Creation of a stratigraphical consistent seismic profile for machine learning

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Summary

Detail seismic stratigraphic analysis is a time-consuming process that tends to be done post-structural interpretation. Fortunately, these methods are based predominately on pattern recognition, meaning that a machine learning solution should help give an initial stratigraphic analysis before a more detailed interpretation. This talk focuses on creating synthetic stratigraphically consistent seismic profiles for the training data for a machine learning stratigraphic analysis.

Theory

Stratigraphic interpretation (Mitchum, 1977; Vail, 1977, 1984 & 1987; Posamentier, 2022) is a well-established principle of seismic interpretation and involves analyzing reflector waveforms and termination geometries (figure 1). The application of machine learning should enable moving stratigraphic and facies analysis earlier in an evaluation to prevent preconceived geological notions from contaminating a study and prevent subtle items from being missed or misinterpreted.

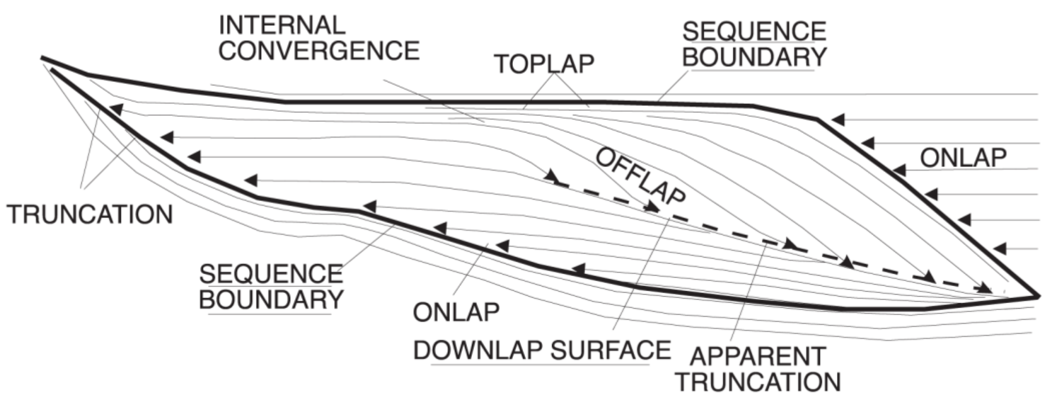

Figure 1: Reflection Termination Patterns, from wiki.aapg.org, adapted from Vail 1987

The principles used to create the detailed models follow the process set out in Plint and Nummedal (2000), which uses a default base-level profile and a fixed sedimentary volume for each layer or cycle. Unlike the Plint-Nummedal model, instead of incrementing only over 21 cycles), a much higher layer count (>500) was used to create the depositional profiles.

Accommodation space in the models was created assuming a smooth lithospheric tilting coupled with tectonic faulting. Eustacy variation is used to generate the sequence of stratigraphic surfaces. The average thickness for each layer is between 1-2 meters, resulting in over 1000+ isopach layers per profile. At least 200 layers are created for each second-order eustacy cycle with embedded third and fourth-order cycles. Fifth-order parasequences are applied as part of the petrophysical filling of the bed layers. The geological profile is expected to exceed seismic resolution, which is nominally restricted to third-order cycles but provides the detail for wavelet distortion caused by the thinner higher order cycles.

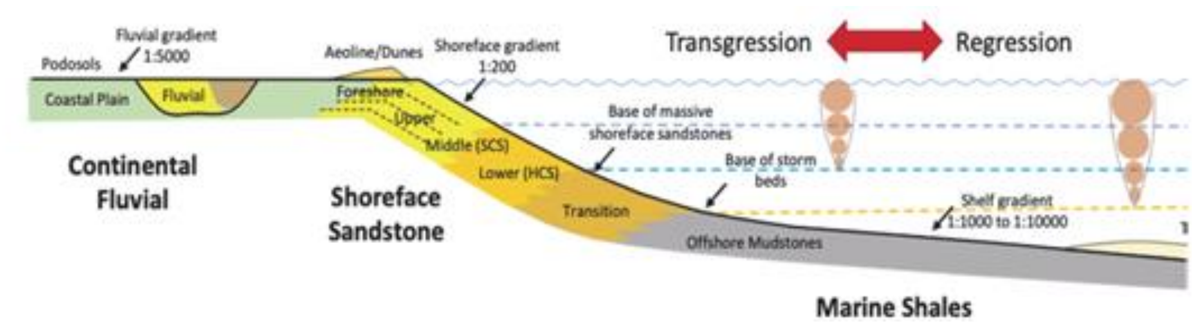

Figure 2: Sequence stratigraphy concepts incorporated into the models, after Plint 2000

The depositional profile (figure 2) is a modification of Plint (2000), with the coastal plain and foreshore sediment representing a percentage of the sediment supply (default 35%). The resulting eustacy changes cause either regression or transgression of the shoreline, resulting in any associated fluvial erosion and the depositional style into the offshore. The existing code is only 2-D, with the degree of fluvial erosion being set from 0 to 100% for each base-level profile (default 10-50%). Any additional volumes created by fluvial erosion are added to the sediment supply to the profile.

Shoreface erosion down to tidal, fair and storm weather base is applied during the initial estimation of shoreline location. Any sediment eroded is only applied after the progradation of the shoreline as either a dune or offshore turbidite deposit. The shoreline progresses from its initial location until the default coastal plain percentage is reached. Progradation of the coastline can result in two conditions: as standard sediment deposition onto a continental shelf and a second case, which typically occurs during a lowstand or falling stage deposition where the shoreline has prograde to the slope break. Deposition during the second case is dominated by turbidites deposited into the offshore.

Reworking of the offshore sediments after progradation is dependent on the resulting gradient, with slope failure occurring when a stability grade is exceeded (default 5%), creating a gravity slump deposit, or by rip tide current when the grade becomes less than 1:10,000 in which case the offshore eroded sediment is just added to the more distally offshore profile. Deposition of the offshore profile is a combination of suspended sedimentation, which is deposited as a wedge to the model edge, and slope sediments deposited from the shoreline into the model. The model's accommodation space commonly exceeds the amount of sediment supplied for creating the 1:10,000 default offshore profile, with the program modifying the grade upward to 1:1000.

Deposition of the turbidite deposits occurs following the establishment of the slope profile, and at present, this sediment are deposited as a mound onto the depositional flat either in the continental slope or into the flat beyond the slope edge. Future work in the 3D implication of the code is hoping to model the feeder channels, evolution and terminal lobe structures.

Sediment compaction is the final stage before the next depositional cycle, where the isopach is reduced as a function of facies to create a base profile for erosion and deposition of the next layer.

The creation of synthetic seismic profiles and angle gathers is presently done using the Aki & Richards (1980) formula for Rpp and Rss reflectivity and for Rps from Stewart (1987). The resulting reflectivity profiles are then convolved with various Ormsby and Ricker wavelets. The code produces migrated Ipp section, 4 offset gathers (6, 16, 26, 36 degrees), Iss and Ips stacks (30 degrees).

Results

The synthetic seismic for the 1000 high-layer geological model (figure 3 & 4) effectively reduces the profile into a sparse sequence of around 40 strong reflections (figure 5). More subtle geological features are challenging to resolve because of the limitation of the seismic resolution, the presence of sidelobes from the more significant reflection, or simply from the lack of impedance contrast.

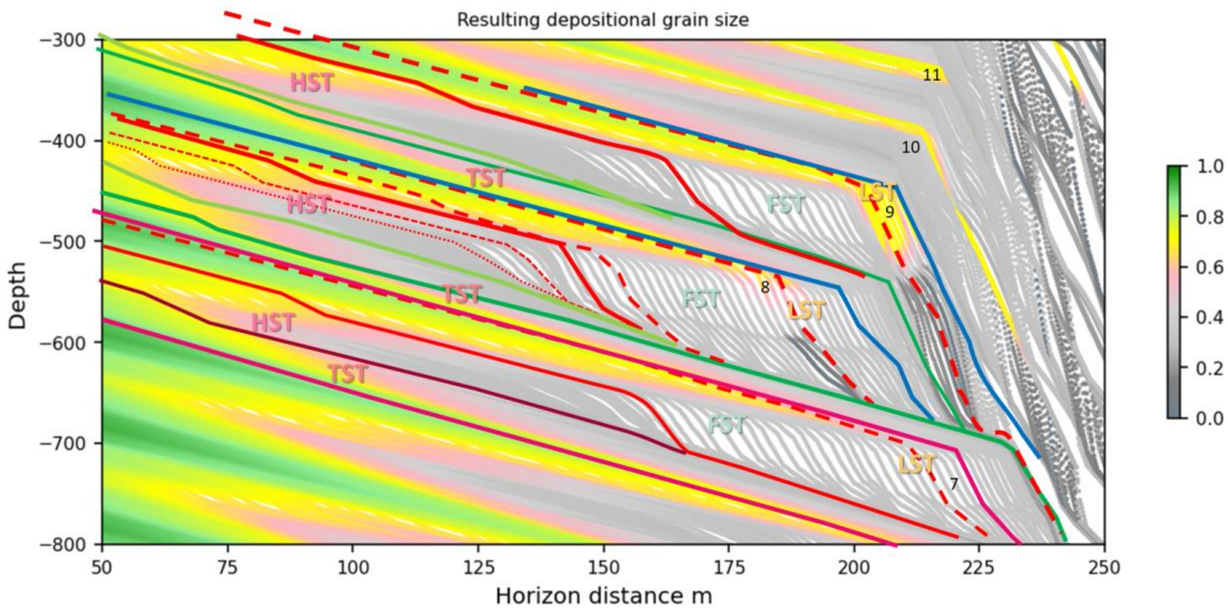

Figure 3: Stratigraphic surface created coloured by input sediment fraction

Conclusions

The advent of machine learning techniques provides a process to accelerate multi-volume interpretation and reduce the time required for a mixture of interpretation methods. Bringing stratigraphic and facies analysis to the start of a geophysical interpretation should enable a professional to concentrate on the critical features of a seismic volume. The ability to model many thin geological layers and convert them into seismic has been demonstrated. Creating synthetic seismic data for learning data that preserves the subtle seismic variation will likely provide the details required to develop a stratigraphy analysis using machine learning.

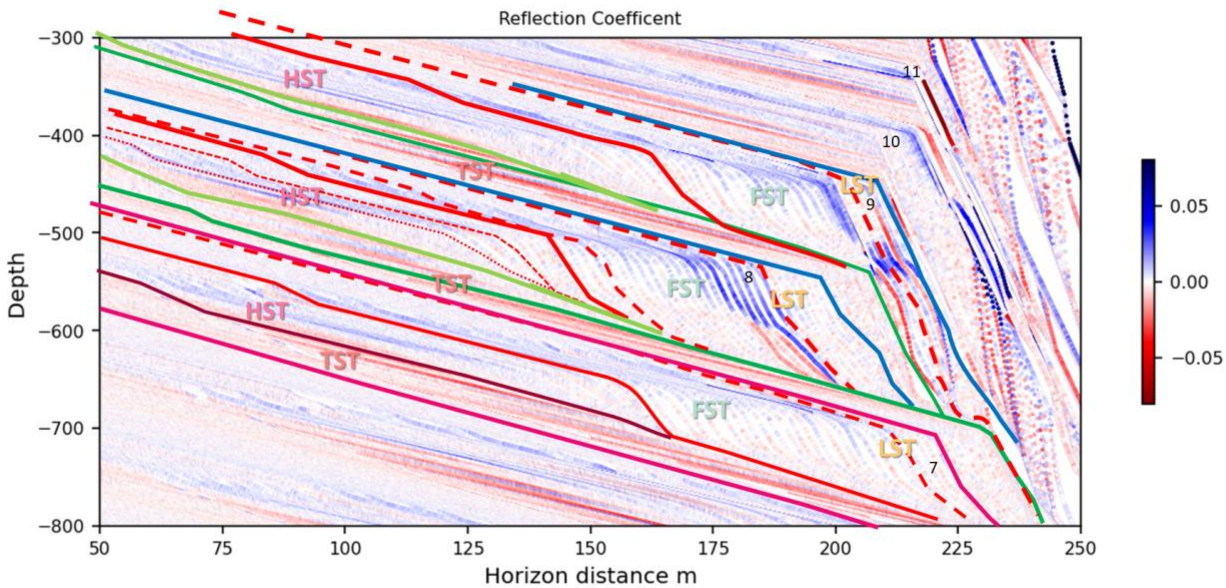

Figure 4: Reflection coefficients for geological model

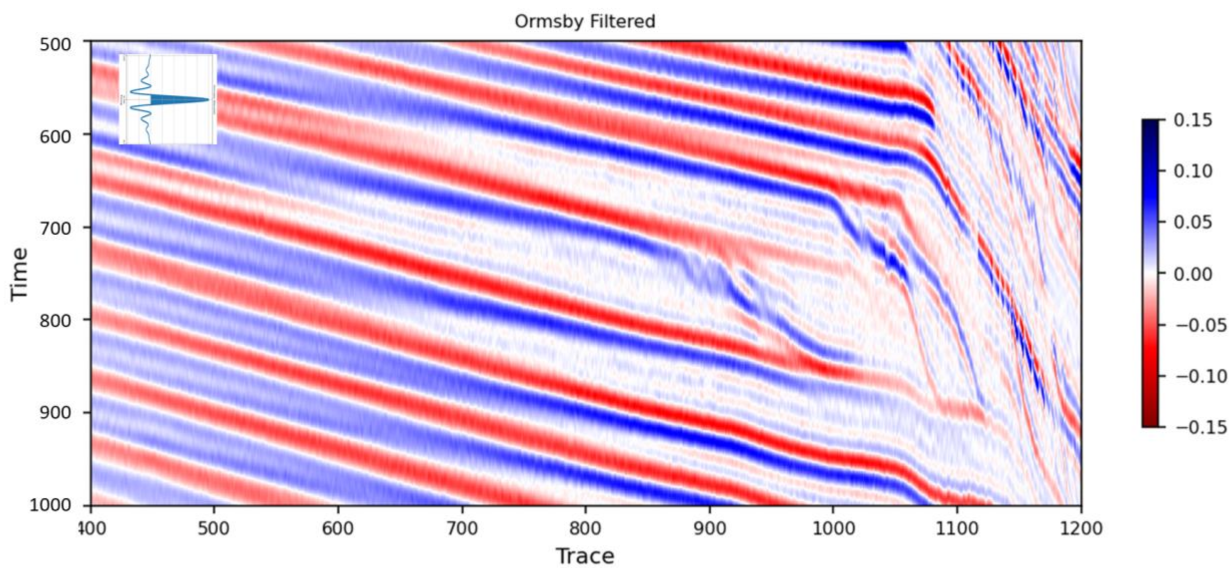

Figure 5: Seismic profile after convolution with a 5-20-60-90 Ormsby wavelet

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