Multi-Scale Sequence Stratigraphy Extending Well-Analyses to 3D Seismic.

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Introduction

It is well known and proven that interpreting a dataset following sequence stratigraphic principles may unlock potential more than conventional lithostratigraphic interpretation. However, experience shows that a proper 3D interpretation usually takes a considerable amount of time and often risks to polarization toward either well or seismic control, depending on the dataset quality and expertise of the interpreters.

We present a workflow that can be implemented in a reduced time, relying on a quick yet robust semi-automated seismic interpretation. The approach starts from a well-based sequence stratigraphic interpretation that is then transferred to the seismic to be extended in 3D domain and finally re-calibrated to the well information, thus balancing the contribution from the two inputs.

Methodology

The target formation, dominated by deep-water depositional systems, was studied using sequence stratigraphic principles (Catuneanu, 2006). The stacking patterns were classified using 17 wells, which allowed the identification of the stacked 4th order cycles and associated systems tracts. The deep-water depositional environment is characterized by four distinct systems tracts: Highstand Normal Regression (HNR), Forced Regression (FR), Lowstand Normal Regression (LNR) and Transgression (T). The regional stratigraphic boundaries for each identified systems tract were defined at well resolution. These surfaces consist of Correlative Conformities (CC and BSFR, Basal Surface of Forced Regression), Maximum Regressive Surface (MRS) and Maximum Flooding Surface (MFS). The well-based sequence stratigraphy was extended to 3D seismic data to understand the depositional architecture. The approach helped in revealing the spatial distribution and thickness variations within the systems tracts. Depositional features within the systems tracts were highlighted by seismic attributes. Several steps were performed prior to seismic interpretation, including:

- *Data Enhancement:* Vertical resolution was enhanced through spectral bluing and the application of structurally-oriented smoothing through industry-standard dip steered median filtering (Blache-Fraser and Neep, 2004; Qayyum et al., 2010).
- *Dip Estimation:* Dips were estimated using the enhanced seismic data. The very local erroneous dips were locally filtered by the application of a conditional dip filter without changing the reflector's dips.
- *Extending Stratigraphic Boundaries*: The stratigraphic boundaries based on the well markers were extended by taking the well marker positions and extending the results through the inversion technique (Wu and Hale, 2013). These boundaries formed the framework for full volume inversion to produce n-horizons (de Groot et al., 2010).
- *3D HorizonCube Processing:* The HorizonCube was iteratively solved by inverting the seismic dips. Contrary to the approach of Wu and Hale (2015), assuming zero shifts where horizons do not exist, this work started with an initial guess (a volume) that was fully filled with time shifts required to perform inversion. This approach approximated to proportional/stratal slicing. It also globally honoured the time shifts based on framework horizons at faults, such that they were linearly adjusted according to the fault jump. Boundary conditions were also set such that the time shifts were minimal. During each iteration, the horizons (solution) were updated to solve a system of linear equations ($Ax = b$). In each iteration, a solution was

estimated and checked against the given seismic dips to compute the residual. The final solution was achieved when the residual was small or changes in residual were negligible.

Interpretation

1 – Well-based interpretation

To proceed with the interpretation, the reservoir likelihood of each systems tract was considered (Figure 1).

- The HNR deposits are mainly composed of pelagic claystones and locally very thin sandy intervals.
- The FR deposits tend to form the bulk of the submarine fan complex (Catuneanu, et al. 2011). The deposition FR starts with muddy facies of mudflow. As forced regression continues and coastlines prograde closer to the shelf edge, sand becomes available in the staging areas, giving rise to high-density turbidites during late stages of relative sea-level fall when the large amount of terrigenous sediment is delivered to the deep water system. The episodic turbidity currents, catastrophic collapse of shelf-edge deltas during stages of late forced regression may give rise to sandy debris flows that consist of large accumulations of massive sand (Catuneanu, 2006).
- The dominant type of gravity flow that carries sediment into the deep-water setting changes from the high-density turbidity currents of Late Forced Regression (LFR) to low-density turbidity flows or the early Lowstand Normal Regression (LNR).
- During the Transgression (T) there is a rapid generation of accommodation (Catuneanu, et al. 2011). The sand sediment supply decreases during this cycle and sedimentation from suspension becomes the dominant process at the time of the Maximum Flooding Surface (MFS).

Therefore, the interest was focussed in finding the areal distribution of FR and LNR. FR deposits are bounded by two surfaces: the BSFR and the CC, which overlies the upper portion of the FR system that contains the coarsest sediment, commonly associated with the occurrence of best reservoirs quality sands. The top of LNR is defined as a MRS.

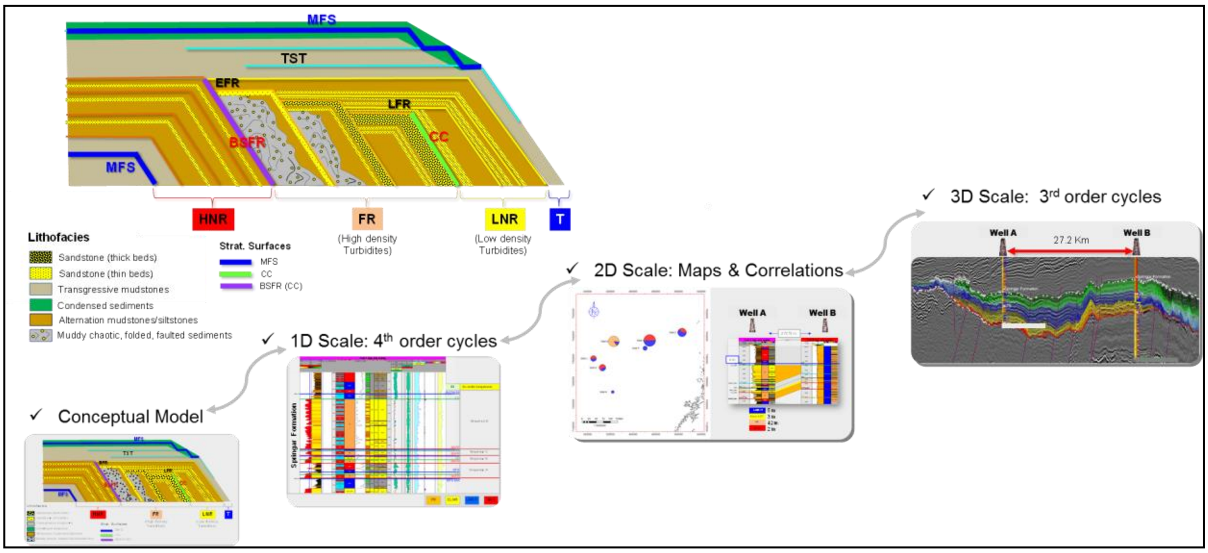

***Figure 1** Above: the conceptual model for systems tracts applied in the study. Below: the workflow to up-scale from well-based 1D interpretation to 3D seismic constrained interpretation.*

2- Integration with 3D Results

Well-based interpretation was extended in 3D making use of the HorizonCube. The 4th order cycles were up-scaled to 3rd order, and the associated regional stratigraphic surfaces (CC, BSFR, MRS, and MFS) were assigned to specific horizons in the Horizon Cube (Figure 1). The systems tracts were defined between main regional stratigraphic surfaces (Figure 2) and their spatial distribution and time-thickness were generated and plotted into maps (Figure 3). Within this process, the carefully processed HorizonCube constituted the key tool to deliver a seismically driven 3D stratigraphic interpretation model with a quick and robust approach. In addition to thickness maps, HorizonCube was used to slice through seismic attributes (notably spectral decomposition, Figure 4) to reveal depositional features within reservoir prone systems tracts.

Discussion

Extension of well knowledge to seismic data has always been challenging. With the approach presented in this study the high-resolution data could be confidently extended to the seismic data to gain better 3D understanding of the depositional system. Though the workflow was done for an exploration scale study, it could also be extended to field development, where the well knowledge is greater, to produce better data-driven maps. Considering this, the workflow has a broader application for integrated studies at various scales.

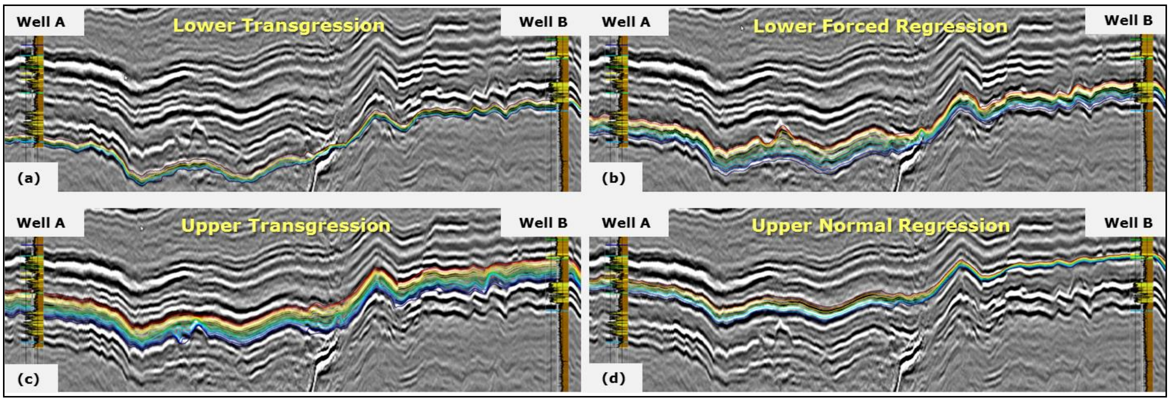

Figure 2 *A seismic section through Well A and Well B with an overlay of HorizonCube events: (a) lower interval dominated by marine transgression; (b) intermediate interval dominated by forced regressive systems; (c) a thick marine transgression sealing the underlying regressive sands; (d) A younger normal regressive system.*

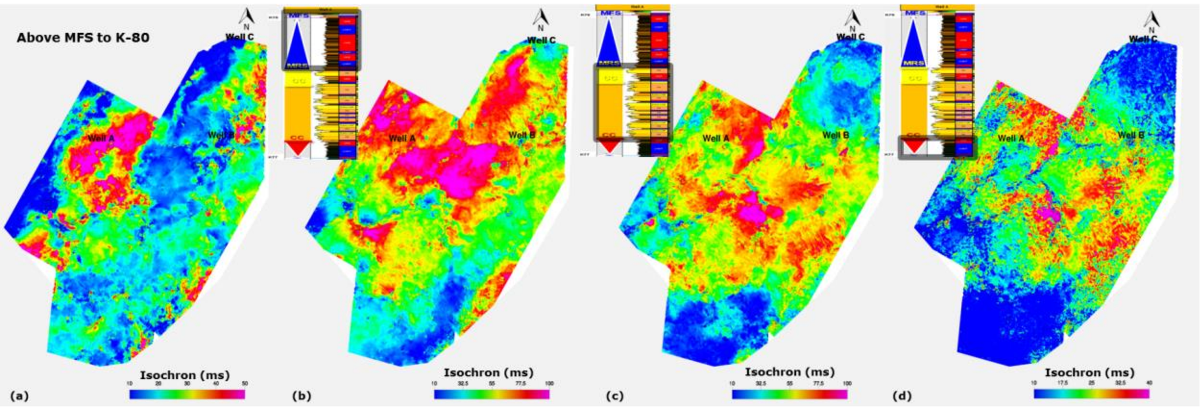

Figure 3 *Thickness maps created from selected HorizonCube events: (a) MFS-K78 to K-80; (b) top MRS to MFS-K78; (c) BSFR (CC) to top MRS; (d) CC to BSFR.*

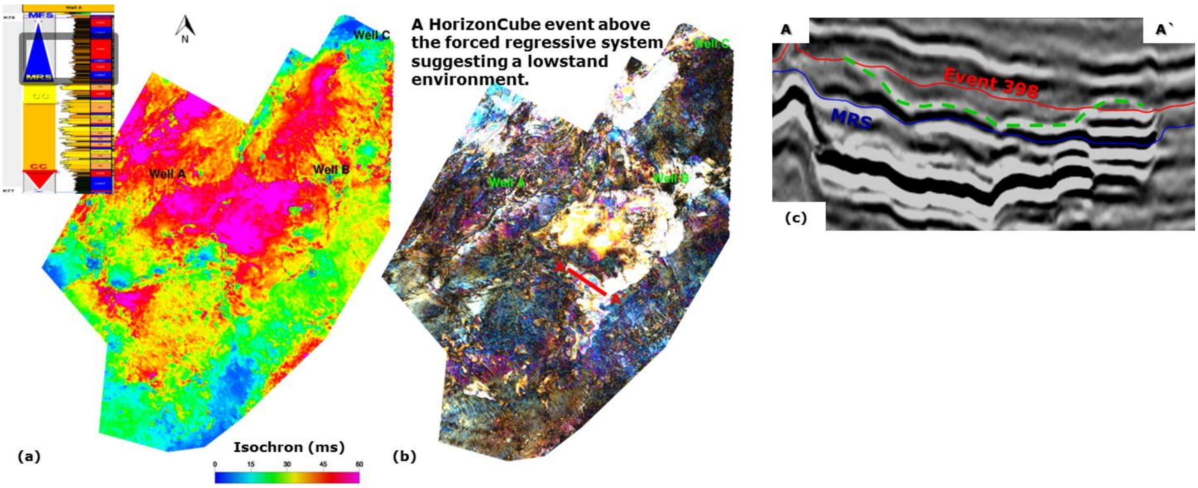

Figure 4 *A seismic interpretation of a possible lowstand lying between the zone defined by MRS and MFS well markers. The isochron map (a) is prepared between a specific HorizonCube event to the defined MRS. The colour-blended spectral decomposition map (b) is defined with a time gate of [-8,40]ms along the HorizonCube event to focus on the underlying seismic response. The section view shows a broad channel system within this interval that shows sinuosity on the spectral decomposition map.*

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