Case History: Spicing up mid-continent seismic interpretation

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Summary

The Dickman field (Ness Co, Kansas) is a mature oil field associated with a regional upper Mississippian unconformity. Dense well control and 3D seismic allow detailed comparison of unconformity interpretation based on amplitude and various attributes, including spice. We find that spice peaks correspond to amplitude zero crossings, but offer tracking advantages at the highly discontinuous unconformity surface. In general tracking on spice peaks can be a viable alternative to difficult tracking on amplitude zero crossings. Furthermore, in high-velocity (low resolution) mid-continent rocks, comparison of spice with amplitude, instantaneous frequency, volumetric curvature, show spice to have much better geological detail in the vertical view, including subtle fault and fracture indications.

Introduction

The Dickman Field is located in Ness County, Kansas, was discovered in 1962 and has produced about 1.7 million barrels of oil. Fractured, porous, and solution-enhanced Mississippian shelf carbonates age are oil-productive from a small structural closure. Original oil water contact is at 1981 subsea and an oil column of 35 feet. Figure 1 shows a location map, Mississippian time structure, and profile A – A'. The contact between the porous Mississippian and the overlying seal (Pennsylvanian limestone, shale and conglomerate) is a karst surface, which is a slight angular unconformity and dips to the southwest. The Dickman Field reservoir also includes sandstones of the Lower Cherokee group locally deposited on the subaerial kast of the Mississippian-Pennsylvanian regional unconformity. Figure 1 shows the Dickman field stratigraphic section, including oil reservoirs (green dot) and deep saline aquifer (blue box).

Available data

Dickman Field well and seismic data have been used to conduct a detailed seismic attribute study. The seismic survey includes 3.325 square miles of migrated amplitude data (bin size 82.5 ft, time sample rate 2 ms). Attributes have been computed on the migrated data volume, including positive and negative curvature, energy ratio, spice, Petrel ant, instantaneous frequency and phase, and acoustic impedance. Here we limit discussion to amplitude, spice, curvature, and frequency. Geological data consists of 142 wells (some outside the 3D survey boundary), of which 45 have logs including GR (42), Neutron (26), resistivity (24), sonic (5, no checkshots), and density (4). Seven boreholes have core porosity and permeability analysis.

Amplitude and spice

Spice is an attribute computed on migrated stack traces using the continuous wavelet transform and the theory of singularity analysis (Li and Liner, 2008). In map view, spice provides evidence of lateral discontinuity similar to coherence (Bahorich and Farmer, 1995) while the vertical spice section contains a rich expression of bedform geometry and other stratigraphic details (Smythe et al., 2004).

Figure 2 shows the detailed relationship between seismic amplitude waveform features and spice. The base map (A) shows the orientation of a vertical section through five wells. All wells and formation tops use a shared time-depth curve for the Elmore 3 well. In the Shaben C-2 well, the Ft. Scott to top Miss interval (105 ft) has average velocity of 11650 ft/s. Dominant frequency is 35 Hz, giving a dominant wavelength of about 330 ft. The amplitude section (B) indicates a complicated relationship between the Mississippian formation top and reflectivity, due to resolution limits and the irregular nature of the Miss unconformity. A channel cut into the top Miss is indicated by the laterally discontinuous feature at the Elmore 3 well. The spice section (C) gives a detailed view of layering features. Variation in stratigraphy and depth at the unconformity are clearly indicated and allow the top Miss to be tracked much more easily than on amplitude data. An overlay of seismic amplitude wiggle plots on the spice attribute (D) demonstrates that spice peaks correspond to amplitude zero crossings. Spice has a similarity to instantaneous phase (not shown), but one of the many differences is that phase extrema (180 an -180 deg) correspond to amplitude peaks (not zero crossings).

Mississippian mapping with amplitude and Spice

The spice volume shows semi-conformable bedding planes, lateral discontinuities that are hard to see in amplitude volumes (like fractures and thin bed terminations), as well as subtle changes in curvature. Spice has a higher apparent resolution than amplitude, and therefore is more useful when trying to map subtle features. At the top Mississippian, a zero crossing in amplitude was auto-tracked as well as the corresponding peak in spice. Both events were tracked first in 8 intersecting 2D lines, with a 2 ms window, followed with 2 iterations of standard 3D tracking. Figure 3 shows the top Miss time structure map...
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from tracking amplitude (A) and spice (B). The spice map has better continuity across the mapped area with fewer tracking gaps. In the difficult channel zone, spice gives a much better time structure picture. Tracking an event in spice seems much more helpful for distinguishing small scale features than tracking the corresponding event in an amplitude volume.

Spice and other attributes

Since spice peaks correspond to amplitude zero crossings, it follows that when spice shows apparent thin beds the zero crossings are closer together, and this must relate to a local increase in data frequency. One such area in our data is near the Miss unconformity (Fig 2D). In Figure 3, we show (A) spice and (B) instantaneous frequency for data along the line in Fig 2. As expected, the frequency is often anomalous (high or low) at the Miss unconformity surface and could be used as a secondary attribute for mapping. However, frequency shows little vertical detail compared to spice and certainly could not be used as a substitute. Also shown in Figure 3 are (C) negative curvature and (D) positive curvature. Much like coherence, curvature attributes (Marfurt, 2006) are computed with an extended operator, while spice is a point-wise computation localized in both space and time. In this case, curvatures were computed with a 20 ms time window (red bar). Setting aside the vertical resolution mismatch, curvature and spice both indicate anomalous between the McKinley A-1 and Elmore 3 wells in the vicinity of the Miss unconformity (Nissen, et al., 2006). Curvature and spice are complimentary attributes that can be used to improve detailed interpretation.

Conclusions

We find that spice peaks correspond to amplitude zero crossings, but offer tracking advantages at the highly discontinuous Mississippian unconformity surface in the Dickman field of Ness Co, Kansas. In general tracking on spice peaks can be a viable alternative to difficult tracking on amplitude zero crossings. Furthermore, in high-velocity (low resolution) mid-continent rocks, comparison of spice with seismic amplitude, instantaneous frequency, and volumetric curvature, show spice to have much better geological detail in the vertical view, including subtle fault and fracture indications.

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Figure 1. Stratigraphic column for the Dickman field (Ness Co., KS). Oil production (green dot) is from the lower Cherokee sand and porosity-enhanced Salem and Warsaw limestone associated with the Mississippian unconformity. A deep saline aquifer (blue box) is also currently being studied for potential CO2 sequestration (Liner et al., 2009).

Figure 2. Relationship between amplitude and spice data. A) Base map showing vertical seismic line through selected wells. B) Amplitude section and formation tops. C) Spice data with tops. D) Spice data with amplitude wiggle trace overlay.
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Figure 3. Top Mississippian time structure maps. (A) Tracking result using zero crossing in the amplitude volume. (B) Tracking result using peak in spice volume. Note improved continuity on this irregular, karsted surface in the spice-generated map.

Figure 4. Relationship of spice to other attributes in vertical view along line in Fig 2. (A) Spice; (B) Instantaneous frequency; (C) Negative curvature; (D) Positive curvature.