AN OLD FAVOURITE

Farrukh Qayyum and Paul de Groot, dGB Earth Sciences, The Netherlands, explore the uses of the Wheeler diagram in seismic interpretation.

There are few better tools for understanding the subsurface than the Wheeler diagram.

Geologists have used the Wheeler diagram, developed in 1958 by Harry Wheeler, for a number of decades as a means of understanding the relation of units of rock in 2D space and time.

The Wheeler diagram generates a time-space relationship, which visualises the geological changes occurring at a particular locality as a function of time. In this way, Wheeler diagrams can help predict reservoir age, systems tracts and areas of prospectivity.

It was in the 1970s that the Wheeler diagram became closely linked to seismic and became one of the key seismic interpretation methodologies for petroleum geologists, when seismic interpreters from Exxon developed the concept of seismic sequence stratigraphy. The aim of seismic sequence stratigraphy is to describe and sub-divide rock units into sedimentary packages by studying seismic reflection patterns.

Today, a significant number of seismic sequence stratigraphers routinely make Wheeler diagrams from manually picked seismic reflection patterns. Although a cumbersome and time consuming process, it is argued that only in the transformed domain is the relationship between space and time and between the deposits fully revealed.

Furthermore, the arrival of new computing techniques has taken this process a step further with it now feasible to apply Wheeler transforms (the equivalent of the Wheeler diagram) onto seismic data sets. The result is that today all seismic interpreters can access and benefit from the advantages of Wheeler diagrams within their seismic interpretation activities.

Wheeler transforms, for example, are today a key element of dGB's own Sequence Stratigraphic Interpretation System (SSIS) which increases geologist insight into the depositional history of sedimentary packages, improves seismic facies and lithofacies predictions, and provides accurate targeting of reservoir, source rock and seal potential.

Through SSIS, seismic interpreters are able to flatten 2D and 3D seismic data through moving data from the structural seismic domain to the Wheeler domain, thereby increasing their understanding of the spatial distribution and timing of sediment deposition.

Furthermore, seismic interpretation using Wheeler transforms does not just apply to the 2D domain today, but also 3D. With no equivalent 3D Wheeler

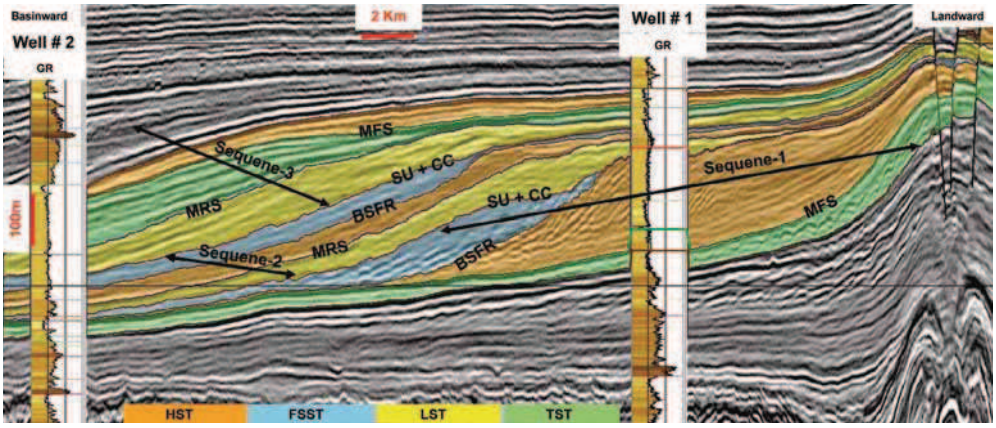

Figure 1. *HorizonCube based systems tracts sub-division of Pliocene interval (Dutch Sector, North Sea).*

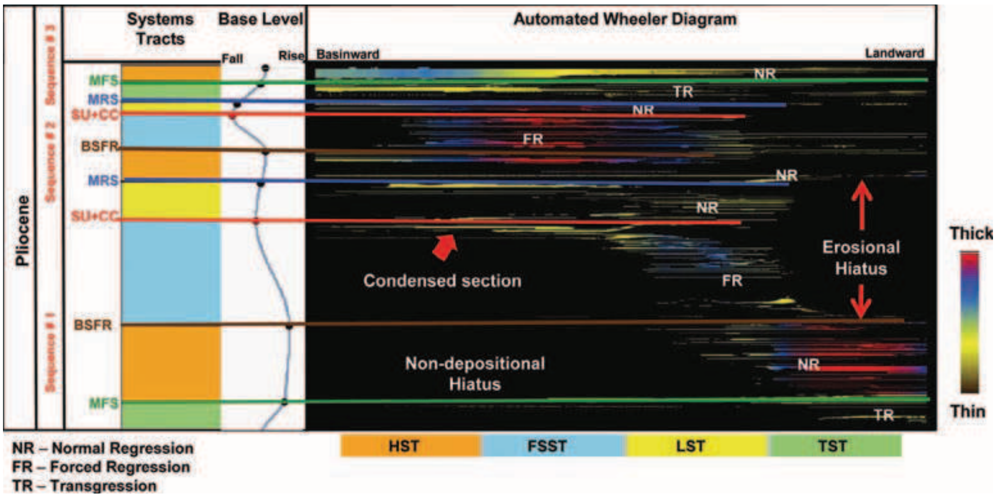

Figure 2. *An automated Wheeler transformed display with interpreted systems tracts sub-division. The colours of Wheeler display represent the thickness per systems tracts in TWT (seconds) units.*

diagram, there is every chance that we may learn even more about sequence stratigraphy.

The rest of this article will look at some examples as to how, 54 years on, the work of Harry Wheeler remains at the forefront of seismic interpretation, helping to illuminate the subsurface and generate detailed seismic knowledge of subtle petroleum reservoirs.

HorizonCube based Wheeler transforms

As previously mentioned, the Wheeler transform is the seismic equivalent of the Wheeler diagram.

In a Wheeler diagram, rock units are plotted in a 2D chart of geologic time (y-axis) versus space (x-axis), with the diagram showing the temporal-spatial relationship between rock units. On the other hand, in a Wheeler transform, the seismic interpreter flattens the seismic data (or derived attributes) along flattened chronostratigraphic horizons. The vertical axis in the Wheeler transformed domain is relative geologic time, as opposed to absolute geologic time.

3D automated Wheeler transforms are today part of dGB's HorizonCube interpretation solution. HorizonCube is a dense set of auto-tracked correlated 3D stratigraphic surfaces, created by an auto-tracker, with each horizon in the HorizonCube representing a (relative) geologic time line. It is this dense set of horizons which enable Wheeler transformations and systems tracts interpretation to operate at their full potential.

The HorizonCube workflow of integrated seismic and well data and the dense set of auto-tracked seismic events can be simultaneously analysed in the relative geologic time (Wheeler) domain and in the structural domain. HorizonCube derived attributes can then be extracted to help analyse relative changes in sedimentation rate, base level variations, depositional trends and geomorphologic patterns. Furthermore, by displaying flattened seismic data through Wheeler transforms, seismic interpreters will see all kinds of stratigraphic details that will help increase their understanding of the depositional environment.

A North Sea example

One example of Wheeler transforms in action comes from a survey in the North Sea carried out by the company. Well seismic correlation and sequence stratigraphic interpretation of Pliocene interval in the Dutch Sector of the North Sea was undertaken. Figure 1 illustrates the sequence stratigraphic interpretation for the interval, which has been developed by correlating the densely mapped seismic events with available well data and available biostratigraphic information. The coloured packages represent systems tracts.

Here, the auto-tracked horizons are sub-divided into packages representing systems tracts, achieved by the 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 then automatically generated from interpreted systems tracts and is illustrated in Figure 2.

The comparisons between the structural domain (Figure 1) and Wheeler transformed domain (Figure 2) are now there for all to see. Figure 2 shows an automated Wheeler diagram highlighting the sequence stratigraphic framework constructed by integrating seismic and well data.

As one can see, three sequences are identified in the Pliocene interval with systems tract thickness being the attribute displayed in the Wheeler domain. This attribute can be used not only as a measure of (preserved) depositional thickness but also as an indicator for sedimentation rate. From the Wheeler domain with the thickness overlay, one can easily interpret the condensed sections, erosional and non-depositional hiatuses (Figure 2). The result is a different view of the seismic data and the target geology in relative geologic time.

An eastern offshore Canada example

The company also recently carried out a seismic interpretation survey offshore Nova Scotia near Sable Island. Mid-Late Jurassic (Abenaki - AB) sequence of mixed siliciclastic-carbonate depositional system was interpreted using HorizonCube and SSIS.

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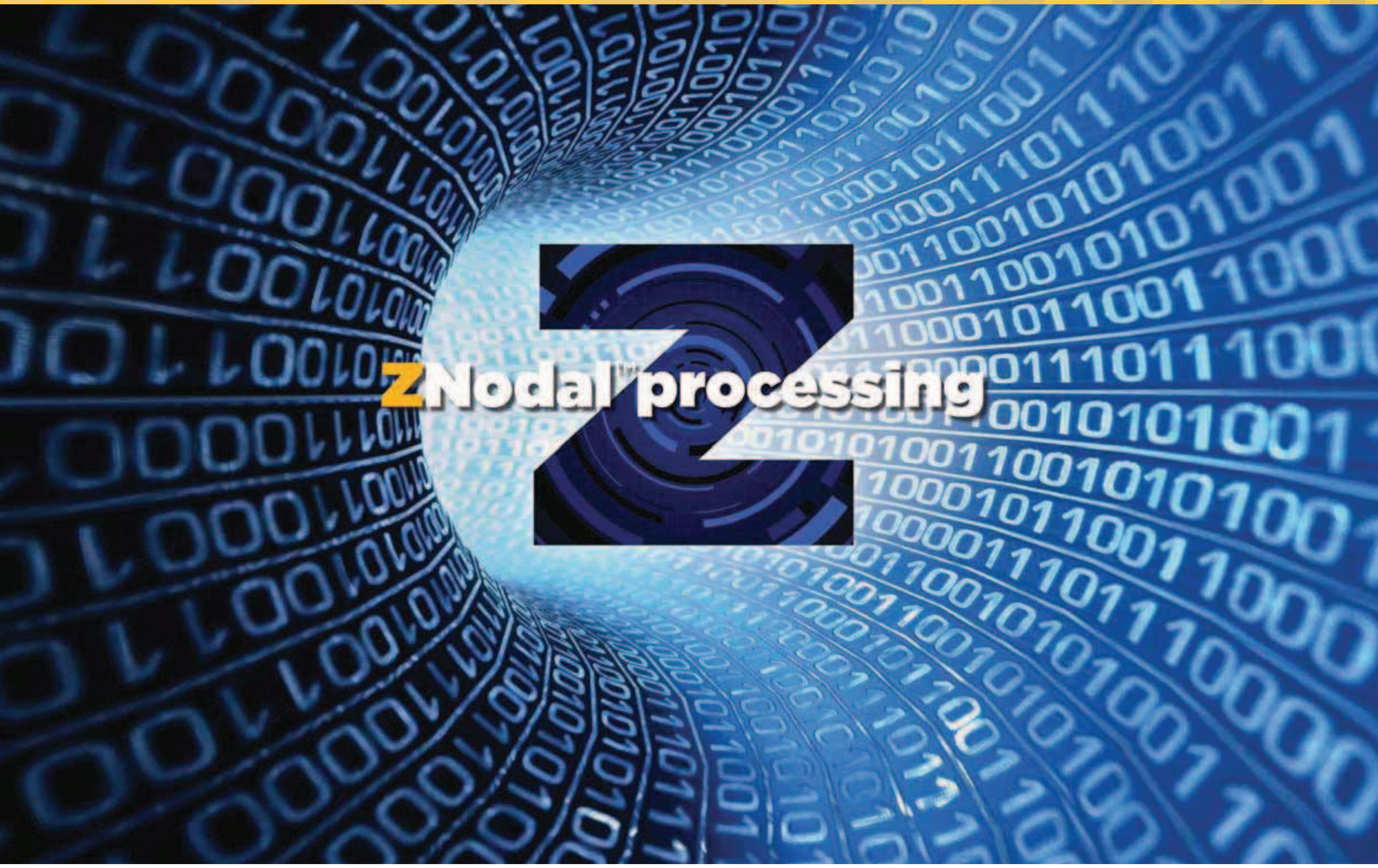
SYSTEMS ACQUISITION LICENSING PROCESSING IMAGING



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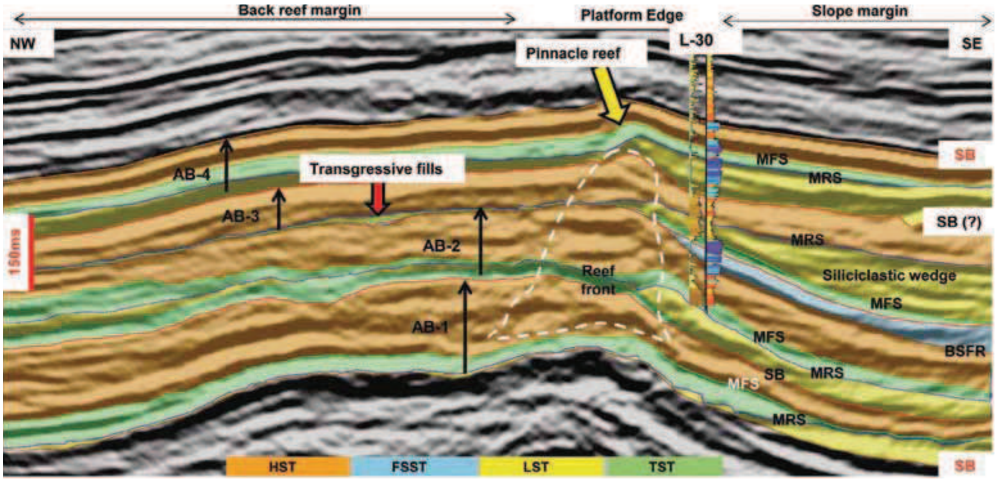

Figure 3. *A structural view of a dip oriented seismic section. The interpretation is done in the Mid - Late Jurassic intervals of Abenaki carbonate bank (Nova Scotia, Sable Island, Canada). The colour coded semi-transparent overlay represents interpreted systems tracts.*

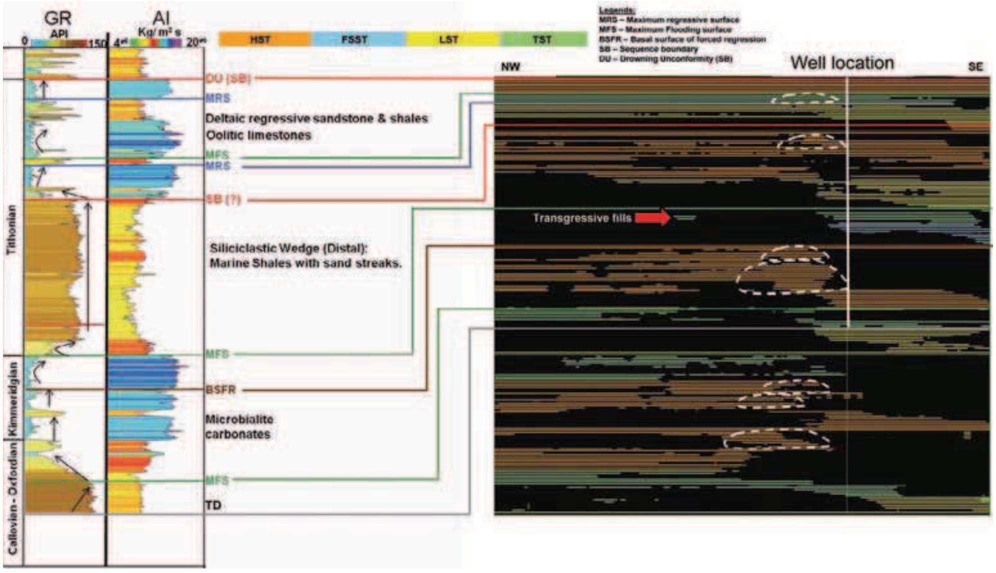

Figure 4. *Wheeler transformed seismic section (Figure 3) and the interpreted systems tracts. The well display presented on the left is located at a white line location on the Wheeler domain. The dashed white lines on the Wheeler display mark the reefs front location (Figure 3).*

The systems tracts are interpreted from the stacking patterns observed in the structural domain (Figure 3), Wheeler transformed domain (Figure 4) and calibrated to the well information. The result is a fascinating insight into the development of the reef complex over geological time.

Four depositional cycles (AB-1 to AB-4) are interpreted in the Mid - Late Jurassic sequence. The seismic section in the structural domain is overlain by interpreted systems tracts and associated sequence stratigraphic surfaces. The well (L-30) has been drilled in the platform edge-slope environment. Note that not all systems tracts are fully observed at the presented seismic level. The back reef margin mainly contains patchy reefs with NW prograding patterns interpreted as highstand systems tracts (HSTs). The dashed outline of reef front (at the platform edge) has also been interpreted on the Wheeler domain to understand the relative preservation and development of the reefs over a geologic time. The slope margin is being filled with sable deltaic sedimentations, which have formed several lowstand systems tracts (LSTs).

The AB-1 cycle of Callovian stage - the late stage of Mid Jurassic period - is a time transgressive unit (Figure 4) marking the onset of a base level rise during the opening of Atlantic margin. The unit contains lowstand systems tract (LST) in the slope-basin margin that is later on overlain by a thin back stepping transgressive systems tract (TST).

The end of this cycle is an aggrading to NW-prograding highstand systems tract (HST). The AB-2 cycle of the Oxfordian stage – the earliest age of the late Jurassic period – is interpreted as a catchup to keep-up cycle. The base of this cycle is a LST deposited in the slope margin environment. The cycle is further divided into TST and HST systems tracts marking the further rise in base level during that time.

At the end of the AB-2 cycle, base level fell and the platform was partially exposed in the northward direction. This fall in base level has developed a thin falling stage systems tract (FSST) in the basinward direction (SE).

Following this stage, the base level started rising and the further siliciclastic sedimentation filled the slope margin and developed a shallow marine environment at the back reef margin. This marine transgression has filled the karstified/channelised shape features with transgressive fills.

Due to the shallow marine environment at the platform, carbonate production resumed again and a thick aggrading to prograding HST is developed. This cycle is marked as AB-3 sequence of early Tithonian stage. The late Tithonian stage of Abenaki sequence is marked as sand shoals cycle AB-4 with prograding siliciclastic delta. The Wheeler domain shows basal prograding LST overlain by thin transgressive and aggrading units. Carbonate production, however, was forced to cease during and at the end of the Tithonian stage, caused by deltaic progradation and marked by a drowning unconformity (DU) at the top of the platform.

Figure 4 takes this a step further illustrating a Wheeler transformed NW-SE trending seismic section.

Generating more information from your seismic data

To build an accurate subsurface sequence stratigraphic framework, an interpreter ideally needs to correlate all seismic events with available well data and to map events simultaneously in the relative geologic time domain and in the structural domain.

What this article has demonstrated is the crucial role the Wheeler diagram and Wheeler transforms are now playing in building detailed sequence stratigraphic frameworks and interpreting seismic data. OT