure 2, bottom right: green contour) and emphasize initially blind zones (Figure 2, top right: red contour). Geobody elements are interpreted accordingly and matched with a depth map for post-geokinematic topography and facies distribution analysis (Figure 2, bottom left).

The RGT-driven halokinetic sequence characterization technique is applied on salt-controlled mini-basins (Brazilian salt basins, Figure 3). A supervised ML technique (image segmentation) is used for salt body extraction, while an unsupervised ML technique (foundation model) is used for fault network imaging and extraction. Geobody waveform classification is carried out using self-organizing maps.

Conclusions

RGT modeling and ML techniques have already been integrated for CO2 storage site evaluation projects in saline aquifers from Southern North Sea (Lower Triassic sandstones, Bunter Formation, SNS Vision project, courtesy of PGS; Reiser et al., 2024) and Northern North Sea (Jurassic sandstones, Johansen

Formation, Northern Lights JV project, courtesy of Equinor, Shell and TotalEnergies; Legeay et al., 2024). Furthermore, this method provides a wide range of tailored workflows to rejuvenate matured and abandoned hydrocarbon fields by characterizing reservoirs, traps, seals and migration pathways. The RGT-driven stratigraphic framework and ML-derived objects stand as high-precision constraints for CO_2 injection simulation workflows, making this approach fully suitable for green field exploration and experimental analogue modeling when production or real-world seismic data are missing.

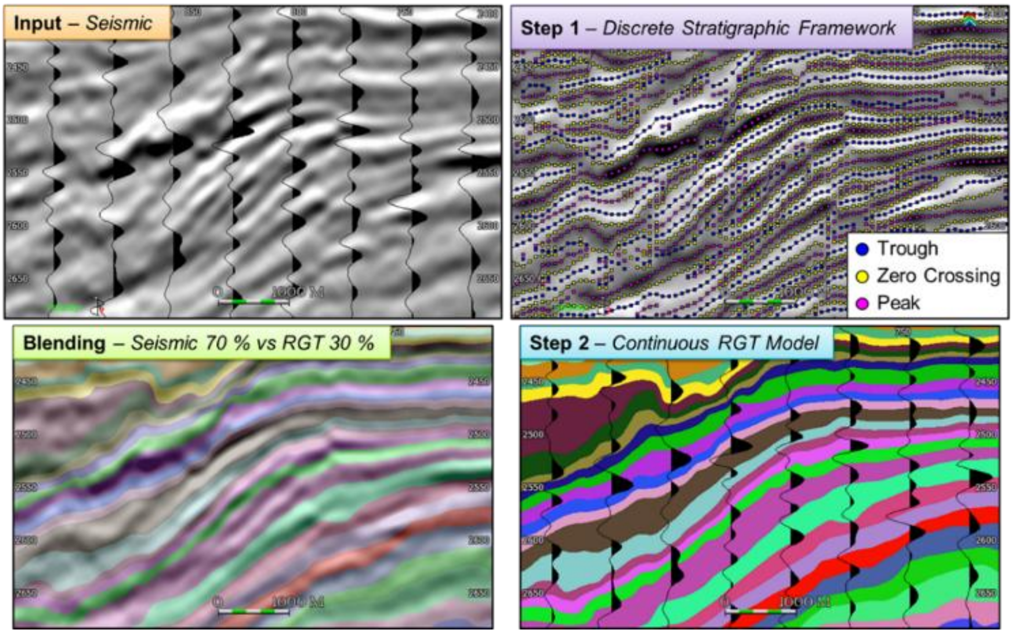

Figure 1 *RGT modelling workflow. Middle Jurassic Cuyo Group, Neuquén Basin, onshore Argentina, data courtesy of YPF.*

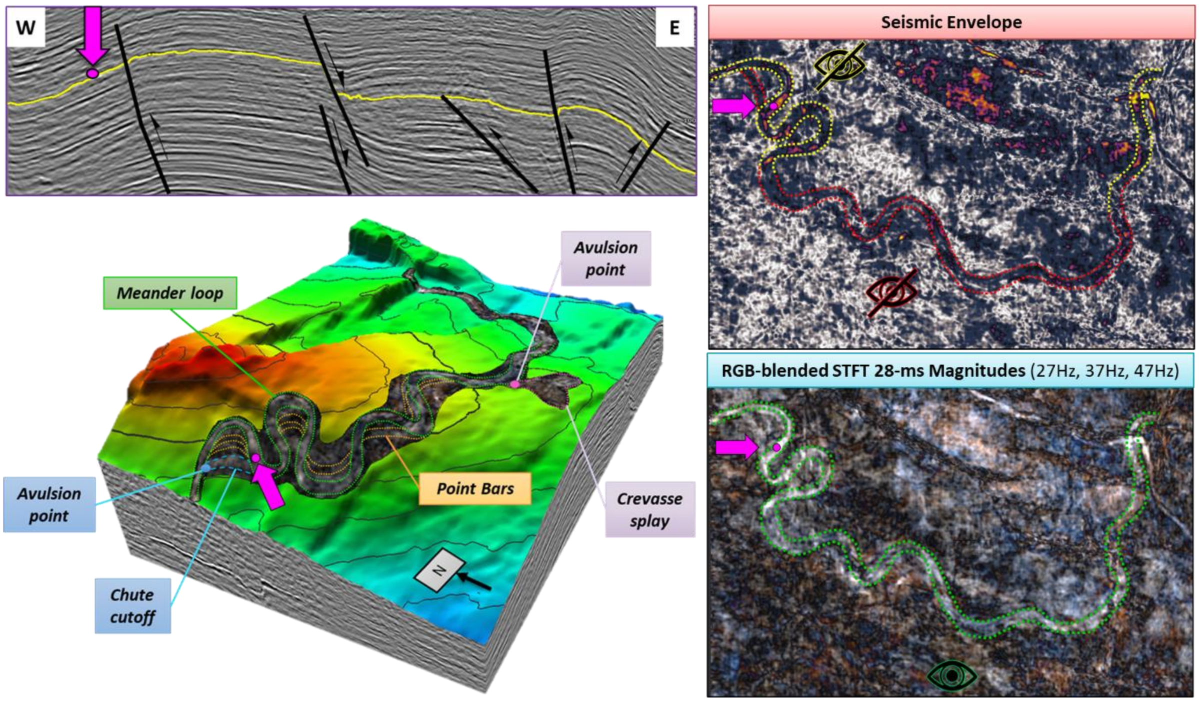

Figure 2 *Imaging and interpretation of a low-resolution, fluvial, meandering system, not visible in vertical section and without the combination of high-resolution, signal-driven stratal slicing and*

spectral decomposition. Cretaceous Chubut Group, Albian Castillo Formation, Western San Jorge Gulf Basin, onshore Argentina, data courtesy of Pan American Energy.

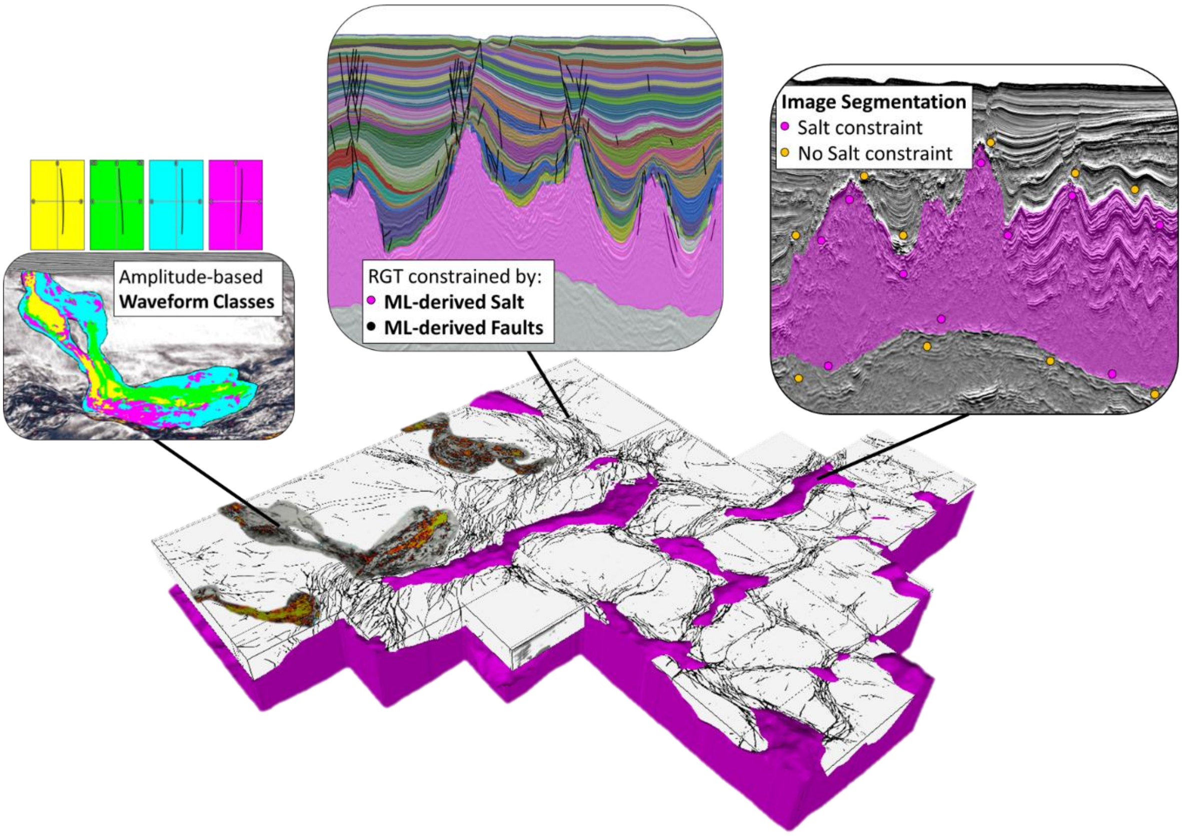

Figure 3 *Application of Machine Learning techniques for salt bodies and fault surfaces extraction, and for turbidite seismic facies classification. Late Lower Cretaceous, Búzios Province, Santos Basin, offshore Brazil, data courtesy of ANP.*

Acknowledgements

The author thanks YPF, Pan American Energy (PAE), New Zealand Petroleum and Minerals (NZPAM), TNO (Dutch Organization for Applied Scientific Research), the Brazilian National Agency for Petroleum, Natural Gas and Biofuels (ANP), the United States Geological Survey (USGS) and SeisMomentum Limited for the authorization to publish the data and results from their datasets.

References

Legeay E., Vinchon, M., Fritz, L., and Adam, J.-P., 2024. Detailed Geological Characterization of the Aurora CO2 Storage Site, Northern North Sea. Fifth EAGE Global Energy Transition Conference & Exhibition (GET 2024), November 2024, Volume 2024, p. 1-5, Rotterdam, Netherlands.

Pauget, F., Lacaze, S., Valding, T., 2009. A global approach to seismic interpretation based on cost function minimization. SEG Annual meeting, pp. 2592-2596, Houston, USA.

Reiser, C., Ruiz, R., Rumyantsev, D., Mueller, E., Legeay, E., Adam, J.-P., 2024. CCS assessment and Near field exploration: a UK Southern North Sea dual-purpose reprocessing case study. 85th EAGE Annual Conference & Exhibition, June 2024, Volume 2024, p. 1-5, Oslo, Norway.