# Time attributes of Stratigraphic Surfaces, analyzed in the structural and Wheeler transformed domain

*Geert de Bruin & Eric Bouanga, dGB Earth Sciences, Nijverheidstraat 11-2,*
*7511 JM Enschede, The Netherlands*

## Abstract

Recent software developments (OpendTect SSIS) enable us to study the time attributes of seismic stratigraphic surfaces within a chronostratigraphic framework by means of Wheeler transformation of seismic data. Studying stratigraphic surfaces in the structural and the Wheeler domain enhances our understanding of time attributes of these surfaces. The maximum flooding surface marks the end of transgression and the onset of normal regression and is a highly isochronous event. The basal surface of forced regression corresponds to the seafloor at the onset of forced regression. This is a highly isochronous event that coincides with the start of erosion at the top of the high stand deposits and the formation of the subaerial unconformity. The subaerial unconformity is a highly diachronous event that starts at the onset of forced regression, when the basal surface of forced regression is formed and stops at the end of forced regression, which coincides with the correlative conformity. The correlative conformity corresponds with the end of forced regression and highly isochronous. The maximum regressive surface marks the end of normal regression and the onset of transgression. This surface is in our case moderately isochronous.

## Introduction

A still debated and controversial issue of sequence stratigraphy is the assessment of stratigraphic surfaces in a chronostratigraphic framework (Catuneanu, 2006.). The assessment of time attributes of bounding surfaces i.e. to asses whether the bounding surfaces of systems tracts or sequences are isochronous or diachronous, is of paramount importance for stratigraphic correlation. Recent software developments (OpendTect SSIS) enable us to study the time attributes of seismic stratigraphic surfaces within such a chronostratigraphic framework by means of Wheeler transformation of seismic data (figure 1).

## Workflow

OpendTect SSIS (Sequence Stratigraphic Interpretation System) allows seismic data to be studied in the chronostratigraphic domain. Numerous chronostratigraphic events (figure 2) are auto-tracked per sequence bounded by (conventionally) mapped horizons. In order to create a 3D chronostratigraphic diagram or 'Wheeler transform' (figure 1), seismic data and (meta-) attribute volumes are flattened in 3D whereby erosional events and non-depositional hiatuses are honored (de Bruin et al., 2006). Furthermore, sequences are subdivided into systems tracts (figure 4), and the stratigraphic surfaces are analyzed simultaneously in both the structural and Wheeler domain.

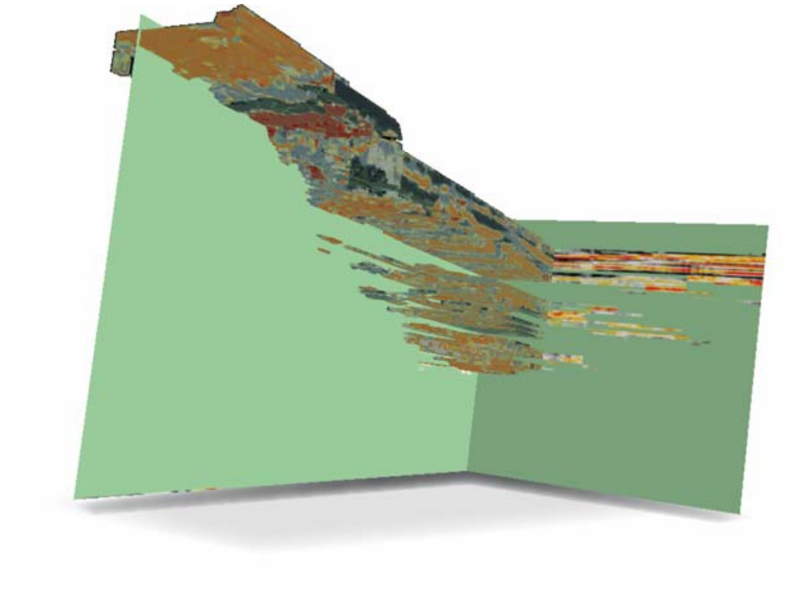

*Figure 1: Example of a 3D Wheeler transform; seismic data displayed in the chronostratigraphic domain. Vertical axis is relative geological time*

## Sequence stratigraphic interpretation

The first package (figure 4) consists of a set of parallel reflectors that are retrograding. Therefore, this package is interpreted as a transgressive systems tract, which is bounded at the top by the maximum flooding surface. The second package consists of a set of steeply dipping clinoforms with a sigmoid reflection pattern that downlap onto the maximum flooding surface (or downlapping surface). The shelf edge trajectory, present just below the upper bounding surface, indicates normal regression. Therefore, the second package is interpreted as being high stand deposits, that are bounded at the top by a subaerial unconformity and the basal surface of forced regression. The subaerial unconformity implies that a part of the highstand deposits is eroded. The third package has an internal chaotic structure, which can be explained by slumping. This structure also explains why this package lacks a clear trend in the Wheeler domain (figure 4d). Since only progradation and no aggradation is observed, this package is interpreted as being forced regression deposits, bounded at the top by a subaerial unconformity and the correlative conformity. The fourth package consists of normal regression deposits, since progradation and aggradation occurs. This indicates that the base level rises, but that the accommodation space consumed by sedimentation is higher than the increase of accommodation space. The hiatuses that are present basin-ward in the Wheeler domain can be explained by stratigraphic thinning (figure 4d). The top of the lowstand systems tract is not defined by the maximum regressive surface as one would expect, but by a subaerial unconformity that marks a second phase of forced regression. The fifth package corresponds to a second phase of base level fall (figure 4e) that is followed by normal regression (lowstand) deposits of the sixth package. The seventh and final package has a parallel reflection pattern and onlapping reflectors, indicating that this package consist of transgressive healing phase deposits (figure 4c).

## Time attributes of stratigraphic surfaces

Assigning an age to a particular seismic event or horizon in the Wheeler domain is not as straightforward as one may think. First of all, a single event in the structural domain is most likely to be at two places in the Wheeler domain (figure 2). It is present at the top of the brown / blue package and at the base of the yellow package. It is possible to assign a (relative) geological age to the deposits just above and just below the event, but these ages do not necessarily correspond to the timing of the event.

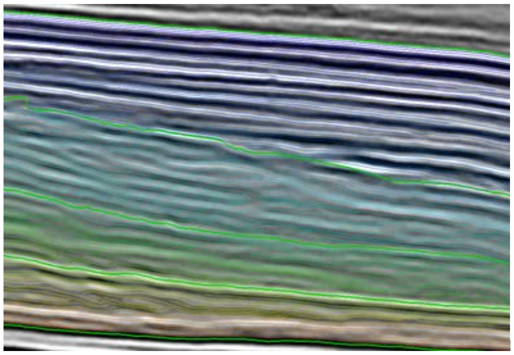

Figure 2

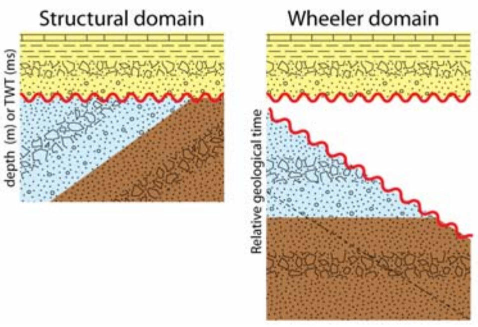

Figure 3

*Figure 2: Chronostratigraphic events are auto-tracked in-between mapped horizons (thick green lines)*

*Figure 3: An angular unconformity (red line) is a single event in the structural domain but is present at two places in the Wheeler domain (base of yellow package and top of brown / blue package)*

### *Maximum flooding surface*

The maximum flooding surface (figure 4) marks the end of transgression and the onset of normal regression. It corresponds to the top of the transgressive systems tract and is present near the base and top of the investigated interval. The deposits that mark the top of the transgressive systems tract in the Wheeler (figure 4d) are moderately diachronous for the lowest systems tract and very isochronous for the upper transgressive systems tract. The timing of the maximum flooding surfaces corresponds to 1.9 and 20 rgt (relative geological time).

*Basal Surface of forced regression*

The basal surface of forced regression (figure 4) (*sensu* Hunt and Tucker, 1992, is equivalent to the correlative conformity of Posamentier and Allen,1999) corresponds to the seafloor at the onset of forced regression (Catuneanu, 2006). This is a highly isochronous event (figure 4d) that coincides with the start of erosion at the top of the normal regression deposits and the formation of the subaerial unconformity. There are two basal surfaces of forced regression present, at 6 rgt and 14,8 rgt.

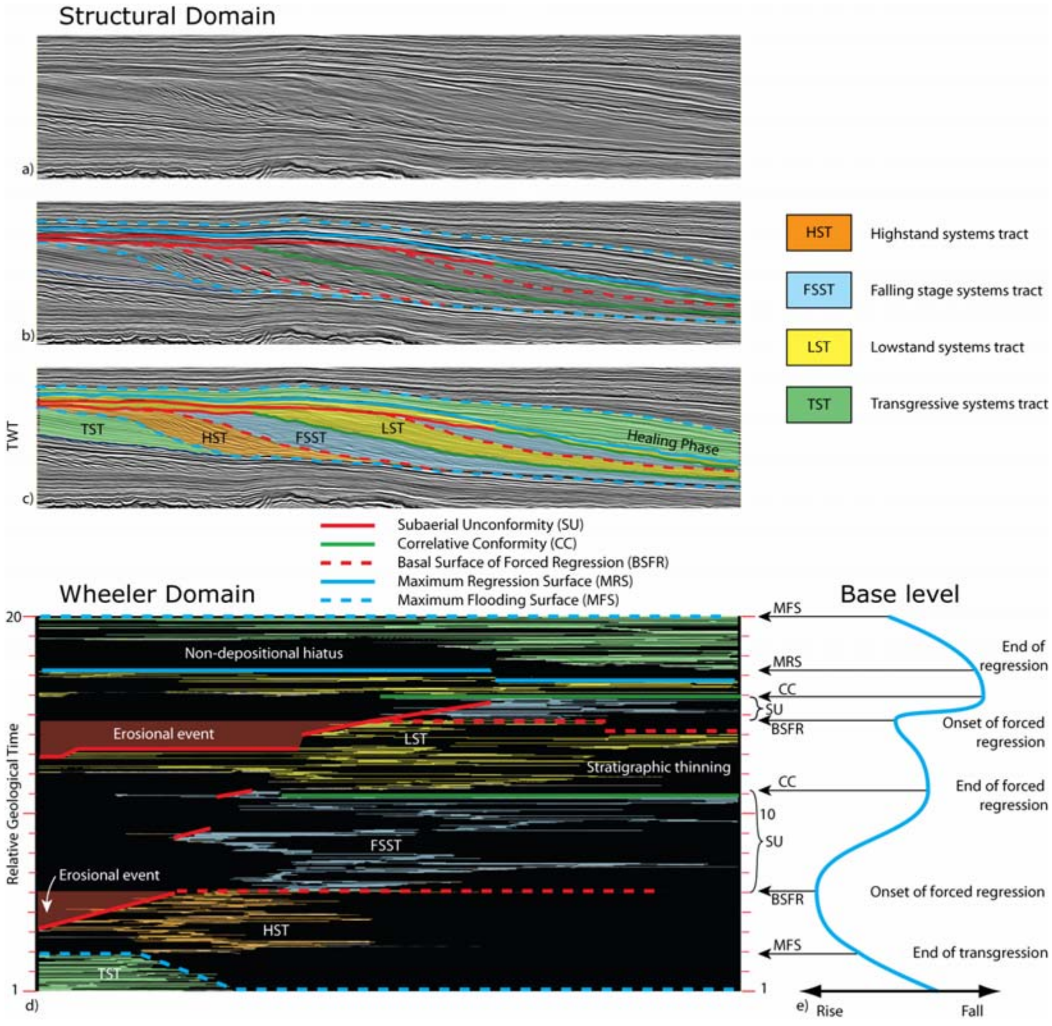

*Figure 4, a) Uninterrupted seismic line; b) Stratigraphic surfaces; c) Systems tracts interpretation d) Wheeler transform of systems tract interpretation e) Base level reconstruction, together with the timing of stratigraphic surfaces.*

*Subaerial unconformity*

The subaerial unconformity is a highly diachronous event. The timing of the first subaerial unconformity is from 6 until 10.1 rgt, i.e. erosion starts at the onset of forced regression, when the basal surface of forced regression is formed and stopped at the end of forced regression, which coincides with the correlative conformity. The timing of the erosion does not correspond with the red line in the Wheeler transform (figure 4d).The red area just above the subaerial unconformities represents the strata that are eroded, emphasizing the erosional nature of the subaerial unconformity. The timing of the second subaerial unconformity is from 14,8 until 15,9 rgt.

### *Correlative conformity*

The correlative conformity (figure 4) corresponds with the end of forced regression and is present at the top of the falling stage systems tract. The correlative conformities coincide with the end of erosion of the normal regression deposits, are highly isochronous (figure 4d) and are present at 10,1 and 15,9 rgt.

### *Maximum regressive surface*

The maximum regressive surface or transgressive surface (figure 4) marks the end of normal regression and the onset of transgression. This surface is present at the top of the lowstand systems tract at 17,2 rgt. The top of this prograding package is moderately isochronous (figure 4d).

## Discussion

Studying stratigraphic surfaces in the structural and the Wheeler domain enhances our understanding of time attributes of these surfaces, but some caution is needed when interpreting events in the Wheeler domain.

First of all, reflections must be geologically meaningful. Multiples and other artifacts can be tracked by the system while calculating the chronostratigraphy.

Secondly, a horizon appears as a single event in the structural domain, but in the Wheeler domain it is present at two places: at the top of the package below the event and at the base of the package above it. It is possible to assign (relative) geological ages to the deposits just above and just below the event, but these ages do not necessarily correspond to the timing of the event. This is especially true when dealing with subaerial unconformities or highly diachronous events.

Finally, since the current implementation of the Wheeler transform yields a Wheeler domain in relative geological time, it is only possible to interpret the relative timing of highly isochronous event and the relative duration of erosional events. Future developments of OpendTect SSIS aim to calibrate the Wheeler transform to absolute geologic time. It will then be possible to assign a geological age to isochronous events or to date the occurrence of erosion. Furthermore, sedimentation rates and duration of hiatuses can then be calculated.

## References:

Catuneanu, O., 2006. Principles of Sequence Stratigraphy. First Edition, Elsevier, Amsterdam, 375 pp.

De Bruin, G., Ligtenberg, H., Hemstra, N. and Tingdahl, K. [2006] Synchronized sequence stratigraphic interpretation in the structural and chrono-stratigraphic (Wheeler transformed) domain. EAGE Research workshop, Grenoble.

Hunt, D., Tucker, M.E. [1992] Stranded parasequences and the forced regressive wedge systems tract: deposition during base-level fall. Sedimentary Geology 81, 1–9.

Posamentier, H.W., Allen, G.P. [1999] Siliciclastic sequence stratigraphy: concepts and applications. SEPM Concepts in Sedimentology and Paleontology no. 7, 210 pp.