Prestack Seismic Attributes Applied to Deep Water Carbonate in the Atlantic Shelf.

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Abstract

Seismic attributes are widely used as an important tool during exploratory interpretation and reservoir characterization. In addition they are used for monitoring to determine facies changes, and to detect fluids and structural deformation patterns such as faults, fractures zones, and other deformations. Many seismic attribute studies have been done based on traditional poststack seismic data.

On the other hand, prestack data provides additional information that are often masked and/or filtered by the stacking process. Nevertheless, prestack data has not been broadly used in the interpretation workflow. In fact, prestack data is usually stored on tapes at some distance from the interpreter's workstation. Partially stacked volumes have been commonly used to generate elastic inversion attributes and AVO (Amplitude Versus Offset) attributes.

However, current technology lets interpreters to explore the prestack data on their workstation and calculate prestack attributes exposing effects that are masked by the stacking process which acts basically as a filter.

This paper presents a workflow for prestack interpretation, attributes calculation and visualization, and subsequently, the application of the prestack attributes on a carbonate reservoir. Seismic attributes which are calculated directly from higher frequency prestack data help to highlight faults and fracture in the reservoir.

Introduction

Seismic interpretation in the oil industry has historically used poststack seismic data which improves the signal-to-noise (S/N) ratio of the data (originally developed for land acquisitions). All of the basic geological interpretation of the subsurface stratigraphic and structural features has been made based on this type of data.

The stacking methodology was originally proposed by Mayne (1962) through a multiple-fold technique called common depth point (CDP). In this technique, sources and receivers are arranged such that the channels that represent CDP are recorded at different horizontal distances between shot points and receiver. Then those channels that have a common reflection point (CRP) in the subsurface, are combined and stacked (summed) being an extremely effective way to increase the S/N ratio.

However, the process of stacking offset seismic traces to a single trace results in a narrower frequency bandwidth.
Figure 1 shows an analogy between 2D raw image and frequency content with poststack and prestack seismic data. The Lena pictures serve as a comparison to illustrate changes caused by the differences in the frequency content of the data. Higher frequency shows more details in the picture. Similarly, prestack seismic data (pane below on the left), shows a wider amplitude spectrum (red curve on the right-below panel), when compared with poststack data (white curve on the right-panel below).

Note in Figure 2, the differences in the low and high frequencies in favour of the prestack data (prestack gathers have wider frequency content).

This paper presents a method for computing and applying prestack seismic attributes in a real dataset from a carbonate reservoir. The methodology starts by defining the seismic attributes. Next is a workflow for working with the prestack seismic data, followed by discussion of the application to our case .

Prestack Seismic Attributes

Prestack seismic attributes can be separated into three categories depending on how they are calculated. The attributes can be calculated in offset section, based on interpreted horizons (Windowed or Measured Attributes) or computed in time slices and calculated in volume.

In this study prestack attributes were calculated in sections, calculated in windows (instantaneous attributes), and exported to volume (Figure 3).

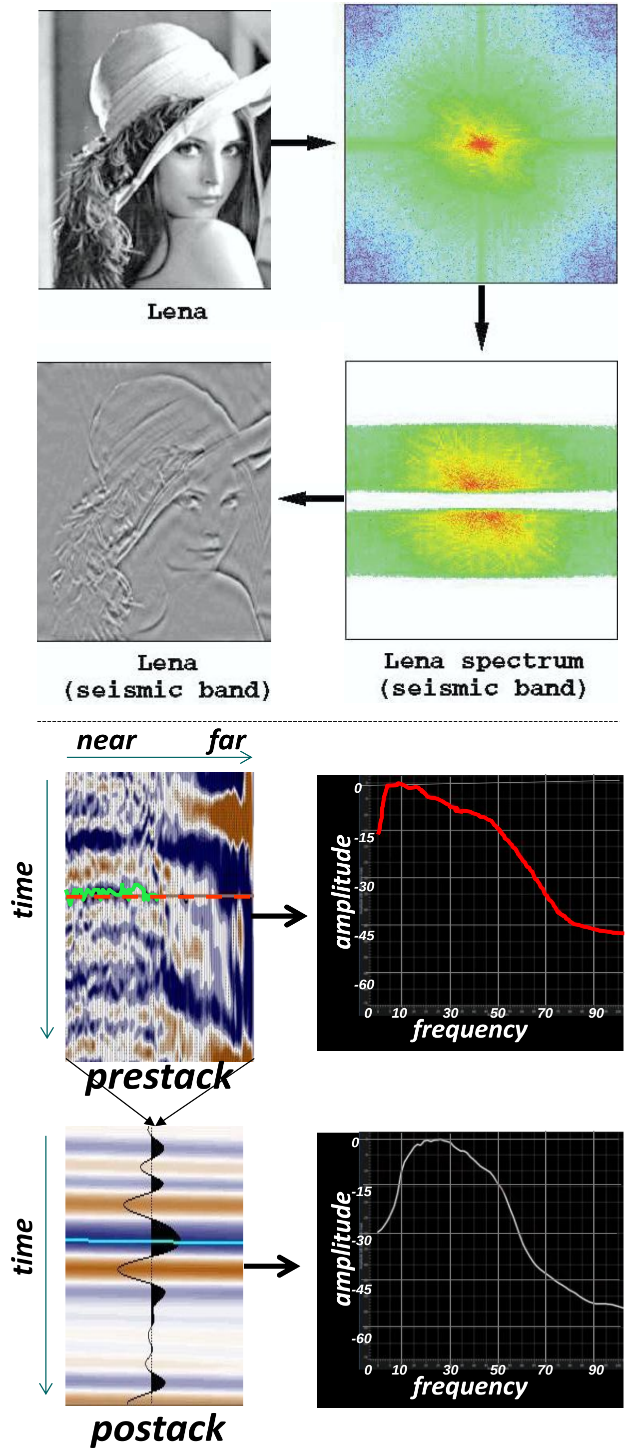

Figure 1. Analogy between 2D raw image and frequency content with poststack and prestack seismic data. The top pictures show a standard 2D image (Lena) and its calculated amplitude spectrum. Clipping the amplitude spectrum through a band pass filter (Lena Spectrum seismic band) results in a difference image (Lena seismic band – modified from (Liner,2000)). Similarly, prestack seismic data (pane below on the left), shows a wider amplitude spectrum (red curve on the right-below panel), when compared with poststack data (white curve on the right- panel below).

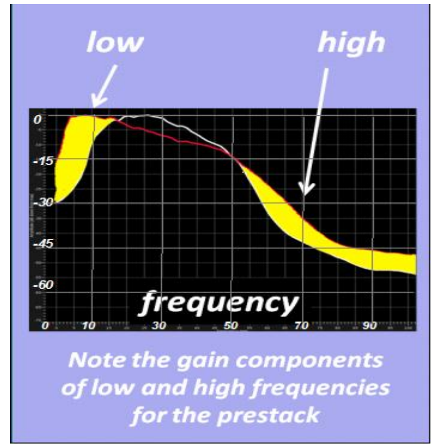

Figure 2. Amplitude Spectrum. White curve represents prestack data, white curve postasck data .Note the gain components of low and high frequencies for the prestack.

To compute prestack windowed seismic attributes, prestack seismic data must be pre-processed with multiple removals, spectral balancing, and NMO correction (Scott, 2011). An interpreted prestack horizon is also needed. This process is a bit more complex than interpreting a structural horizon directly from poststack seismic data because for a given time, amplitudes must be interpreted as a function of offsets. In conventional interpretation, for each time (t) and UTM coordinate (x, y) one amplitude value (a) is extracted. In prestack interpretation, for each time and UTM coordinate (x, y, t), an amplitude vs. offset or angle vector is obtained ($\vec{a}(\theta)$), and therefore one more dimension.

To facilitate this process, a method of auto-picking the prestack horizon was applied. In this process, the previously interpreted traditional stacked horizon works as a seed providing a reference time for automatic tracking.

Prestack Seismic Attributes Workflow

To compute prestack seismic attributes, an interpreted prestack horizon is needed. The idea is to select amplitudes associated with the target reflector in a reflection seismic data set corrected for NMO on each CMP gather.

The following steps must be completed prior to calculating prestack attributes: 1. Conventional structural interpretation performed using poststack seismic data; 2. Detailed velocity model building; 3. Incidence angle computations (optional – build and visualize angles of incidence).

The proposed workflow for the calculation and visualization of prestack seismic attributes is divided into three steps:

1. Interpretation of the prestack horizon to obtain selected amplitudes as a function of offset or angles of incidence (could be semi-automatic interpretation)
2. Calculation of the prestack attributes
3. Visualization and analysis of the results

An interesting challenge is related to the visualization of prestack seismic attributes. Because attributes varies as a function of offsets, another dimension is added (besides XYZ). There are ways to solve this, for instance, view the attribute above the gathers (header plot display – top side of Figure 3) or try to combine poststack data with prestack data using (2D or 3D) interpretation packages (bottom side of Figure 3).

A key step in this work was the prestack attributes visualization with post-stack seismic amplitude and attributes. Basically amplitudes vs. offset are rotated 90° clockwise so that the vertical axis becomes the offset. Then it is projected into a conventional seismic section (offset projected in the time direction, (x,y,t)) and can be used as a volume (Figure 4). By applying an opacity curve to this prestack attribute volume it becomes possible to co-visualize other 3D information with a regular time-of-depth seismic section.

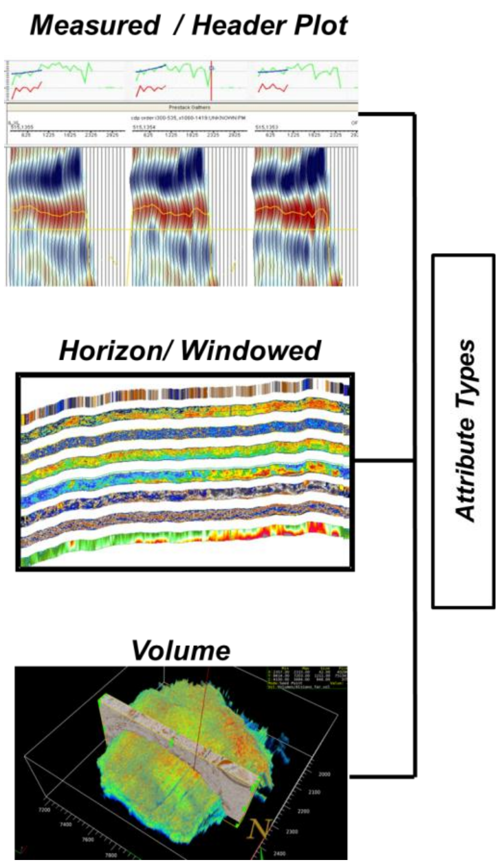

Figure 3 Prestack attribute classes – Measured attributes (visualized as header plots at the top-of-gathers); Windowed attributes (Instantaneous) using interpreted prestack horizons as guides, and exported to Volume.

Analysis and Discussion

25 different pre-stack attributes were calculated, including amplitude (Figure 5b), instantaneous frequency (Figures 5c to 5f), RMS amplitude, average amplitude, cross correlation (Figure 5g), instantaneous phase (Figure 5h), modeled amplitude, residual amplitude, intercept, and gradient.

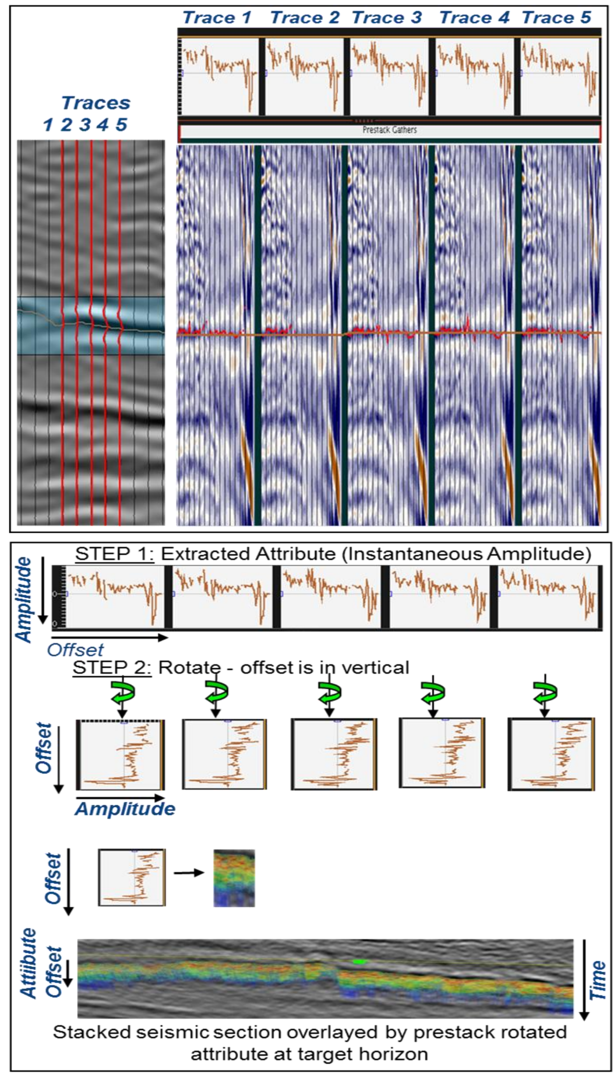

Figure 4 The top panel shows the poststack seismic and corresponding gathers, a correlation window for semi-automated interpretation, an interpreted prestack horizon, and a header plot of amplitudes. The bottom panel was inspired from Fink (Fink, 2010) and shows how to visualize prestack and poststack data.

Figures 5b to 5h present different pre-stack attributes computed for the same target horizon and underscore the value these attributes have when compared to a conventional amplitude map (horizontal slice - Figure 5a). These pictures look like a map, but they are actually attribute volumes obtained using 3D visualization techniques combining color and an opacity curve and visualized from top to bottom (optical stacking). Note the regions where the discontinuities occur such as faults and fractures (black lineaments NE-SW) marked differently in each attribute.

The instantaneous frequency prestack attribute (Figure 5c to 5f) turned out to be of great interest due to characteristic variations depending on the frequency bandwidth being studied. Low frequencies emphasize certain discontinuities differently. For example, comparing Figure 5d (frequency range 10Hz to 25Hz) with Figure 5e (frequency range of 25Hz to 35Hz (green)) and Figure 5f (frequency range of 35Hz to 55Hz (red)), we can highlight different faults and their extensions and influence zones.

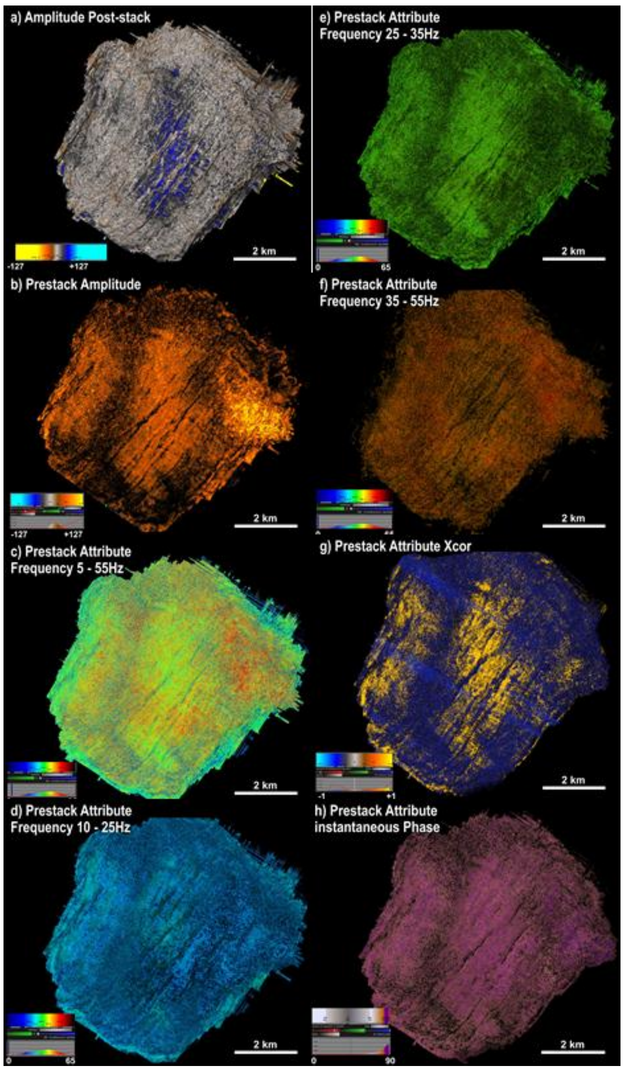

Figure 5 Map view of prestack attribute volumes with opacity curves (optical stacking) computed for the same target horizon: a) conventional amplitude map (horizon slice); b) prestack amplitude, c to f) instantaneous frequency; g) cross correlation (Xcor); and h) instantaneous phase. Note the regions where the faults or discontinuities occur are well marked as a NE-SW trend in black.

Figure 5g shows the prestack Xcor attribute that is the cross-correlation coefficient between the pilot trace and its neighbor in the chosen time window. In this case it measures the degree of similarity in the same gather for different offsets. This attribute presents interesting features because some faults (blue - low correlation) are well marked among the high correlation values (represented by yellow).

Conclusions

Prestack seismic data has a richness of information that is usually hidden from interpreters because the data is generally stored on tapes remote from the interpreters' workstations. However, prestack seismic data has higher frequency content than conventional poststack one. Therefore, some features such as faults and fractures are highlighted when prestack seismic attributes are computed, visualized, and correlated with other informations.

By using prestack seismic data and calculating prestack seismic attributes, we can obtain structural and stratigraphic information that is often masked by the stacking process.

Prestack attributes let us discover more geologic features than poststack attributes do. Depending on attribute selection, different characteristics can be exposed and in this carbonate case study, these attributes became an important interpretation tool that disclosed faults' deformation zones features.

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