An Overview of a New Data-driven Workflow for Seismic Sequence Stratigraphic Interpretation

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Summary

An overview is given of a new workflow for seismic sequence stratigraphic interpretation, and its implication for existing and new applications in seismic interpretation. The workflow uses a digital, data-driven approach, increasing the amount, the resolution and the confidence of sequence stratigraphic information extracted from the seismic volume(s), while using less interpretation time. The major steps of the workflow are discussed, as well as the main advantages and pitfalls of the methodology. Using several examples taken from recent case studies world wide it is shown how data-driven seismic sequence stratigraphic interpretations can be integrated with seismic attributes, well logs, regional geology and modern analogs. Finally an overview is given of the most current state of the workflow and the range of existing and new applications that are improved or unlocked using this new workflow.

Introduction

Recently many new techniques for advanced geological interpretation of seismic data have been developed. For example, various methods to aid interpretation of sequence stratigraphy and geomorphology by using dense chrono-stratigraphic frameworks have been developed, see for examples de Bruin et al., 2007a, Lomask et al., 2006, Stark, 2004, Zeng et al. 1998a and Zeng, et al. 1998b, as well as others. In this presentation we will focus on the data-driven SSIS method described by de Bruin et al. (2007a), and recent extensions of his method.

Many of the before mentioned workflows have not yet been implemented routinely in the seismic interpretation cycle. In some cases they were hampered by practical pitfalls and only show good results on a few show-case datasets. However, new insights obtained from test-studies and continuing advances in workstation computation power has led to the development of a more robust version of the data-driven workflow of de Bruin, et al., and the development of a user-driven toolbox to overcome common obstacles in the workflow. As a result, sequence stratigraphic information now can be extracted routinely from a majority of datasets using the data-driven work-flow and a wide variety of previously unsolved seismic-geological interpretation problems can be solved using the workflow. It is our belief that continuing advances in digital data-driven seismic sequence stratigraphic interpretation by the undersigned and other workers in the field will lead to a step-change improvement in many qualitative and quantitative geological interpretation and characterization problems in the next few years.

Multi-2D Workflow for Data-driven Seismic Sequence Stratigraphic Interpretation:

The SSIS workflow described by de Bruin, et al. can be applied to 2D and 3D datasets. In this section we described the workflow applied to a grid of 2D transects, usually oriented parallel and perpendicular to the main axis of deposition in the basin. These 2D transects can be true 2D seismic data or derived from a 3D seismic volume. The workflow contains 2 phases: 1) processing of a dense chrono-stratigraphy, including stratal terminations, on all transects; 2) seismic sequence stratigraphic interpretation of 2D transects and expansion to a 3D understanding. Figure 1 shows all major stages: dips, chrono-stratigraphy, seismic wheeler diagram and interpretation.

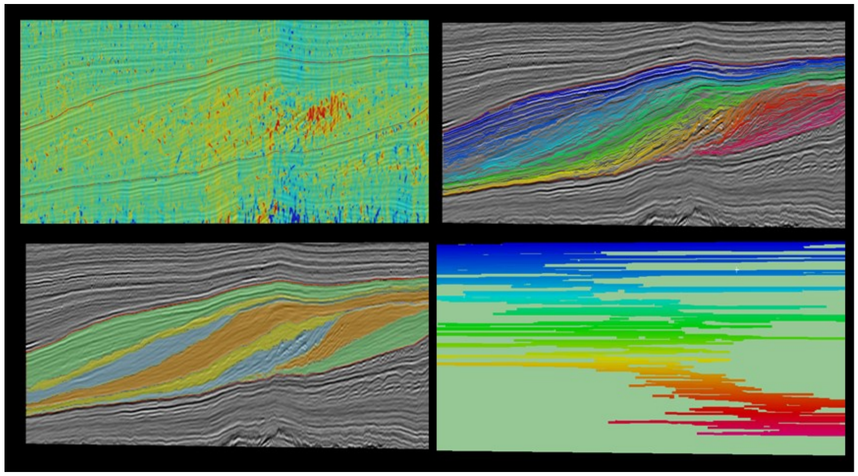

Figure 1: The main data stage in the SSIS workflow. From upper left, clock wise: seismic dips, chrono-stratigraphy, seismic Wheeler diagram and systems tract interpretation.

Creating the data-driven chrono-stratigraphy is a three step procedure. First major horizon and major fault systems are interpreted. Second the seismic dip is calculated. Third, the seismic dip constrained by major horizons and faults is used to track a dense set of chrono-stratigraphic horizons, including stratal terminations. Then each horizon is assigned a chrono-stratigraphy index (relative geological time, 0 for the upper horizon).

During the interpretation, the stratal terminations are used to place hiatuses in the seismic Wheeler diagram. Using the seismic Wheeler diagrams and the original seismic views, a seismic sequence stratigraphic interpretation is made on the transects. Provided the grid of transects is spaced close enough relative to the lateral scale of the systems tracts under investigation, the interpretation will provide a complete 3D understanding of the systems tracts. This is illustrated in Figure 2.

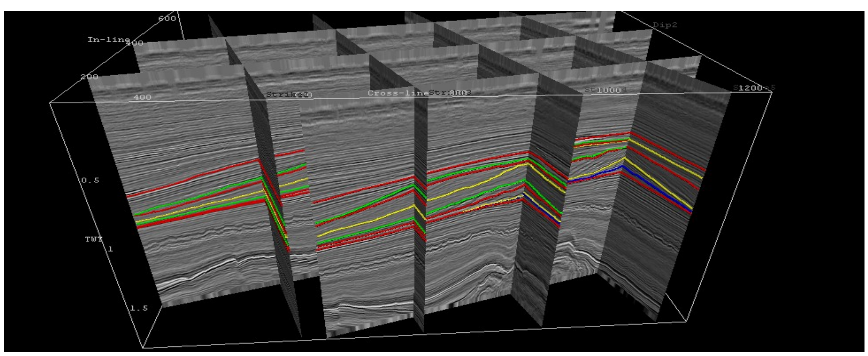

Figure 2: The end product of the multi-2D workflow, a 3D understanding of the systems tract boundaries.

Advantages and problems of the data driven approach.

Most interpreters are used to a user-driven workflow for interpreting seismic sequence stratigraphy, either on paper or digitally. The data-driven workflow has a differents set of advantages and problems compared with manual interpretation. Two of the main problems are: 1) The seismic data is not a true representation of the geological stacking pattern. 2) Some geological configurations can not be uniquely solved without additional information.

These two problems are inherent to the general seismic-geological interpretation workflow and thus are obstacles likely to be encountered to some extend in every dataset. To counter this, an toolbox was developed that allows manual (user-driven) interpretation to be inserted and seamlessly combined with the data-driven method. This integration has made the workflow robustly applicable to most datasets.

The three main benefits of a data-driven interpretation are: 1) Stratigraphic details previously overlooked in the seismic data are highlighted and better understood (see figure 3 for an example). 2) The 3D aspect, and high lateral and vertical resolution of the analysis enables a better geological understanding of the sequence stratigraphy. 3) 3D data-driven stratigraphic frameworks allow analysis on geotime slices throughout 3D data-volumes.

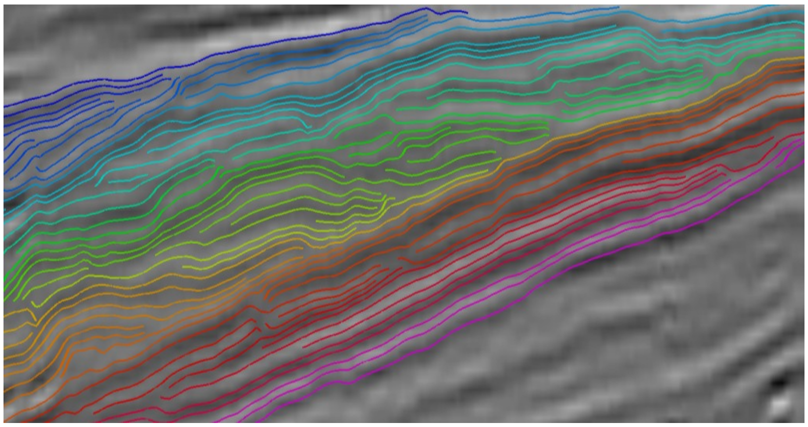

Figure 2: Illustrating the level of detail extracted by the chronostratigraphy. In the lower transgressive sequence we see aggradation and backstepping, in the upper second sequence we see hummocky apparent backstepping horizons onlapping on a unconformable surface, followed by aggradations and progradation, which represents the transition to a high-stand normal regression systems tract.

Examples from selected case studies

Through the development of the workflow, case studies have been conducted in many basins world-wide and different sedimentary settings, including several published examples we use to illustrate the applicability of the workflow to different problems in different environments world-wide. In de Bruin, et al., 2007a the workflow is applied to a shelf, slope, deep-water environment in the Møre South Basin, Norway. In de Bruin, et al., 2007b the development of a complex carbonate platform located off-shore W-Africa is analyzed. In Brouwer, et al., 2008 the method is applied to a deltaic sequence in a Central North Sea Block. Badalini, et al., 2009 applies the method to the Tertiary section of a number of regional lines in Santos Basin, Brazil.

New Applications and the Road Ahead

The higher lateral and vertical resolution of the data-driven seismic sequence stratigraphic workflow allows a much closer integration of the seismic interpretation and well interpretation. Closely integrating high resolution stratigraphic interpretation from wells and seismic is one of the focus points of the further development of the workflow.

Recent work by the authors has proven the concept of automated systems tract interpretation using a rule based analysis of the seismic Wheeler diagrams. While a completely automated systems tract interpretation may not be feasible, this application has the potential of becoming a systems tract auto-tracker, extending the users seed interpretations throughout a seismic volume.

The 3D version of the SSIS workflow and similar workflows by has unlocked many new interpretation possibilities. For example, Rickett, et al. 2008 discusses the application of mapping a pseudo-depositional rate called instantaneous isopachs through a seismic volume. This application allows the interpreted to map the migration of depo-centers through space and geological time.

The creation of 3D data-driven chrono-stratigraphy, calculated along the same principles as the 2D chronostratigraphy allows the authors to build fine scale 3D models for applications such as inversion, basin modeling, and reservoir modeling. In figure 4 we show the result of a benchmark test comparing an acoustic inversion done with standard low frequency model and a SSIS supported low frequency model. The example shows that in the presence of complex meso-scale to small-scale stratigraphic structures, such as sigmoidal clinoforms, the integration of the inversion workflow with the SSIS workflow delivers superior results.

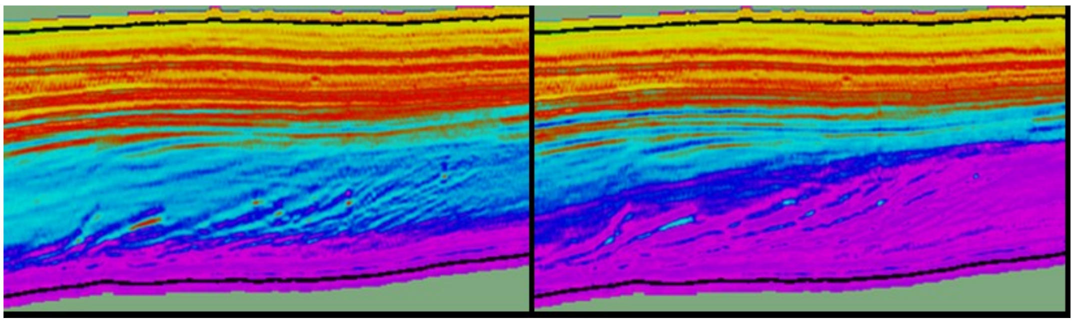

Figure 4: Left conventional inversion result, right the inversion result supported by the SSIS workflow.

Conclusions

A robust method for data-driven seismic sequence stratigraphy has been developed by integrating into the new workflow elements of manual (user-driven) interpretation. Case studies applied worldwide prove the viability of the multi-2D workflow. The development of a robust 2D and 3D workflows has unlocked the possibility to improve many other workflows used today for geological interpretation and characterization, as well as develop complete new workflows. This improved geological interpretation and characterization will be one of the drivers that will revolutionize the exploration and production of hydrocarbons once again.

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