

E017

## Building a Sequence Stratigraphic Framework from HorizonCube and Well Data

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### SUMMARY

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To build an accurate subsurface sequence stratigraphic framework, an interpreter ideally needs to correlate all seismic events with available well data. Without a (semi-)automated correlation approach, such a workflow is not feasible. In this article, we present a workflow that integrates seismic data and well data through a HorizonCube, a dense set of auto-tracked seismic events. The mapped events are simultaneously analysed in the relative geologic time (Wheeler) domain and in the structural domain. Among others, HorizonCube derived attributes are extracted to help analyse relative changes in sedimentation rate, base level variations, depositional trends and geomorphologic patterns. All extracted information is collectively interpreted and calibrated to well data. The workflow is illustrated in two subsurface case studies representing a fluvio-deltaic and a mixed siliciclastic-carbonate settings.

## Introduction

In standard seismic interpretation workflows, a coarse 3D structural or sequence stratigraphic model of the sub-surface is constructed from a limited set of mapped horizons. The number is limited because mapping horizons with conventional auto-trackers, based on tracking amplitudes and similarities, is a time-consuming business. In particular, mapping unconformities or primary targets in sequence stratigraphic interpretations is cumbersome with conventional trackers as amplitudes tend to change laterally along unconformable surfaces. The method described in this article maximizes the amount of information that can be extracted from seismic data by significantly increasing the number of mapped horizons.

The auto-tracker used in the examples tracks the dip-field. This has a number of distinct advantages over tracking amplitudes and similarities. Firstly, the dip field is a continuous field. Even if amplitudes vary laterally, the dip continues. Secondly, the dip field can be smoothed before applying the tracker, which enables the controlling of the detail that needs to be captured. The auto-tracker is applied to a target interval and generates hundreds of horizons that are separated on average by a sampling rate. The result is called HorizonCube. In this paper the HorizonCube approach is used to build a detailed sequence stratigraphic framework and to understand subsurface depositional trends. The proposed methodology integrates seismic and well data. The sequence stratigraphic interpretation of well data may need to be up-scaled before integration. Up-scaling in this context refers to the order of sequences, which at the seismic scale are of 1<sup>st</sup>, 2<sup>nd</sup> or 3<sup>rd</sup> order sequences.

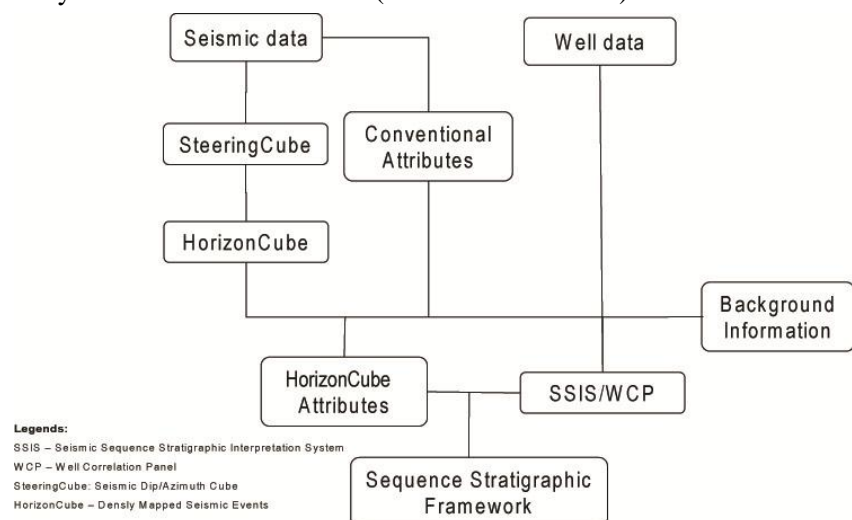
Two case studies are presented to elaborate the workflow. The first study concerns a fluvio-deltaic setting (Overeem 2011). The data is from F03 block in the Dutch sector of the North Sea. The sequence stratigraphic framework is established for 3<sup>rd</sup> order sequences of Pliocene epoch. The second case study describes the construction of a sequence stratigraphic framework covering a mixed siliciclastic-carbonate sequence of upper Jurassic age. The data is from offshore Sable Island in Nova Scotia, Canada.

## Workflow

The workflow is depicted in Figure 1. First, a SteeringCube is computed from the seismic data. It contains local dip/azimuth information at every sample position. Next the dip-steered auto-tracker is applied to track hundreds of horizons in the dip/azimuth field. The auto-tracker is further constrained by conventionally mapped horizons that act as bounding surfaces and by mapped fault planes. The auto-tracked horizons are collectively stored in a HorizonCube (de Groot et al. 2010).

Along the mapped events, numerous seismic attributes are extracted to visualize depositional elements and to help unravel the evolution of deposition over time and space. Two sets of attributes are computed: attributes extracted from seismic data and attributes extracted from HorizonCube. The latter category forms a new set of attributes with great potential for characterising seismic

facies. For example, HorizonCube attributes are: density (number of events per

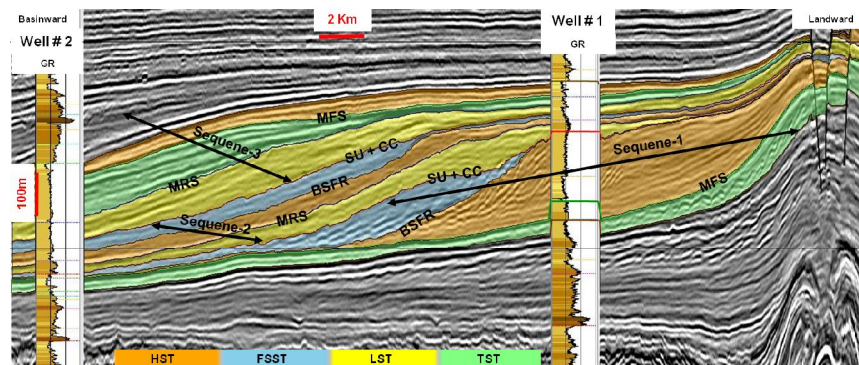


**Figure 1** A workflow to establish a subsurface sequence stratigraphic framework using OpendTect's software tools: HorizonCube, SSIS, and WCP.

defined vertical window), spacing (thickness between events) and systems tracts. Finally, seismic and well data are matched using an interactive software tool that simultaneously displays seismic data, HorizonCube events, system tracts interpretations, well logs and well log interpretations. To avoid correlation problems caused by the differences in resolution, well interpretations may have to be up-scaled to the scale of seismic data prior to matching well and seismic observations.

### Case study: Pliocene siliciclastic shelf (North Sea)

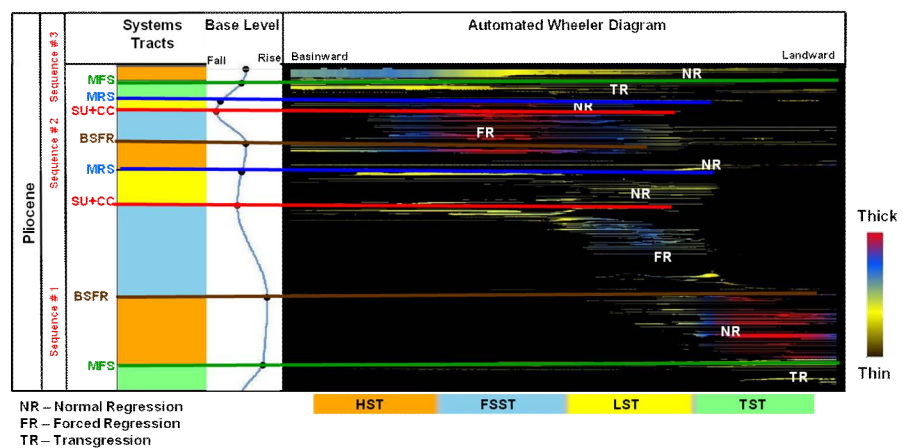
The target interval in F03 consists of a classic siliciclastic succession of 3<sup>rd</sup> order prograding sequences that were deposited during Pliocene epoch. The sequence stratigraphic framework for the interval is established (Figure 2) by correlating the densely mapped seismic events with available well data and biostratigraphic information. The auto-tracked horizons are sub-divided into systems tracts (using Depositional Sequence Model IV). This is done by simultaneous inspection of stacking patterns in the structural domain and the Wheeler (chronostratigraphic-) transformed domain and by calibrating against available well information. The relative base level curve is automatically generated from interpreted systems tracts (Figure 3).



**Figure 2** Well-Seismic correlation and sequence stratigraphic interpretation of the Pliocene interval (Dutch Sector, North Sea). The coloured packages represent systems tracts. Well #1 is projected (~3.4Km) on the section whereas well #2 is located on the section.

Three sequences are identified in the Pliocene interval. The coloured coded attribute displayed in the Wheeler domain

(Figure 3) represents thickness of systems tracts. It is a measure of (preserved) depositional thickness and is used as an indicator for sedimentation rate. Note that the absolute sedimentation rate requires calibration of the HorizonCube to an absolute geologic time using bio-stratigraphic information. The lower sequence # 1 marks an initial deltaic phase with high sedimentation rate during the late normal regression (Highstand system tract - HST). The uplift in the landward direction caused a large scale landward erosion and subsequent fall in base level at the shoreface. This phase has developed a distinct forced regressive wedge that is interpreted as a falling stage system tract (FSST). As a consequence, a highly diachronous composite surface is developed that correlates up-dip to a subaerial unconformity (SU) and downdip with a relative conformable correlative (correlative conformity - CC) surface capping the forced regressive deposits. The composite surface is interpreted as the first sequence boundary (SB) separating the lower sequence # 1 from the upper sequence # 2. Deposition of sequence # 2 started while the base level was slowly rising with a relatively slow sedimentation rate compared to sequence # 1. During the initial stage, normal regressive deposits filled the available accommodation



**Figure 3** Automated Wheeler diagram: A sequence stratigraphic framework constructed by integrating seismic and well data.

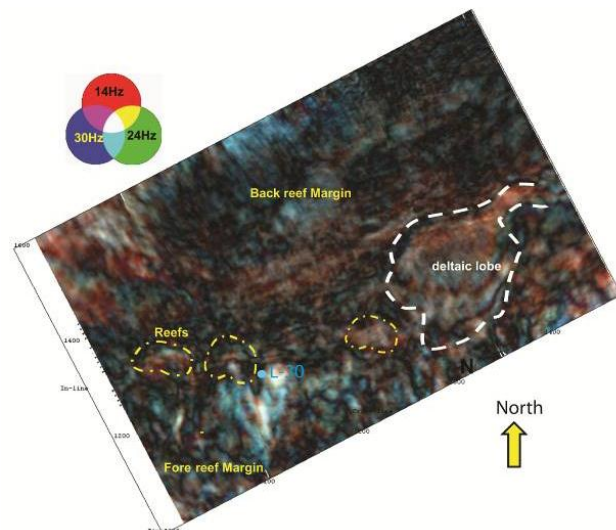
During the initial stage, normal regressive deposits filled the available accommodation

space. The normal regressive deposits developed during this stage are further subdivided into two systems tracts: lowstand system tract (LST) and HST. These systems tracts are separated by a distinct maximum regressive surface (MRS). During the deposition of sequence # 2, the Permian salt was still moving slowly which caused further uplift at the proximal vicinities. Salt movement caused the base level to fall again at the shoreface where another FSST was deposited. The top of the FSST systems tract is interpreted as the second SB marking the end of sequence # 2. The third sequence is more wave-tide dominated than the previous sequence. The initial stage of this sequence is interpreted as a LST. It is followed by a rapid rise in base level (transgression) and deposits featuring large scale wave (and tidal) erosion at the shelf. Parts of the LST deposits were reworked at the shelf-slope settings. This stage is a transgressive systems tract (TST) and is called the healing-phase of the sequence. The end of healing phase is interpreted as a maximum flooding surface (MFS). Above this surface, normal regressive deposits are observed with a relatively low sedimentation rate. This final package is interpreted as HST.

### Case study: Mid-Late Jurassic mixed siliciclastic-carbonate platform (Sable Island, Canada)

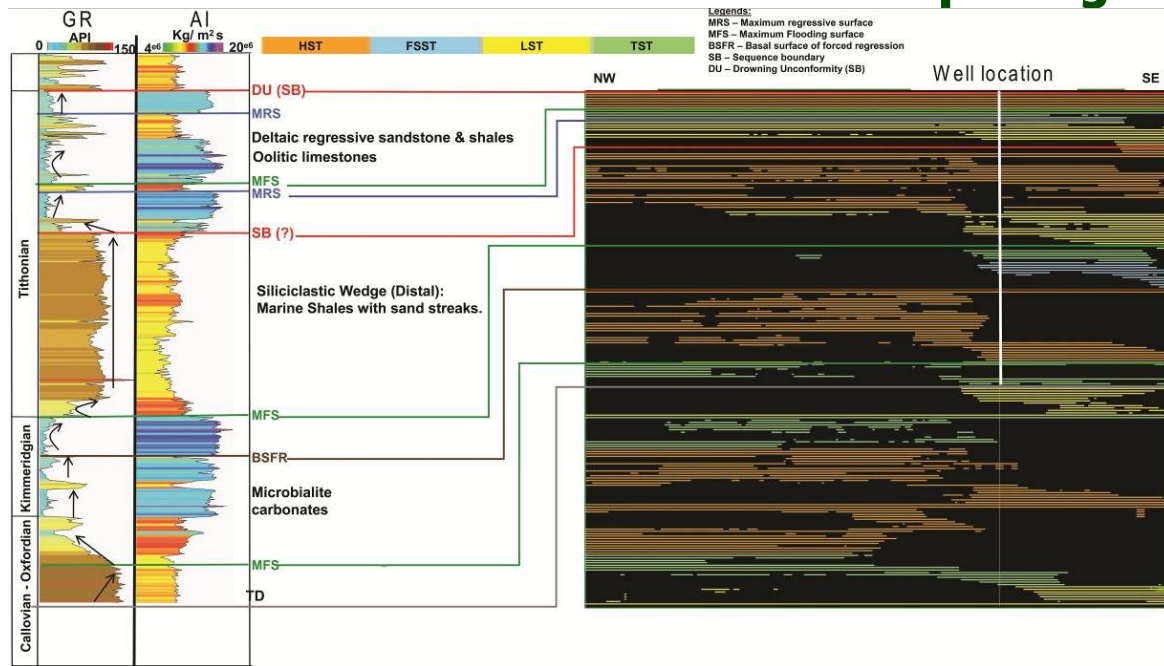
The mid-late Jurassic sequence at Sable Island (Nova Scotia, Canada) is an example of a mixed siliciclastic-carbonate depositional system (Figure 4). The lower sequence is dominated by carbonate build-ups on the initial ramp setting (Kidston et al. 2005). The upper sequence contains contemporaneous shoaling upward carbonate and siliciclastic deltaic deposits (Figure 5).

Figure 5 shows a Wheeler transformed NW-SE trending seismic section. The systems tracts are interpreted from the stacking patterns observed in the structural and Wheeler transformed domains and calibrated to the well information. During the opening of the Atlantic Ocean, the base level started to rise and the basal Misaini sequence started developing on top of an early Jurassic horst structure. The rise in base level continued throughout the basal Abenaki sequence and resulted in a succession of LST, TST and HST. At the end of the basal Abenaki sequence, base level fell and local scale erosional features developed at the top of the platform. A subsequent rise in base level triggered a transgression at the platform (TST) characterised by a thin north-westward back stepping pattern. During the Oxfordian stage, a normal regressive (LST) unit was formed at the toe of platform slope, which was capped by marine shales interpreted as a TST developed at the platform edge. A subsequent rise in base level increased the accommodation space basinward and created a relatively shallow water environment at the inner platform. Shallow water carbonates were produced at the platform while deep water (wackstones and microbialites) carbonates were developed at the slope margin. Carbonate production kept on building upwards whilst simultaneously prograding landward (HST) because of low accommodation space. During the mid-late Kimmeridgian stage, the platform was attached to the main land. At the same time, the Sable delta system reached the platform location and filled the slope and basal parts with fine siliciclastic deposits including marl. The fall in fluvial base level partially incised the north-eastern parts of the platform edge (see deltaic lobe in Figure 4). This forced regression deposited a thin sandy unit (FSST) just above the early Kimmeridgian HST. The base level started rising slowly again as siliciclastic LST deposits filled the available accommodation space. At the end of this stage the platform was again located in a shallow



**Figure 4** Colour-blended spectral decomposition map at the late Kimmeridgian sequence boundary. The map reveals the base of deltaic lobes (white) towards the northeast whereas in the southwestward direction the base of normal regressive carbonates (yellow) show up. The blue circle is the well location.





**Figure 5** Sequence stratigraphic framework of the late Jurassic Abenaki Sequence (Sable Island, Nova Scotia, Canada). The automated wheeler diagram is constructed from the seismic data and calibrated with the well information. For well location, see **figure 4**.

water environment in which shallow water carbonates were building up. The increase in carbonate production resulted in a landward prograding HST with contemporaneous deep water facies basinward. The later stage of mixed carbonate and siliciclastic deposits is quite complex. During the end of Tithonian stage, the increasing deltaic progradation caused carbonate production. This is marked by a drowning unconformity (DU) at the top of the platform.

## Conclusions

A workflow for building detailed sequence stratigraphic frameworks from seismic and well data was described. The HorizonCube is a prerequisite for such analysis. The dense set of horizons enables Wheeler transformations and systems tracts interpretation. The two case studies showed that the proposed workflow is applicable in fluvio-deltaic and mixed siliciclastic-carbonate settings.

## Acknowledgements

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