Sequence Stratigraphic Interpretation in the Wheeler Transformed (Flattened) Seismic Domain

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Abstract

In this paper we discuss a seismic interpretation technique that is based on the geological Wheeler diagram in which stratigraphic events are plotted versus geological time. We transform 2D or 3D seismic data to the space-geological time domain. This means that we perform a chrono-stratigraphic flattening of the seismic data. In the transformation geological hiatuses and truncations are honoured. The Wheeler transformed data allows us to study seismic events in space and geological time, which is one of the key aspects of sequence stratigraphic interpretation. In the paper we first describe the method we use for creating a Wheeler transformed dataset. Thereafter we show an example and discuss interpretation aspects.

Introduction

Flattening seismic data along a mapped (chrono-stratigraphic) horizon enables us to study the seismic response of individual stratigraphic events. This well-known interpretation technique is the basis for visualization methods such as “stratal slicing” and neural network-based waveform clustering. By restricting the analysis to a single stratigraphic unit we may pick up patterns and details from which valuable geological information can be deducted. In stratal slicing the seismic data is flattened relative to a mapped horizon. The method is only accurate for the slice at the level of the mapped horizon itself. At other levels parallel layering relative to the mapped horizon is assumed. When geology is dipping the accuracy deteriorates the further away we slice from the mapped horizon through the flattened data. To increase accuracy additional horizons must be mapped. The ultimate accuracy for stratal slicing is obtained when every seismic sample is flattened according to its corresponding chrono-stratigraphic event. If the flattening takes into account horizon truncations and non-depositional / erosional hiatuses between horizons, the flattened data is the seismic equivalent of the geological Wheeler diagram.

Flattening an entire seismic volume is not new. To our knowledge, the first Wheeler transform of seismic data was performed in SeisStrat, a commercial sequence stratigraphic interpretation package developed in the 1990’s by IES of Germany. Oil Company Total developed a proprietary software system called GeoTime that performs a Wheeler transform on 2D seismic data. The system was demonstrated at the EAGE conference and exhibition in Amsterdam in 2001 (Keskes, 2002). Around the same time Stark developed his concept of the Geological Time Cube (Stark, 2004). In a Geological Time Cube a relative geological age is assigned to every seismic sample position. Following the samples with the same age in the Geological Time Cube is equivalent to auto-tracking in a conventional cube. The Geological Time Cube can thus be used as an intermediate step to a Wheeler Transformed cube. Lomask (2003) describes a method for flattening seismic without picking. In this method all seismic events are auto-tracked by following the local dip- and azimuth as calculated from the gradient of the seismic data at every sample position. Tingdahl et.al. (2001) use the same technique for creating local horizons from a steering cube that is calculated either by Fourier transforms, or by gradient methods. The local horizons are calculated automatically in a process called dip-steering. The process is used for calculating attributes and applying filters along seismic events without picking horizons.

The method presented in this paper was developed in the context of the OpendTect SSIS project. This two-year multi-client sponsored project aimed to develop a Sequence Stratigraphic Interpretation System on top of OpendTect, dGB’s open source seismic interpretation platform.

Wheeler Transformation

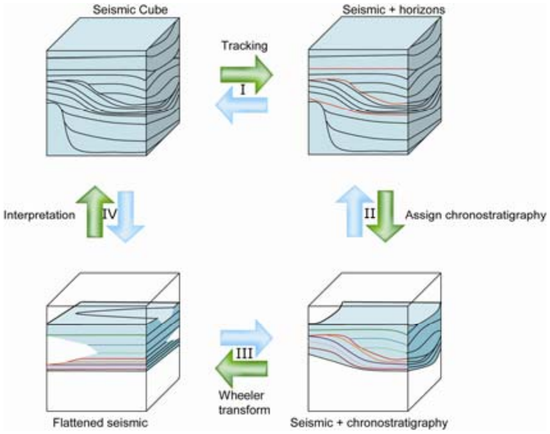

Figure 1: SSIS workflow.

OpendTect SSIS supports a workflow comprising four steps, depicted schematically in Fig. 1. First some important horizons are mapped with a semi-automated horizon tracker. Next intermediate chrono-stratigraphic events are tracked through each seismic sample position. This is a crucial step in the approach as it determines the accuracy of the Wheeler transform. Tracking is performed per sequence bounded by mapped horizons. Two modes are supported: model-driven and data-driven. In the model-driven approach intermediate horizons follow the geometric configuration of the model and an index is assigned to each horizon (Fig, 2). This approach works well for simple geometries but when the geometry becomes more complex a data driven approach is needed. The approach supported in OpendTect SSIS is based on dip-steering. First a steering cube containing local dip-azimuth information is calculated from the input seismic cube. At every sample position the steering information is followed outward in a process called dip-steering. The result is a set of tracked chrono-stratigraphic horizons going through each sample position and bounded by the mapped horizons. As with the model-driven approach an index is assigned to each horizon for identification purposes. The final step is the Wheeler transform in which the chrono-stratigraphic events are flattened. The user controls the transformation with the number of manually mapped horizons, the choice per sequence of model-driven vs. data-driven approach and the assignment of indices per sequence. The software supports on-the-fly Wheeler transformations and visualization procedures to Q.C. results and update intermediate steps where needed.

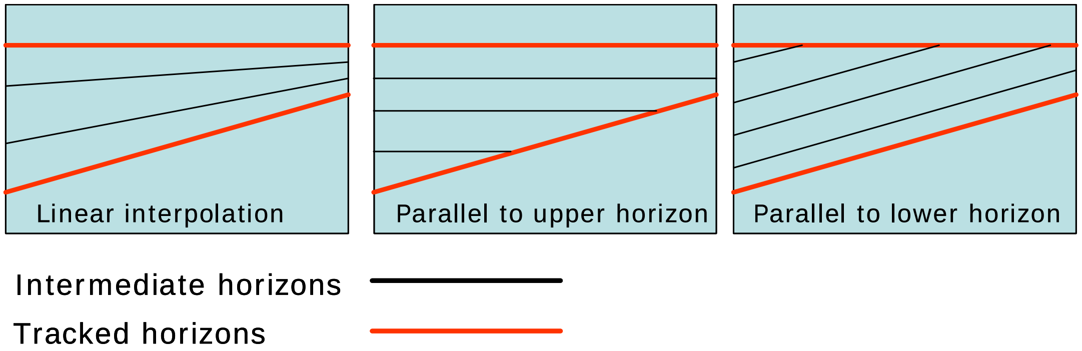

Figure 2: Model driven approach. Chrono-stratigraphic events follow the geometric configuration of the model.

North Sea example

The dataset is from the F3 block in the Dutch sector of the North Sea. The 3D seismic was acquired to explore for oil and gas in the Upper-Jurassic – Lower Cretaceous strata, which are found below the interval that is analyzed with the Wheeler transform. We focus on a Miocene deltaic package consisting of sand and shale, with some carbonate-cemented streaks. This large-scale delta system was described by Sørensen et al (1997) and Overeem et al (2001). A number of interesting features can be observed in this package. The most striking feature is the large-scale sigmoidal bedding, with text-book quality downlap, toplap, onlap, and truncation structures, which will be the target for our analysis. Several seismic facies can be distinguished in the shallow seismic section: transparent, chaotic, linear, shingles. Well logs show the transparent facies to consist of a rather uniform lithology, which can be either sand or shale. The chaotic facies likely represents slumped deposits. The shingles at the base of the clinoforms have been shown to consist of sandy turbidites.

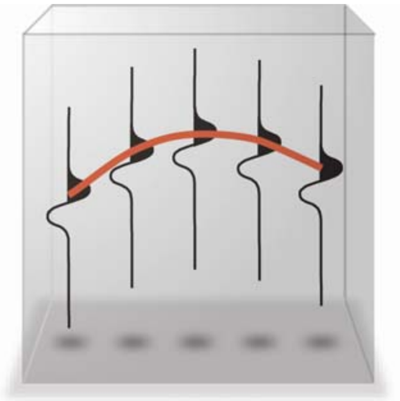

Figure 3: Data driven approach. Chrono-stratigraphic events are tracked from a pre-calculated steering cube by "dip-steering".

For the sake of this discussion we limit our analysis to an interval bounded by four horizons but it is noted that there is neither a theoretical limitation to the size of the interval, nor to the number of mapped horizons. Fig. 4A shows a cross-section of the selected interval bounded by the mapped horizons. The overlay rainbow colours (4B) is the chrono-stratigraphy that was calculated with the data-driven dip-steering approach. Note that the chrono-stratigraphy follows the seismic reflection patterns thus confirming that the data-driven algorithm performed well. Visualizing the chrono-stratigraphy facilitates the interpretation of system tracts in the interval. The colours reveal three complete sequences with varying sea-level / sediment input ratios. E.g. the pink/red sequence displays a progradation with high sedimentation rates, whereas the blue sequence shows mainly vertical aggradation, indicating much less sediment input and/or a faster sea-level rise.

Fig. 4C shows the same cross-section in the Wheeler transformed domain. Notice that the upper and lower boundaries corresponding to the mapped horizons are not chrono-stratigraphic events. The events are slightly dipping in the Wheeler transformed domain which shows correctly that it took time to deposit sediments along these surfaces. The flat hard events that are stepping outwards are the flattened high angle clinoforms building out as the sea-level fell. Sequence boundaries are clearly visible in the Wheeler transformed domain as the vertical boundary between data and undefined region. The development of the sequence in geological time and space is best studied in the Wheeler transformed domain, e.g. by movie-style visualization of time-slices. Since each time-slice corresponds to a chrono-stratigraphic event we are performing a kind of stratal slicing but with two differences: 1) the surfaces are bounded in space and 2) the accuracy does not deteriorate with increasing distance away from the mapped surface, provided of course that our chrono-stratigraphy assignments were correct. The SSIS software allows Wheeler transformations to be performed on the original data as well as on any attribute that can be calculated from the data.

Conclusions

In a Wheeler transform seismic data is flattened in a chrono-stratigraphic manner. The transformation described in this paper is based on a workflow that is controlled by the user by assigning chrono-stratigraphy to sequences bounded by mapped horizons. The Wheeler transformed data allows the seismic response to be studied in space and geological time, which is a key aspect of sequence stratigraphy. Visualization techniques such as data clustering should work better in the transformed domain because of the simplified ordering of the data in horizontal lines.

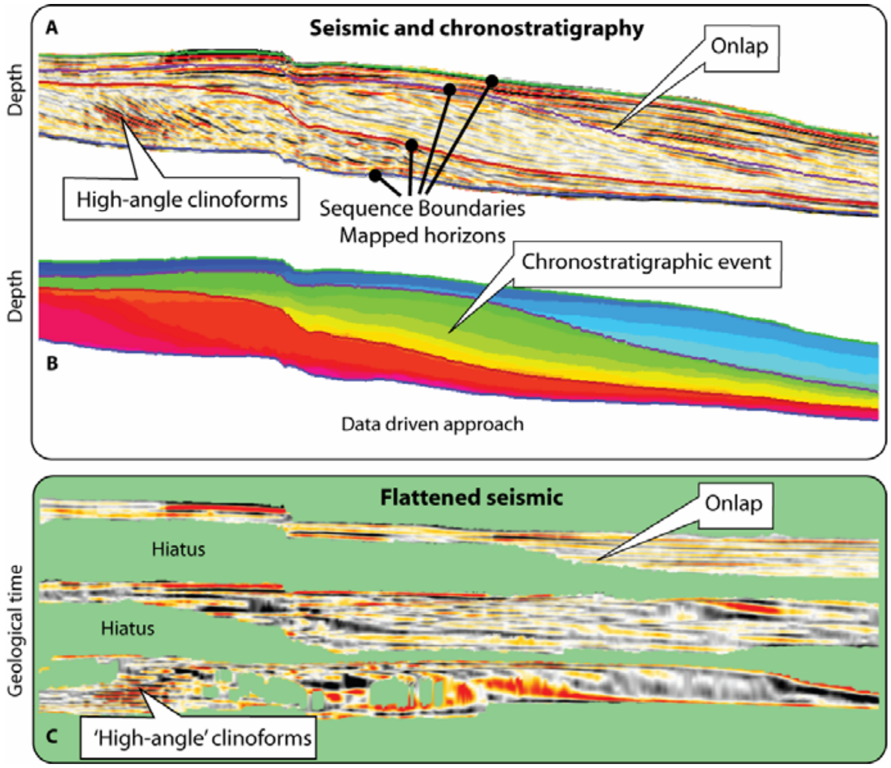

Figure 4: A:Cross-section of selected interval bounded by the horizons. B:Rainbow colour overlay shows chrono-stratigraphy calculated by the data-driven dip-steering approach. C: Wheeler transformed data.

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