Prestack Visualization Strategies for Reservoir Analysis

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Abstract

Camargo et al. (2013) present a workflow for prestack interpretation, attributes calculation and visualization, and, subsequently, the application of the prestack attributes on a dataset. Seismic attributes, which are calculated directly from higher-frequency prestack data, help to highlight faults and fractures in the reservoir.

This paper focuses on detail visualization techniques of these prestacked attributes and results, in addition to interactive integration between prestack gather and post-stack seismic data within the same interpretation environment.

Figure 1 illustrates the methodology of extracting prestack attributes along an offset/angle domain at a target horizon. The offset/angle attributes from each prestack gathered are rotated 90° into vertical position and hang at the time (or depth) specified by a target horizon to create a post-stack volume of prestack attributes at all trace locations. This volume can be co-rendered with other seismic in the section and a three-dimensional (3D) cube view. Interpreting the prestack attribute volume with the correct use of an opacity curve, color scale, and histogram can reveal additional geological details than using the conventional seismic interpretation approach alone.

Furthermore, volume interpretation techniques that derive a combination of multiple attributes pixel shading, directional light sources, and voxel illumination using graphics processing unit (GPU) computational resources are discussed. The possibilities of co-rendering and combining prestack attributes are presented. Additionally, various methods are discussed and examples are given of interpreting faults in a prestack cube to capture additional details, which can be used for improving geological models.

Introduction

Interactive visualization of available prestack data in workstations provides a vital integration with various types of information available in a volume rendering, such as maps, seismic sections, seismic cubes, horizons, well logs, cultural geo-referenced data, dynamic models, etc.

Through the volumetric interpretation, it is possible to interpret a large amount of seismic data in its true spatial location, facilitating the mapping and understanding of stratigraphic features and complex structures. It also helps reservoir characterization, validating how the given seismic information can be integrated into the wells and through other reservoirs, which provides new insight into the depositional models of reservoir rocks, stratigraphic stacking patterns, structural geology, and architecture (Abreu et al. 2001; Spinola et al. 2001).

By using several seismic sections, 3D cubes, several seismic attributes, and the possibility of data visualization through different perspectives and different angles, it is possible to better realize and understand the spatial relationship of seismic reflection characteristics.

Fink (2010) proposes an elegant approach to analyze and interpret prestack seismic data (Figure 1). The main challenge is that the prestack gather exists in a nonphysical domain (x, y, z, and offset/angle) instead of the physical space domain (x, y, and z). Because geoscientists do not usually interpret on the angle or offset domain, a common practice is to bypass the prestack seismic data and/or use the simple forms of partially stacked volumes, known as volume near/mid/far. There is a strong requirement to fully integrate the prestack data to the two-dimensional (2D) and 3D seismic interpretation environment, so that the interpretation work can be performed interactively and effectively. Figure 2 shows a realization of a dynamic interpretation environment with prestack and post-tack data that are seamlessly integrated.

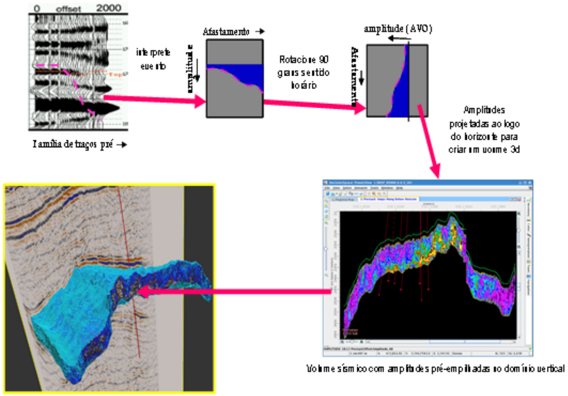


Figure 1. Method to create prestack attribute volume where the prestack attribute is rotated 90° and positioned at the interpreted horizon on the vertical axis (top images). Results in a section and cube view are displayed in the lower images.

Geoscientists should use the prestack gather to validate if an observed seismic anomaly is truly related to geological changes or just an artifact from seismic acquisition or processing. Visualization of prestack gather and prestack attribute volume simultaneously with post-stack seismic data in an interpretation environment enables the interpreter to achieve this validation effectively. Figure 2 illustrates a realization of advanced technology developed to support this high level of integration (prestacked seismic data and 2D and 3D visualization), both geological and engineering. Each set of data has a specific color scale and can be combined through a section where the bottom is conventional seismic data and prestack data can be superimposed by an opacity curve.

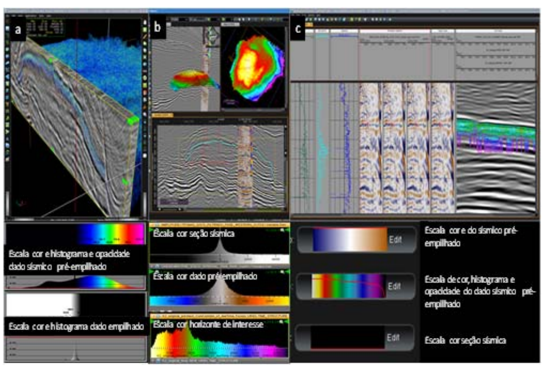


Figure 2. Interactive 2D and 3D visualization and interpretation incorporating prestack data. Note that all panels, seismic sections, and well logs are dynamically integrated and connected. From left to right: a) volume interpretation with stacked seismic (black and white color scale) and prestack instantaneous frequency attribute (high frequency in red and low in blue); b) horizon of interest, seismic (black and white), well trajectory, and a family of prestack gather (colored); c) well logs, seismic gather, and section with co-visualization of instantaneous frequency.

Camargo et al. (2013) present a list of proposed prestack seismic attributes applied to carbonates. Additional attributes were also tested, and a smaller list of nine is presented in Table 1. The table highlights the respective attribute name, its applicability in terms of diagnosis or detectability of geological features, and a suggestion of color scale and opacity curve based on a histogram of attributes values computed.

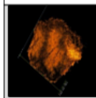
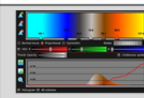
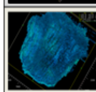
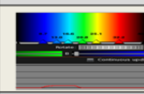
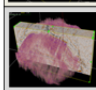
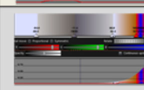
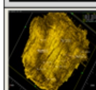
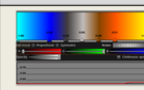
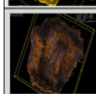
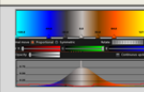
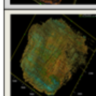
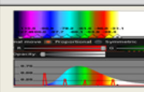
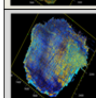
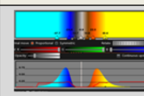
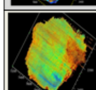
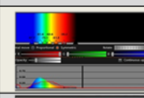
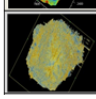
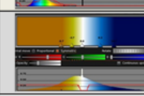
Horizon	Seismic Attribute	Application	Color Scale, Histogram and Opacity
	Instantaneous Amplitude (AMPINST)	Base for all attributes. Structural and stratigraphic discontinuities	
	Frequency (FREQ)	Shown to be good to reveal faults depending on frequency	
	Phase (PHASE)	Indicator of lateral continuity	
	Cross Correlation (XCOR)	Structural and stratigraphic discontinuities	
	Amplitude Median (AMPMDN)	Stratigraphic Discontinuities	
	Average Absolute Amplitude (AMPAVGA)	Structural and stratigraphic discontinuities	
	Absolute Maximum Amplitude (AMPABSMX)	Stratigraphic Discontinuities (read outliers)	
	RMS Amplitude (AMPRMS)	Structural and Stratigraphic Discontinuities	
	Pick Offset (PKOFFSET)	Overall quality control of data stacked. Difference lies in the greater offsets contribute less to the final stacking	

Table 1. List of proposed prestack volume attributes, their application and color scale histogram, and opacity as applied to carbonate.

A good practice is to display semitransparent prestack attributes in the foreground (e.g., similarity Xcor, AMPMOLD, phase, or frequency) with conventional seismic in the background in either the 2D section or 3D cube. This practice helps ensure the knowledge of the geological formation and is appreciated while highlighting specific properties of the reservoir; for example, faults and fractures (Figure 4).

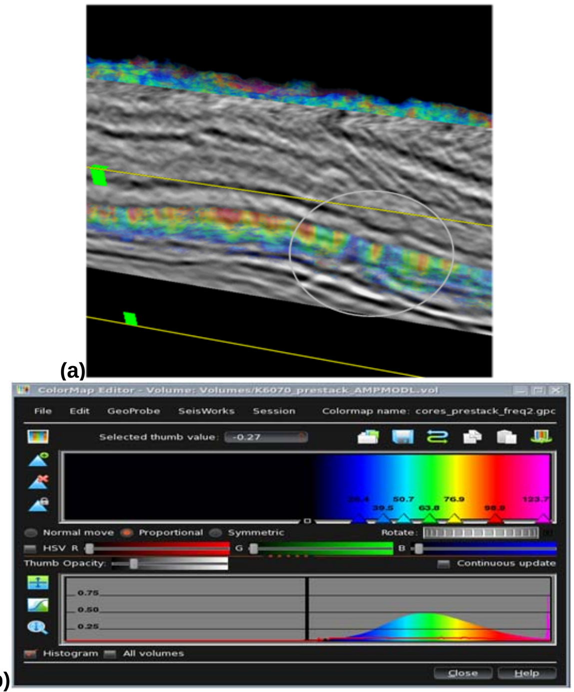
(a)
(b)


Figure 4. (a) Seismic section at background and modeled amplitude (AMPMOLD) prestack attribute in a semitransparent mode at the foreground. Note that in the highlighted region in the vicinity of faults, amplitude values for all offsets disappear; (b) an opacity curve is applied to AMPMOLD. Warm colors represent high values of the attribute.

A useful strategy for structural interpretation is to select a seismic section display post-stack and pre-attribute and observe behavior of the faults in a map view (Figure 5).

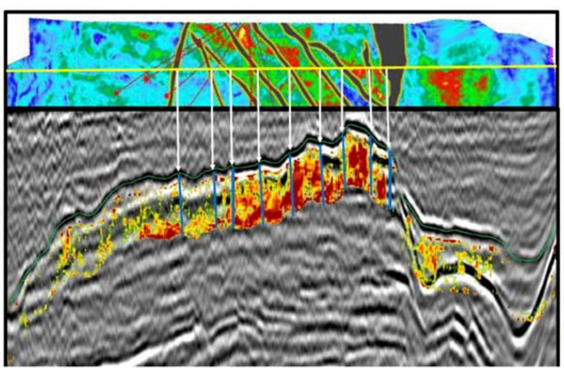


Figure 5. Strategy: a map view and seismic section overlaid by semitransparent prestacked attribute.

Co-visualization and Attributes Combination

The combination of two prestacked attributes through co-visualization or co-rendering (dynamically calculated using the computational resources of a graphics card—GPU) is fundamental in the process of interpretation and interrogation of data. Several techniques of volume rendering using the mixture of colors (probe blending), pixel lighting [pixel shade or bump mapping (Barnes 2008)], directional light (shaded illumination) and positional, and voxel lighting (voxel illumination) are used. Table 2 summarizes key prestacked attribute volumes using color scale, histogram, opacity, and voxel lighting.

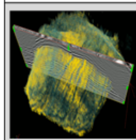
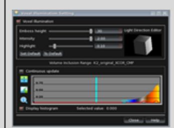
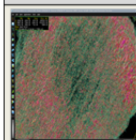
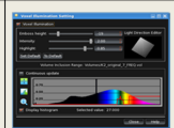
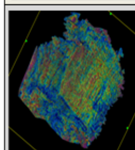
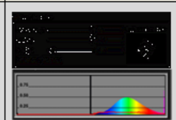
Target Horizon	Seismic Attribute	Application	Color Scale, Histogram and Opacity
	Cross Correlation voxel with illumination (XCOR)	Structural and stratigraphic discontinuities	
	Instantaneous frequency with voxel illumination (FREQ)	Shown to be good to reveal faults depending on frequency	
	Modelled or Predicted Amplitude (AMPMODL)	Straight line calculation (dip, tend, gradient) of the measured amplitude for each offset richness details provided in this type of visualization, allowing identify depositional features that occur in carbonates	

Table 2. Summary of volumetric prestack attributes, application, color, histogram, opacity, and lighting applied to the carbonates. Note the possibility of revealed geological features.

Barnes et al. (2011) address the challenge of making the seismic data look more like geology, taking into account processing, seismic attributes and visualization tools, including co-visualization. Basically, co-rendering using structural attributes (curvature, dip, azimuth, fault attribute, and discontinuity) in the background (on a scale of gray tones) and stratigraphic attributes (original seismic, reflection strength, sweetness, parallelism, and acoustic impedance) in the foreground using opacity scale and joining lighting (pixel shade, bump mapping, or voxel illumination) is a recommended strategy for post-stacked attributes.

Table 3 summarizes a general strategy with three different visualization techniques—namely, illumination, opacity, and co-visualization. With illumination, a directional source of light can be obtained in a 3D rendering scene, which can be adjusted to highlight discontinuities. Applying directional lightning on attributes, such as amplitude or semblance, can help to reveal faults, especially if a light source is positioned at a low angle (Figure 6).

If a zone in a 3D scene appears in shadow or too dark, using a positional source of light (positional illumination) helps clarify the scene and visualize stratigraphic details (Figure 7).

Finally, with voxel illumination, each individual voxel receives an incident directional light, and a combination of these voxel forms texture-like attributes that help highlight variations in stratigraphy or structure. Interesting results using instantaneous frequency are shown in Figure 8 and Table 2. Figure 9 illustrates a comparison of prestack AMPMOD attributes with and without voxel illumination.

Opacity sculpting, either in a section or in volume, helps reveal details about stratigraphy when volume sculpting the area of interest, generally between the top and base of the stratigraphic sequence (Table 2, Line 1). Only the interest area in a reservoir can be volume rendered.

Finally, co-visualization is a powerful tool for rendering simultaneously myriad attributes. Figure 8 combines stratigraphy and structural prestack attributes (orange is a Class II amplitutde versus offset (AVO) (Rutherford and Williams 1989) anomaly volume rendered with voxel illumination, and prestack semblance computes are shown in blue with discontinuities in black).

VISUALIZATION			
Visualization Techniques		Attribute	Application
Ilumination (Light Source)	Direcional	Amplitude Semblance	Faults
	Posicional	Amplitude	Stratigraphy
	Voxel	Frequência Instântanea	Faults & Stratigraphy
Opacity	Section	Amplitude	Stratigraphy
	Volume Sculpting	Pre-stack Attribute (AMPMOLD)	Faults
Co-rendering	Bump Maping/Pixel Shade	Amplitude, Semblance, Curvature	Structural
	Proble Blending	Correlação Cruzada Amplitude Semblance	Depositional features
	Pre-stack and stack seismic	Instantaneous Frequency	Faults

Table 3. Summary of the possibilities of visualizing and integrating prestack and post-stack seismic data (inspired by Barnes et al. 2011).

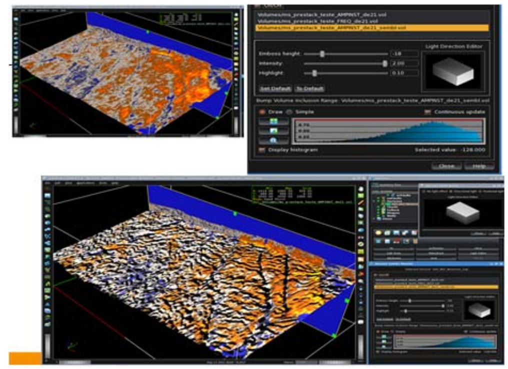


Figure 6. Strategy: a horizon slice overlay with prestack attributes: amplitude in combination with correlation (semblance). The possibility exists of using a section with the co-visualization attributes (blending volume).

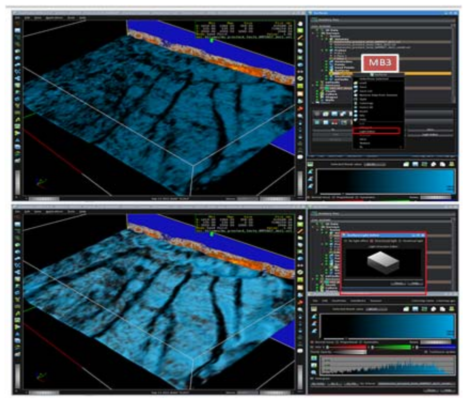


Figure 7. Strategy: apply directional light above the horizon of interest showing the pre- or post-stack seismic attribute. The possibility exists of using a seismic section with co-visualization attributes.

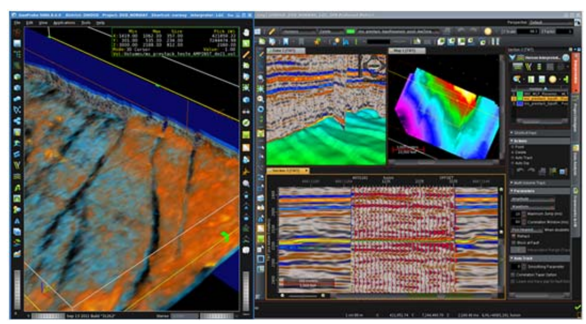


Figure 8. Strategy: advanced visualization combines a volume interpretation and traditional interpretation environment to integrate various types of information and data available. (Left) Prestack amplitude with opacity through voxel lighting co-rendered with a semblance horizon (blue and black); (right) seismic data with prestack in a section and cube and interpreted horizon (color scale in depth) .

Fault Interpretation in Prestack: Interpreting Faults Segments

The traditional method of interpreting faults is performed on 2D seismic sections, where the fault segments are marked and then interpolated to generate fault planes. In general, faults and fractures interpretation confidence is also strongly dependent on the seismic quality.

In the volume interpretation method, an animation of volumes displaying as probes (either in horizontal slices or vertical sections) or employing the horizon volume range is an effective tool to understand the structural framework for the interpretation process (Abreu et al. 2001).

Another valuable tool for fault interpretation is based on the analysis of post-stack seismic attributes. During the last few decades, seismic coherence has been one of the most heavily used attributes. By combining horizontal coherence slices with previously interpreted fault planes, the risk of incorrect interpretation is reduced significantly. Ideally, the interpretation of fault planes should be performed using the opacity monitoring technique on a volume of calculated coherence. In this approach, a suitable opacity curve should be used to improve the low coherence values associated with the fault planes of consistency calculated volumes. Two strategies for the interpretation of faults using seismic data prestacked are presented in Figures 9 and 10.

In Figure 9, a section of traditional gray scale seismic is in the background and the modeled amplitude prestack attribute is in foreground. Note that prestack attributes become discontinuous at the closing to each fault segment. Fault segments could be interpreted in each section and build the fault plane in 3D.

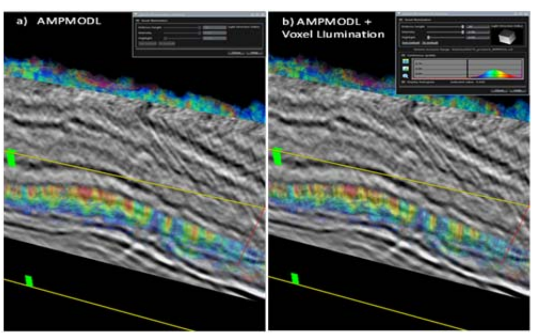


Figure 9. Strategy: (left) fault correlation with prestack attributes (modeled amplitude) superimposed on a seismic section. Note that regions in red appear between faults and might be related to stratigraphic features also. The faults appear as blue valleys. (Right) Modeled amplitude acquired 3D texture features with voxel illumination.

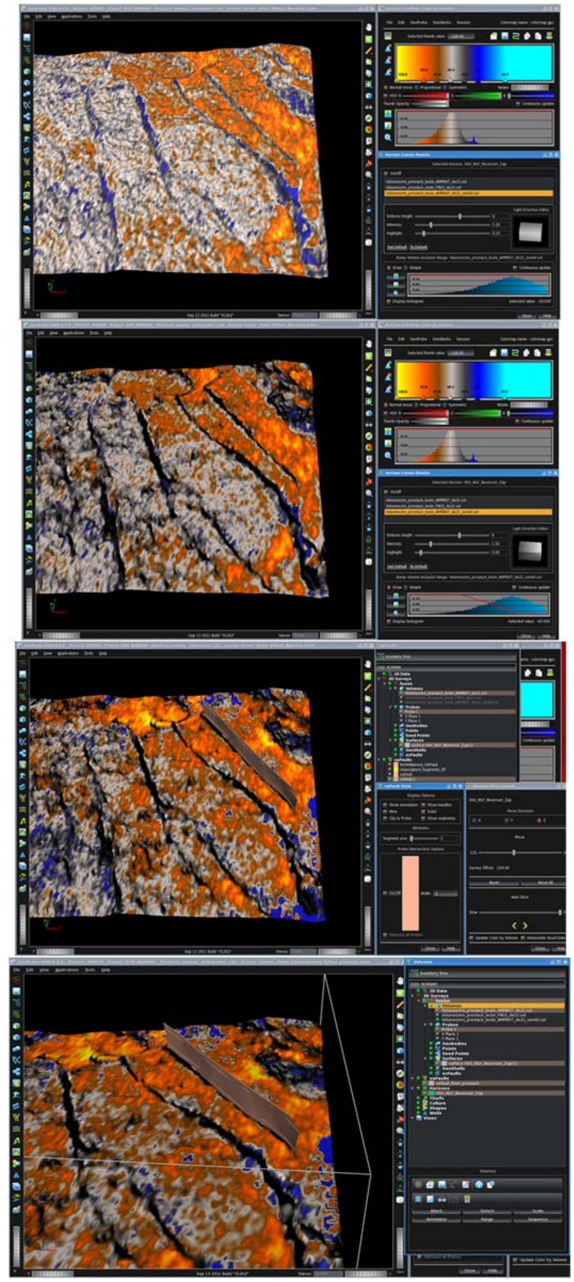


Figure 10. Strategy: interpret fault segments in different offsets using a prestack amplitude volume along the horizon of interest. Begin to interpret fault segments at offset zero. Then, through the animation (displacement) of the interest horizon, continue to interpret fault segments belonging to the same fault planes. Repeat this for other faults using the same horizon. Calculating other prestack attributes volume to different horizons should be completed.

The interpretation in the prestack attribute with fault segments being interpreted at different offsets simultaneously with amplitude and semblance co-rendered at one offset is applied as a different strategy (Figure 10).

Conclusions

The combination of prestacked attributes through co-visualization or co-rendering is fundamental in the process of interpretation and interrogation of data.

A best practice is to display prestack attributes applying an opacity curve in the foreground and conventional seismic in the background, either in 2D sections or 3D cubes. This guarantees the knowledge of the geological formation is respected while highlighting specific properties of the reservoir; for example, faults and fractures or stratigraphic details.

Incorporating full prestack data interactively into the 2D and 3D seismic interpretation environments enables integration of all available data sources, improves reservoir characterization, and might indirectly impact reservoir management and production optimization strategies.

A number of possibilities for co-rendering and combining prestack attributes is presented to capture additional details and information that can be used to update geological models.

Acknowledgments

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