

How to create and use 3D Wheeler transformed seismic volumes

Paul de Groot*, Geert de Bruin and Nanne Hemstra, dGB Earth Sciences, Nijverheidstraat 11-2, 7511 JM Enschede, The Netherlands

Summary

In this paper we discuss benefits of interpreting seismic data in the Wheeler transformed domain. In this domain seismic data or derived attributes are flattened along chrono-stratigraphic lines whilst truncations and non-depositional / erosional hiatuses are honored. We start by explaining the workflow and the data-driven chrono-stratigraphic assignment algorithm we use to flatten the data. We continue with a discussion on sequence stratigraphic interpretation and how chrono-stratigraphy and lap-out patterns are used to perform system tracts interpretation. Finally we give a preview of sequence stratigraphic interpretation techniques that are under development.

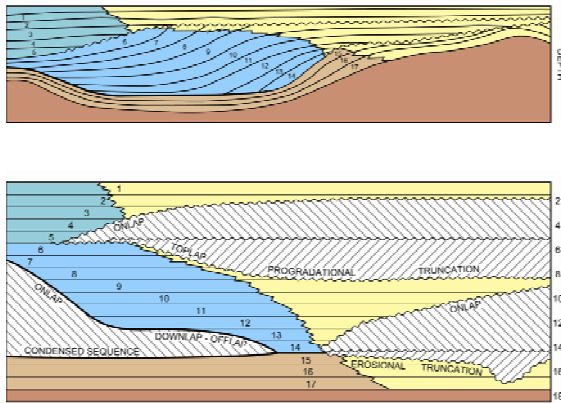


Fig 1: Geological Wheeler diagram, from Shell Standard Legend.

Introduction

Depositional features such as channels, levies, overbank deposits etc. are in general much better visible along flattened horizons than along time-slices. The reason is that time-slices usually cut through geological time lines, while mapped horizons, at least the ones that follow seismic

events, are in general iso-chronous surfaces. Flattening thus enables us to study the seismic response per stratigraphic event. If we map a horizon to go through every sample position in the volume and we order the amplitude response of all these horizons in a logical (chrono-stratigraphic) way we can thus study the seismic response at every stratigraphic level. If we also ensure that the positioning and ordering of the horizons honours truncations and erosional / depositional hiatuses we have thus performed a Wheeler transform, which is the seismic equivalent of the geological Wheeler diagram (Fig. 1).

Sequence stratigraphic Interpretation workflow

The workflow described in this paper is implemented in OpendTect SSIS and Dip-steering plugins (Ligtenberg et al., 2006).

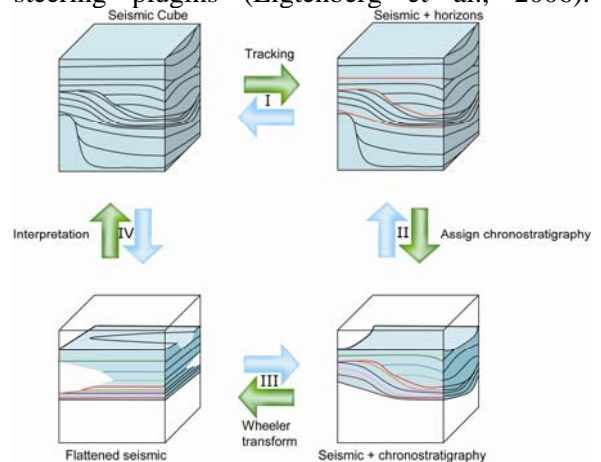


Fig 2: Schematic workflow for SSIS (Sequence Stratigraphic Interpretation System).

The Wheeler transform is part of a sequence stratigraphic interpretation workflow that comprises four steps, depicted schematically in Fig. 2. First some important horizons are

How to create and use 3D Wheeler transformed seismic volumes

mapped with a semi-automated horizon tracker. Next intermediate chrono-stratigraphic events are tracked through each seismic sample position. This information is used to flatten the seismic data and finally the results are interpreted in both domains.

Assigning Chrono-stratigraphy

Assigning Chrono-stratigraphy 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 (Fig. 3). In the model-driven approach intermediate horizons follow the geometric configuration of the model and a chrono-stratigraphic index is assigned to each horizon. This approach works well for simple geometries but when the geometry becomes more complex a data driven approach is needed. The approach described here is based on dip-steering (Tingdahl et al., 2001). First a steering cube containing local dip-azimuth information is calculated from the input seismic cube. This can be done in different ways. Two algorithms are supported: one based on Fourier transforms and another based on instantaneous phase variations. Optionally the steering cube is filtered by a median filter to smooth the dip- azimuth field.

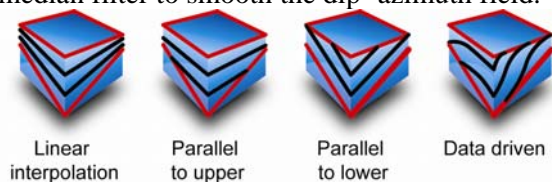


Fig 3: Chrono-stratigraphy assignment: model driven vs. data-driven approaches.

Dip-steered tracking starts from one selected inline, cross-line position at all seismic sample positions that lie between the two mapped horizons that define the sequence boundaries (Fig. 4). The default start position is the inline, cross-line position with the largest iso-chore (i.e.

the position where the sequence is thickest) but it is also possible to start the process at a user-defined location, e.g. at a well position. Each horizon is assigned a temporary index. From the starting position each horizon grows in all directions by simply following the local dip- and azimuth information at the evaluation point to find the corresponding Z (two-way time, or depth) position at neighboring traces. Note that only the starting position is tied to a sample position (Fig. 4). Once all horizons at the initial X,Y locations are tracked the algorithm adds horizons laterally. Seismic sample positions that are not closely visited by any of the tracked horizons will be assigned an index that is interpolated between the nearest top and bottom horizons. Finally the temporary indices are re-scaled to a user-defined chrono-stratigraphic range and the horizons are stored as a Wheeler-transformed chrono-stratigraphic cube, Fig. 5. The advantage of storing the information in this way is that horizons, stratigraphic intervals, and calculations along stratigraphic events are readily available.

The user controls the chrono-stratigraphy calculations with the number of manually mapped horizons, the chronostratigraphy range per sequence, the choice per sequence of model-driven vs. data-driven approach, and for the latter it's starting position.

Wheeler transform

With the chrono-stratigraphic assignments in place we can now transform any seismic (amplitudes, (meta-) attributes) volume to the Wheeler domain. In the vertical direction the chrono-stratigraphic information corresponds to an irregular sampling of the Z axis (Fig. 4). The Wheeler transformation thus requires a re-sampling in Z, which is done with a 3rd-order polynomial function. Where large jumps in Z-values exist the data is not interpolated. Instead the values are set to undefined, hence they show

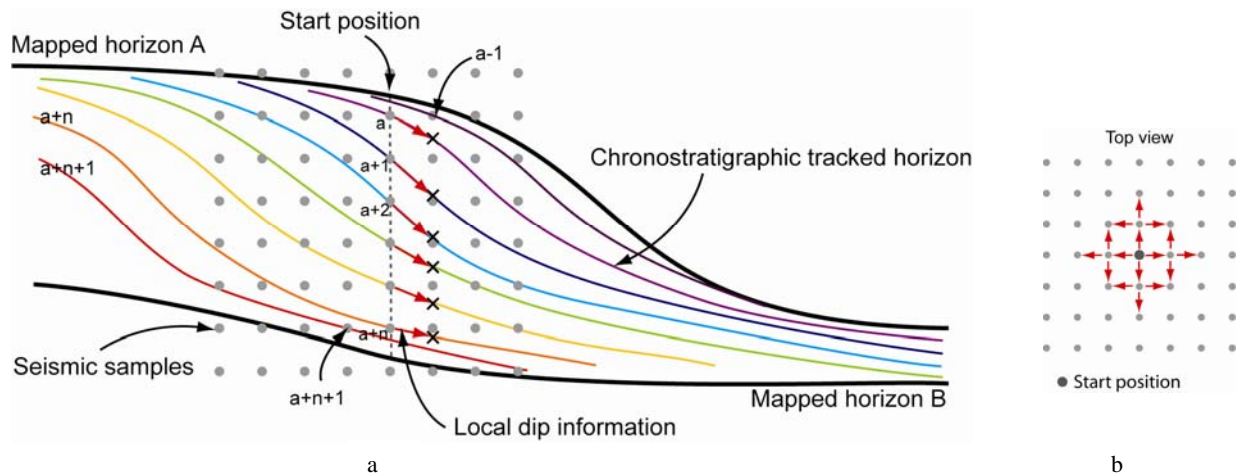


Fig 4a: Starting position for the data-driven, dip-steered tracking approach. Temporary chrono-stratigraphic indices are assigned to each sample starting from a to $a+n$. By following the dip-azimuth information chronostratigraphic horizons are tracked to the next trace depicted by the x 's. The z -values of these locations are stored, and the horizons are tracked to the next trace, using the local dip-azimuth information from the nearest sample. When all horizons a to $a+n$ are tracked the algorithm adds horizons laterally starting from sample positions $a+n+1$ and $a-1$. In a final step, the temporary indices are re-scaled to a user-defined chrono-stratigraphic range.

Figure 4b Horizons grow radially in all directions by following the local dip- and azimuth information from the pre-calculated steering cube (top view).

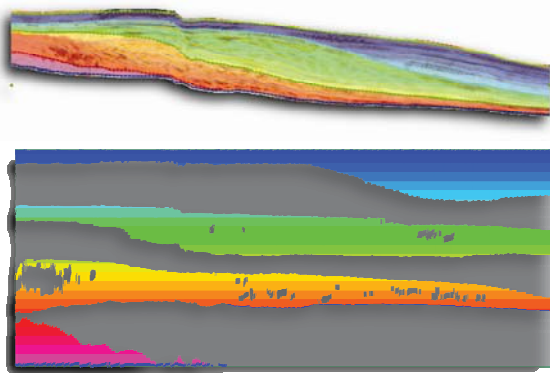


Fig 5: Chrono-stratigraphic information displayed as overlay over the normal seismic (top) and in the Wheeler transformed domain. (bottom)

up in the Wheeler transformed domain as hiatuses possibly caused by erosion, or non-deposition (Fig. 6). The software supports on-the-fly Wheeler transformations and visualization procedures to Q.C. results and update intermediate steps where needed. When satisfied the user can transform entire volumes

in batch mode for further analysis and interpretation

System tracts interpretation

Inspecting the spatial distribution of the sequences and lap-out patterns of seismic events, in both the normal domain and the Wheeler transformed domain, enables us to segment the seismic sequences into system tracts. Tract are specified per chrono-stratigraphic range. To reflect the variation in naming conventions, the software allows the default system tract names (High Stand, Falling Stage, Low Stand, Transgressive) to be replaced by user-defined names.

System tracts interpretations can now be visualized as overlays over sections in the normal and Wheeler transformed domains (Fig. 7). Optionally arrows and annotations are added to complement the interpretation.

How to create and use 3D Wheeler transformed seismic volumes

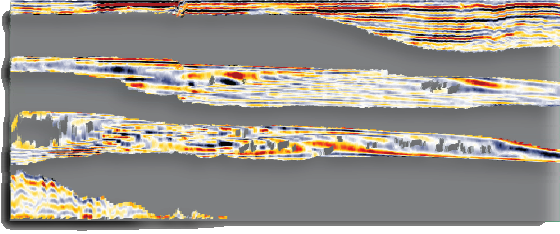


Fig 6: Wheeler transformed seismic data. Hiatuses are caused by the user-defined chrono-stratigraphic ranges that were defined per sequences. Furthermore, intra-sequence hiatuses are automatically created when large jumps in Z values are detected between subsequent horizons.

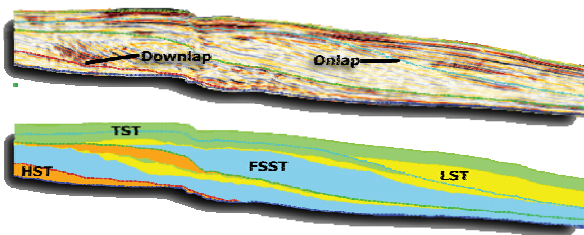
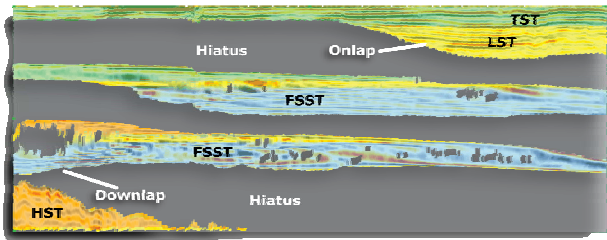


Fig 7: System tracts interpretation

Preview of further developments

OpendTect SSIS is a new product. The functionality described above is released in the first version (June 2006). Planned extensions are a/o 1) calibrating chrono-stratigraphy to absolute geologic time, 2) clustering of seismic facies per sequence, 3) visualization of lithology symbols per seismic facies, and 4) extraction of chrono-stratigraphic events (horizons) for export to other systems.

Conclusions

The workflow described in this paper combines human interaction (mapping of important horizons) with automated procedures to optimize chrono-stratigraphy assignments. The accuracy of these assignments determines the success of subsequent Wheeler transformations. The sequence stratigraphic interpretation workflow and the combination of normal and Wheeler transformed seismic domains open new ways for studying seismic data and the underlying geological processes.

References

- Ligtenberg, H., de Bruin, G., Hemstra, N. and Geel, C., 2006, Sequence Stratigraphic Interpretation in the Wheeler transformed (flattened) seismic domain, 68th EAGE Conference & Exhibition, Vienna.
- Tingdahl, K., de Groot, P. and Heggland, R. (Statoil), 2001. Semi-automated object detection in 3D seismic data. Offshore, August 2001.
- Wheeler, H.E., 1958, Time stratigraphy, AAPG Bulletin 42, pp. 1047-1063.
- Witt, W.G., 1995, Shell Standard Legend.