

Cascaded Deterministic Inversion with Progressive High Resolution Sequence Stratigraphy Input from the Seismic and Wells

Introduction

Seismic Inversion has been critical part of the hydrocarbon exploration and development workflow. Since its early implementation in late 1970's seismic inversion has undergone multiple reinventions to take advantage of new formulation and ever-enhancing computer capabilities. Inversion is now becoming everyday required tools for a seismic interpreter. As seismic inversion is a non-unique solution due to limited bandwidth and imaging constraints, well data and other frequency enhancement tools are often used to refine the property estimates.

There are numerous high frequency restoration methods that could broaden the seismic frequencies but often at the expense of amplitude distortion. To deal with the inversion relevance problem we carry out multi-level inversion of seismic data using cascaded spectral limited inputs with increased geological information at each step. Sequence stratigraphic interpretation of seismic data and its integration with well logs produces results that are stochastically distributed but carries fine stratigraphic fabric.

Theory

Seismic Inversion first introduced by Lindseth 1979, played one of the key roles in quantitative seismology. The stratigraphic and lithological information could be quantified using various inversion methods developed over the years.

Acoustic Impedance Inversion led to the development of Elastic Impedance Inversion (Connolly 1999) that was later further modified with the concept of Extended Elastic Impedance. All these methods were based on error minimization between the original seismic and the synthetics generated from the inverted seismic property such as impedance. Simultaneous inversion of pre-stack data allowed better calibration of P- and S-Impedance relationships while adjustments to low frequency background. A major limitation of deterministic inversion is its bandlimited nature where a-priori information is needed outside the seismic bandwidth.

In 1990s stochastic inversion methods were introduced. Using the geostatistical methods of kriging and covariance, one can simulate a distribution of high frequency models where reflectivity of each model yields similar reflectivity as observed in the seismic data. By applying stochastic simulation, the range of the inversion results could be obtained where the average result from all possible solutions is still deterministic. Such stochastic inversion methods assume that the error close to the wells is always lower than the seismic traces far away from a well location. The above assumption is often not true within complex stratigraphic depositional systems.

In 2000's there were further advancements not only in the deterministic and stochastic methods but also in geological modeling. It has been observed that if we use geological and stratigraphic models based on seismic interpretation and relative inversion, we could achieve more realistic inversion solutions. Geological constraints used in the inversion methods are often vertical in nature as high resolution logs are used for the information.

High resolution sequence stratigraphy derived from the seismic data provide lateral constraints that are far finer than the quantitatively resolvable inversion results. As the signal to noise ratio increases with the increasing frequency, we cannot introduce high frequency stratigraphic constraints in the lower bandwidth (main bandwidth). In this case we carry out first inversion pass using low frequency model and lower bandlimited seismic to achieve base inversion solution. Only major seismic horizons with marked impedance contrasts are used in this pass. After the first pass we apply low-cut bandpass filter

to the seismic data and use the first inversion results as the background model. During the second pass high resolution background model through interpolated wells is used to invert higher bandlimited seismic data. The contribution of the model is increased in the second pass to introduce higher stratigraphic fabric. Following example shows the workflow applied to the seismic data in Western Canada Sedimentary Basin (WCSB) Blackfoot field area.

Case Study

Blackfoot Lower Mannville field contains numerous small oil-condensate fields. Blackfoot 3D dataset was acquired by University of Calgary CREWES consortium to cover the field area. In this field a complex siliciclastic channel reservoir system is filled in an incised post-Mississippian unconformity. The multi-component dataset has been a key test dataset for the development of many software and algorithms and has been presented at various conferences to show the efficacy of algorithms to detect incised valley and hydrocarbon bearing high porosity channel systems hiding within many lithic channels and shales. Some of the excellent work published by Pendrel 2001 clearly describe the application of deterministic inversion method to the Blackfoot 3D dataset.

Frequency enhancement is applied to the data. This process uses a stochastic deconvolution. The data is divided into multiple frequency windows through spectral decomposition. This is an ensemble approach that follows the method used by Nagarajappa and Downton, 2009.

To preserve the AVO trend, it is assumed that, over some reference bands, the frequency spectrum is flat and has a high signal-to-noise ratio. The process then defines a signal envelope set over larger spectral range thus enhancing the higher frequency without compromising the amplitude integrity.

Each frequency window within the trace is then whitened to the same energy level as the reference band, thus preserving the amplitude trend.

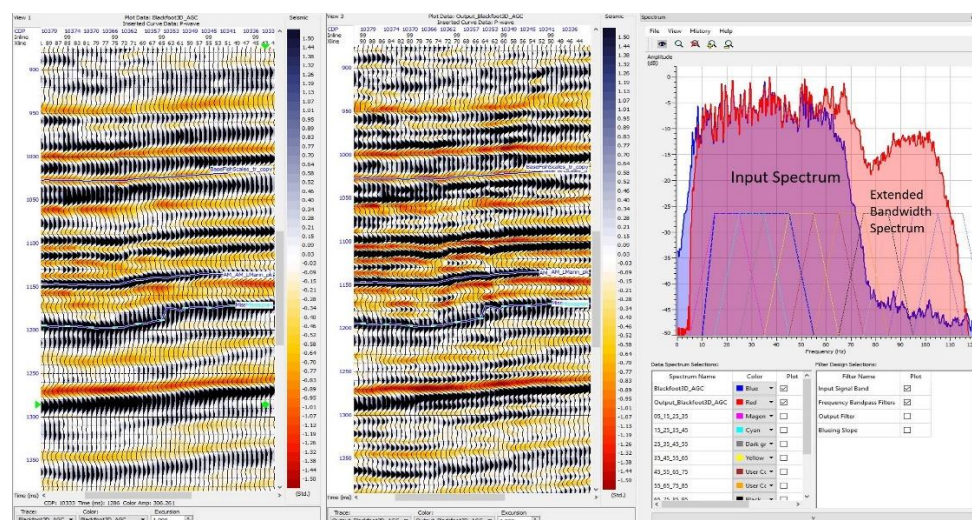


Figure 1: Spectral enhancement showing better definition of Mississippian unconformity

Seismic stratigraphic interpretation is carried out using a method of creating a dense set of horizons following polarity and energy trends within the seismic wavelet. The method thus allows sub-seismic resolution interpretation of sequence boundaries and flooding surfaces

(Figure 2). During the second step the inversion uses the results of the first step co-rendered with high resolution well data interpolated through seismic sequence stratigraphic framework.

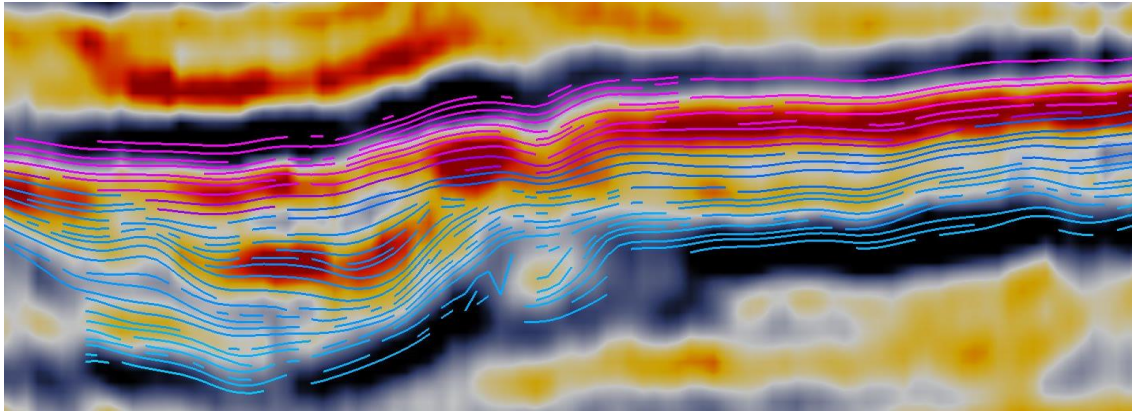


Figure 2: *Application of seismic sequence stratigraphy to enhance framework interpretation*

Input gathers are filtered using low cut filter thus leaving only high frequency information in the dataset. The data is then inverted using pre-stack simultaneous inversion to yield better inversion results while using 50 percent of the background model.

Discussion of the Results

Although the seismic bandwidth enhancement tries to preserve the amplitude information, certain amplitude effects of highly reflective unconformities where siliciclastic sediments lie over the carbonate beds could not be fully preserved during bandpass enhancement process.

By using cascaded inversion method, we could invert the main pass first and then detect the thin beds through the second pass of inversion while preserving the large geological framework.

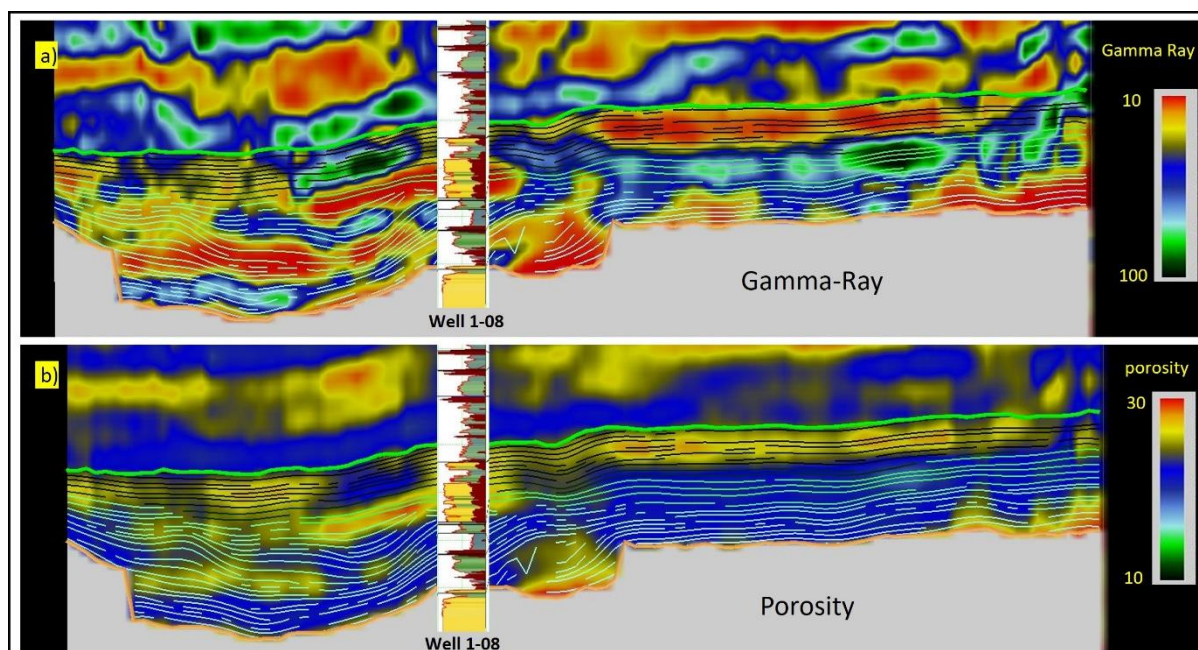


Figure 3: Porosity and GR property prediction using cascaded inversion technique with sequence stratigraphy controls

Conclusions

This study further confirms some of the concepts and limitations of band-limited seismic data to predict log properties but also shed light to the influence of geological details where algorithms are more efficient for limited frequency ranges.

Quantitative interpretation has progressed through many decades of advancements and has been reaching a mature stage where the answers to the rock property prediction lie in the integration of advanced gather conditioning, inversion methods, geological and statistical models and neural networks.

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