Curvatures lineament and multi-attribute display of full-stack PP, SS, and Acoustic Impedance seismic data – Diamond-M field, West Texas

Ha T. Mai*, Carlos F. Russian, Kurt J. Marfurt, Roger A. Young, University of Oklahoma, Norman, USA; Alison Weir Small, Parallel Petroleum Corp.

Summary

Geometric attributes are routinely used in mapping tectonic deformation and geomorphology. AVO and inversion analysis is routinely used to map lithology and the presence of hydrocarbons. We apply geometric attributes to full-stack PP and SS as well as acoustic impedance inversion volumes over the Diamond M survey, Horseshoe Atoll, west Texas, and find lineaments corresponding to the edges of the Pennsylvanian-age reef structure.

Introduction

The large subsurface feature termed the Horseshoe Atoll, located in the Midland Basin of west Texas, is a series of primarily Missourian and Virgilian-age carbonate reservoirs (Reid, 2001). The data available for this research covers part of the Diamond-M field which lies in the Scurry Reef Trend in Scurry Co., Texas (Figure 1). Since the development of the Kelly-Snyder oil field, exploration has moved southeast of the atoll in search of small reef bodies (Jumper and Pardue, 1996). Our goal is to evaluate the effectiveness of curvature-related lineaments in better defining reef edges as well as internal fractures within the reefs.

Theory and Method

Curvature of a surface is measured by the radius of two circles tangent to it. The circle with the tightest radius defines the maximum curvature ($k_{\text{max}}$) while the circle perpendicular to it defines the minimum curvature ($k_{\text{min}}$). In further clarification, $k_{\text{max}}$ of a surface with an anticlinal shape has a positive value, while $k_{\text{max}}$ of a surface with synclinal shape has a negative value (Figure 2). Also, the intersection of the plane containing the circle defining minimum curvature with the horizontal defines a strike, which is commonly referred to as the azimuth of minimum curvature, $\psi_{\text{min}}$.

A folded surface can be further defined as having a certain shape, measured by the shape index (e.g Roberts, 2001). Furthermore, the long axis of elongated domes, ridges, saddles, valleys, or elongated bowls corresponds to $\psi_{\text{min}}$. By modulating the shape indices with the curvedness, $c$ (where $c^2 = k_{\text{min}}^2 + k_{\text{max}}^2$) Al-Dossary and Marfurt (2006) show how we can generate different shape components.
Combining multiple attributes in a single image allows us to visually ‘cluster’ mathematically different attributes that are sensitive to the same underlying geology. In Figure 2, we show a composite image of the ridge component of curvedness, $c_r$, and $\psi_{min}$.

For a more conventional display of these lineaments, we generate rose diagrams for any defined $n$-inline by $m$-crossline analysis window. Within each analysis window, we threshold the ridge or valley components of curvedness, $c_r$, or $c_v$, bin each voxel according to its azimuth, $\psi_{min}$, and sum the threshold-clipped values of the ridge or valley components, thereby generating volumetric rose diagrams over a suite of windows spanning the entire seismic volume (Figure 4).

**Data**

We apply this simple workflow to three different data types for this project: the PP full stack, the SS full stack, and the acoustic impedance (AI) derived from a model-based sequential inversion. The zone of interest is isolated to a single time slice below the top of the Canyon Reef Formation where isolated reef build-up structures can be found. To this end, we analyze both the conventional P-wave and the more experimental S-wave (SH-SH) data volumes over the approximately 25 mi$^2$ (~65 km$^2$) of the Diamond M field described by Small et al. (2007). Both data volumes have a high signal-to-noise ratio and have been pre-stack time migrated onto 75ft x 75 ft (22 x 22 m) CMP bins.

The P-wave data was subjected to a model-based impedance inversion that used the well control to increase the overall bandwidth of the data. We anticipate that attributes computed from this acoustic impedance volume may illuminate structural lineaments not seen on the seismic reflection data.

**Interpretation**

The time-structure map corresponding to the top of the Canyon Reef Formation (Figure 5) gives a general idea of structure alignment related to the reef build up formation. The map shows a central big reef that expands laterally towards the eastern portion of the survey. Also, in the SE portion of the survey we can identify a smaller reef build up. Using the previously-defined workflow, we are not only able to estimate the outer most edges of the reef structure but also lineaments that might suggest the inner fabric and depositional control of this Pennsylvanian-age reef.

Nissen et al. (2007) have shown that volumetric curvature can delineate karst-enhanced fractures in the Fort Worth Basin, Central Kansas, and Western Kansas. Our goal here is to apply the described workflow to the three different data sets, thereby highlighting structural features such as minor reef build-ups or karst-enhanced fractures not previously seen.

We begin our interpretation with the PP data set, and include interpretation of what the authors interpret to be reef associated lineaments (Figure 6). Note the correlation of the most positive curvature anomalies and the edges of the central reef. Furthermore, interpretation of the western portion of the survey suggests that the previously identified reef structure continues to the west. This trend is also seen on the most negative curvature image. In most-positive and most-negative curvature blended image (Figure 6c), besides edges of the reef, we see indications of a reef talus slope deposited in the eastern flank of the central reef (white...
Curvatures lineament and multi-attribute display of full-stack PP, SS, and Acoustic Impedance seismic data – Diamond-M field, West Texas

arrow) correlating to a high amplitude respond on the amplitude map. In addition, we generate 2D multi-attribute display, combining ridge curvedness with minimum curvature azimuth, overlaid with volumetric rose diagrams (Figure 6d). This composite display, helps visualizing lineaments, with their intensity and orientation, which not only corresponds to the reef’s edges, but also potentially indicates inner-structure compartmentalization of the reef.

Although the lineaments from the PP and SS data volumes are similar, detailed comparison suggests that lineaments differ in some areas. In Figure 7, it can be seen that the most westerly lineaments (green arrows) cannot be detected and a central valley (black arrow) is not apparent. On the other hand, the SS dataset allows improved interpretation of the central “main” reef since the edges are better resolved and defined. Subsequent rose diagrams (Figure 7d) better define lineaments associated to the central reef.

Interpretation over acoustic impedance can lead to a more straight forward definition of lineaments, since the wavelet side lobes are strongly attenuated in the inversion process. Hence, the better delineation of the lineaments associated with the central main reef in Figure 8 (a-d), western reef build up, valley between the buildup reef previously denoted on Figure 7, and SE smaller patch reef showing very symmetrical and circular lineaments. As would be expected on the acoustic impedance results, there is a better definition of intensity and orientation when analyzing the rose diagrams (Figure 8d).

Conclusions

Volumetric curvature for lineament determination and multi-attribute display shows differences on the three different surveys: PP, SS, and Acoustic Impedance. Reef related structures were identified as their edges correspond to curvature lineaments. Sub-lineaments cutting reef edges suggest the possibility of compartmentalization, an interpretation that needs to be confirmed with production data. Curvature lineaments are more continuous in the acoustic impedance inversion volume.

Acknowledgments

The authors would like to acknowledge Parallel Petroleum Corporation for providing the data for this research, and the sponsors of the OU Attribute Assisted Seismic Processing and Interpretation (AASPI) consortium. Thanks to Schlumberger for providing OU with licenses to Petrel used in the interpretation and display.

Figure 6: PP data at time slice $t=935ms$ just below the top of the Canyon Reef Fm through (a) most-positive and (b) most-negative curvature volumes. (c) Multi-attribute display using transparency to show anomalous features seen in (a) and (b) on top of the seismic amplitude time slice. (d) Multi-attribute ridge-$\varphi_{max}$ display described in Figure 3 overlain by rose diagrams (in white).
Curvatures lineament and multi-attribute display of full-stack PP, SS, and Acoustic Impedance seismic data – Diamond-M field, West Texas

Figure 7: SS data at time slice $t=1871\text{ms}$ (just below the top of the Canyon Reef Fm and equivalent to 935ms in PP data) through Reef Fm through (a) most-positive and (b) most-negative curvature volumes. (c) Multi-attribute display using transparency to show anomalous features seen in (a) and (b) on top of the seismic amplitude time slice. (d) Multi-attribute ridge-$\psi_{min}$ display overlain by rose diagrams (in white).

Figure 8: Acoustic Impedance data at time slice $t=935\text{ms}$ just below the top of the Canyon Reef Fm through (a) most-positive and (b) most-negative curvature volumes. (c) Multi-attribute display using transparency to show anomalous features seen in (a) and (b) on top of the seismic amplitude time slice. (d) Multi-attribute ridge-$\psi_{min}$, display overlain by rose diagrams (in white).