Seismic Anisotropy in Coal Beds

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Abstract

Methods of measuring seismic azimuthal anisotropy are being used increasingly to detect fractures in reservoirs. Coal beds contain cleats, which are fractures in the coal that allow fluids, particularly methane, to flow through this type of reservoir. This suggests that estimates of seismic anisotropy may be useful for detecting cleats in coal bed methane (CBM) reservoirs. In this study, the azimuthal anisotropy estimated from a small 3D, shot over an area in Western Canada known to contain significant coal beds, is examined showing that significant anisotropy is associated with them. This suggests that estimates of azimuthal anisotropy may be a useful tool to optimize CBM reservoir management in the future.

Introduction

This paper is an examination of seismic azimuthal anisotropy and the possibility of its applicability to CBM exploration and development. CBM is an increasingly important fossil fuel resource in the USA (Figure 1) and there are substantial reserves available within North America, 60 TCF within the US Lower 48 alone according to the Energy Information Administration.
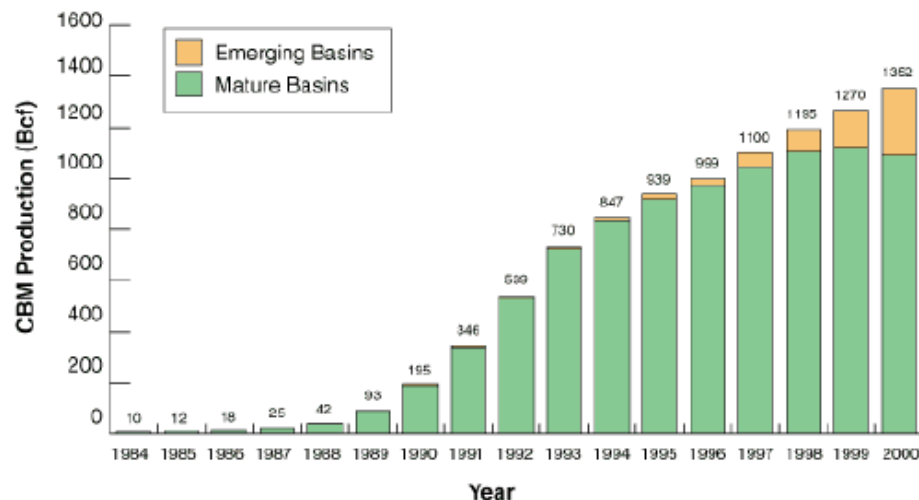

Figure 1. CBM production in the U.S. Lower 48 (www.eandpnet.com/cbm).

CBM is produced through a system of fractures in the coal beds that are known as "cleats" (Figure 2). If the system is entirely coal, as water is removed from the cleat system the reservoir pressure declines and methane is desorbed from the coal into the cleats causing gas production to begin through these cleats (Hower, 2003). It is thought that the cleats provide the permeability pathways in the system that allows the methane to be produced from the coal beds.

Fractures have been shown to produce azimuthal anisotropy in seismic data by many authors, e.g. Gray et al (2002), Gray et al (2003), Vetri et al (2003), Williams and Jenner (2003), Todorovic-Marinic et al (2004), and Hall and Kendall (2003). Since coal cleats can be considered to be fractures in the coal, then they should also be observable by seismic anisotropy estimates.

Figure 2. Outcrop showing cleats observed in coal (Alberta Geological Survey). The dominant cleat is oriented from bottom right to upper left and the secondary cleat is perpendicular to it and can be seen to truncate against it.

Azimuthal anisotropy estimates have been derived for a 3D seismic survey acquired in an area of Alberta, Canada that is known to contain extensive coal beds. Significant anisotropy is seen at the same depth in the sections as the coals of the Cretaceous Mannville Formation. The coal cleats are the most likely cause of the observed anisotropy. This suggests that seismic azimuthal anisotropy may indicate the distribution of the coals and/or the location of preferred permeability zones within them.

Theory

Azimuthal anisotropy is observed in seismic data when a seismic wave passes through a single set of vertical or near-vertical fractures with a density that is below the seismic wavelength. Coal cleats meet these criteria and so swarms of cleats may be observable through the use of seismic anisotropy. Cleats tend to occur in pairs with a dominant set of "face cleats" providing a preferred directional permeability and a secondary set of "butt cleats" that truncates against the dominant cleat providing connectivity (Figure 2). There may be scenarios that cause the dominant and secondary cleats to exchange permeability roles, such as a strong maximum horizontal stress field perpendicular to the dominant cleat. There is a strong possibility that seismic azimuthal anisotropy will be able to observe the dominant cleating direction since this anisotropy "sees" fluid-filled and gas-filled fractures (Gray and Head, 2000).

Seismic anisotropy has been observed in all modes of seismic waves (e.g. Liu et al, 2000). Early methods concentrated on the measurement of anisotropy using shear waves, but more recent developments have shown that significant anisotropy can be observed in P-wave amplitudes (e.g. Gray and Head, 2000) and velocities (e.g. Jenner, 2001). The most useful form of seismic anisotropy for coal beds is likely to be azimuthal AVO (AVAZ), which is a measure of the variation in the P-wave AVO gradient with azimuth, because it has the a similar resolution to standard seismic data and so may be able to detect anisotropy associated with these seismically thin layers.

Method

The Amplitude versus Angle and Azimuth (AVAZ) method (Rüger, 1996) is used to detect HTI (Horizontal Transverse Isotropy) anisotropy. It has been applied to the seismic gathers from the Erskine 3D seismic survey (Anderson and Gray, 2001) to generate estimates of seismic amplitude anisotropy. The Erskine 3D was shot over a part of the Mannville Formation that is known to contain coal beds. The coals can be seen on density logs from wells within the area of the 3D (Figure 3). We can compare the location of the coals as indicated on the logs to zones of high anisotropy within the Mannville Formation to see if they correlate. If they do, it is a strong indication that these coals cause azimuthal anisotropy in the seismic amplitudes. If so, then seismic anisotropy may be a tool to find areas of better permeability within the coals.

Results

Figure 3 clearly shows that seismic amplitude anisotropy is associated with the coals of the Mannville Formation. Significant seismic anisotropy starts in the section where the density log deflects to the left, indicating the Upper Coal. Another zone of high anisotropy seems to be associated with the Middle Coal, although the anisotropy is not exactly at the time of this coal. Tuning of the seismic wavelet with the thin coal beds may cause this. Overall, the Mannville section where the coals occur has the greatest level of anisotropy in the clastic section above the Paleozoic. In the Paleozoic, carbonate lithologies are encountered. Carbonates are frequently fractured or have anisotropic porosity like aligned vugs. These probably account for the increase in anisotropy observed in the Paleozoic. Gray et al (2002), Jenner (2001) and Pelletier and Gunderson (2005) have observed anisotropy in Paleozoic carbonates. The most likely cause for the anisotropy observed in the Mannville section is the cleats in its coals.
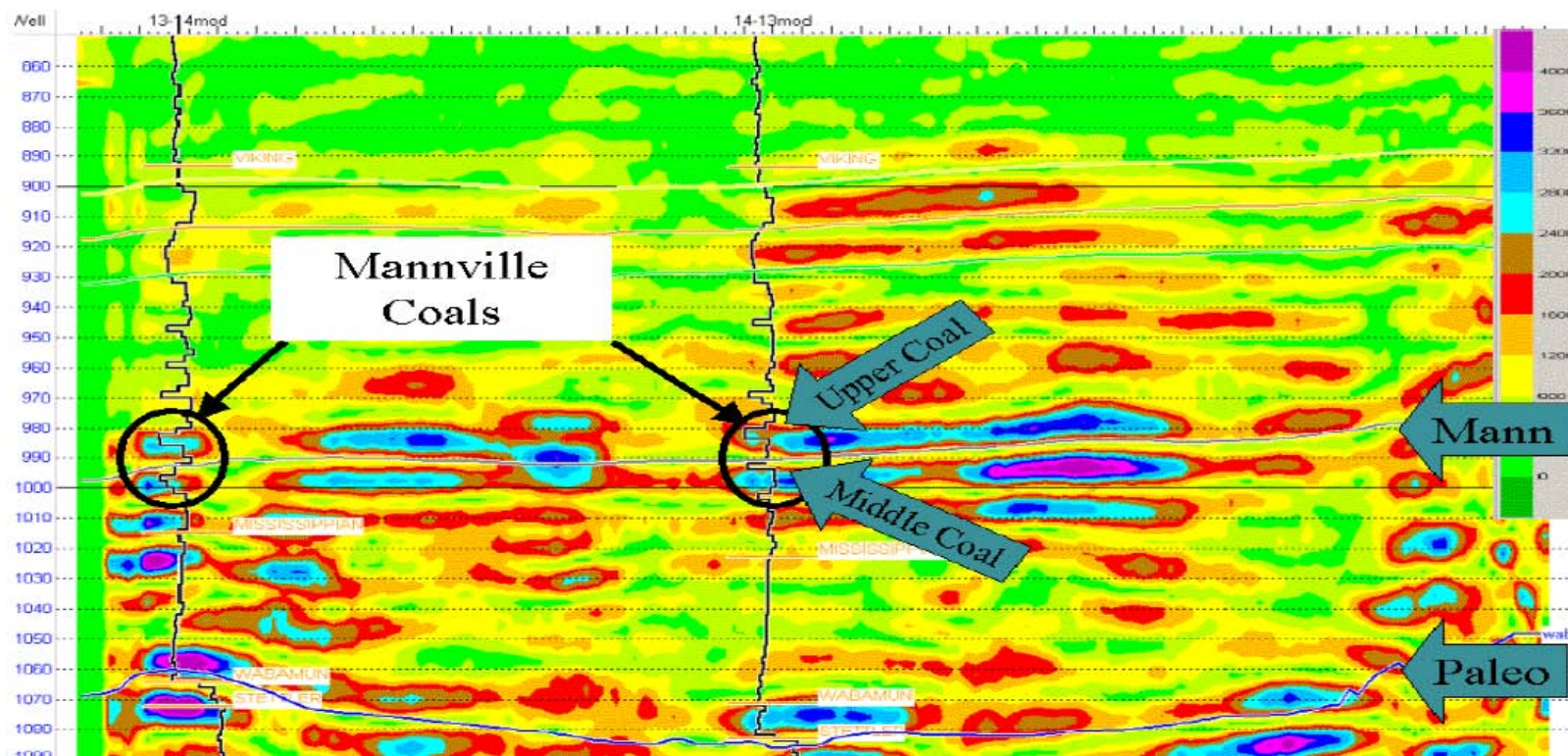
Figure 3. Observations of seismic anisotropy associated with the coals of the Mannville Formation, Erskine, Alberta Canada. The color represents the intensity of seismic anisotropy. The logs overlaying the section are density logs in which low values (deflections to the left) indicate the location of the Mannville coals.

The azimuthal anisotropy associated with the coals shows some lateral variation in Figure 3. Maps of this anisotropy shown in Figures 4 and 5 indicate the spatial distribution of the anisotropy for the Upper and Middle coals respectively. These maps show significant spatial variation in the intensity of the anisotropy associated with these coals. Furthermore, they show that the distribution of the anisotropy changes from coal to coal. Since the anisotropy is most likely caused by the cleats in the coals, these results suggest that there may be zones in these coals that have more significant cleating than others do. Alternatively, if the cleating in the coals is consistent, then the anisotropy may be indicating the distribution of the coals. In addition, since the method measures HTI, then zones of high anisotropy indicate areas where there is a preferred direction to the anisotropy. The lines overlaid on the anisotropy maps in Figure 4 and Figure 5 show the orientation of the HTI isotropic plane (the direction of the anisotropy). From this, it may be inferred that there is a dominant cleat direction in these areas. This indicates that there may be a preferred permeability direction and that it is likely be in the same orientation as is indicated by the anisotropy.

Conclusions

The amount of azimuthal anisotropy of the seismic amplitudes in the Mannville section is significantly higher than in the other clastic formations surrounding it. The anisotropy levels in the Mannville are similar to those seen in the carbonates of the Paleozoic section where such anisotropy has previously been associated with fractures. Numerous authors have observed that fractures in both carbonates and sandstones cause significant seismic anisotropy in P-wave seismic data. The strongest azimuthal anisotropy observed in the seismic data of the Mannville section occurs at the depths of the coals in this formation. Coals are known to have cleats, which can be considered fractures within the coal seams. Therefore, the most likely cause of the observed seismic anisotropy in the Mannville section is the cleats in its coals.

The observed seismic anisotropy varies within each coal and from coal to coal. This suggests that there is significant variance in the permeability and perhaps the distribution of these coals. If this indeed the case, then anisotropy should be useful in finding where the coals are and where within a coal the cleating is more dominant. Therefore, it is suggested that seismic anisotropy be used to optimize development of CBM reservoirs. Further work needs to be done to correlate seismic anisotropy with cleats observed in core and logs from existing CBM reservoirs in order to fully substantiate these conclusions.
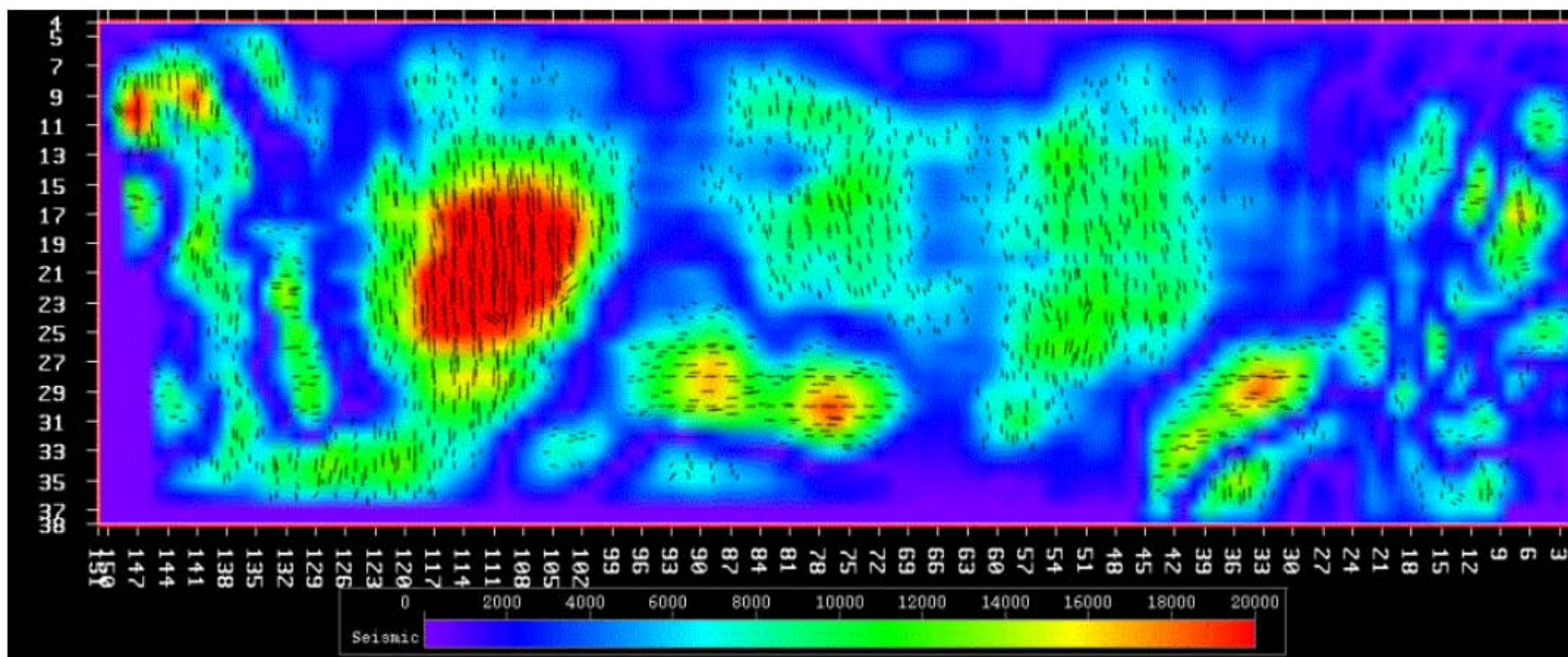

Figure 4. Map of seismic anisotropy in the Upper Coal indicated in Figure 3. Hot colors indicate higher levels of seismic anisotropy. The lines on the image indicate the orientation of the anisotropy. North is to the top of the figure.
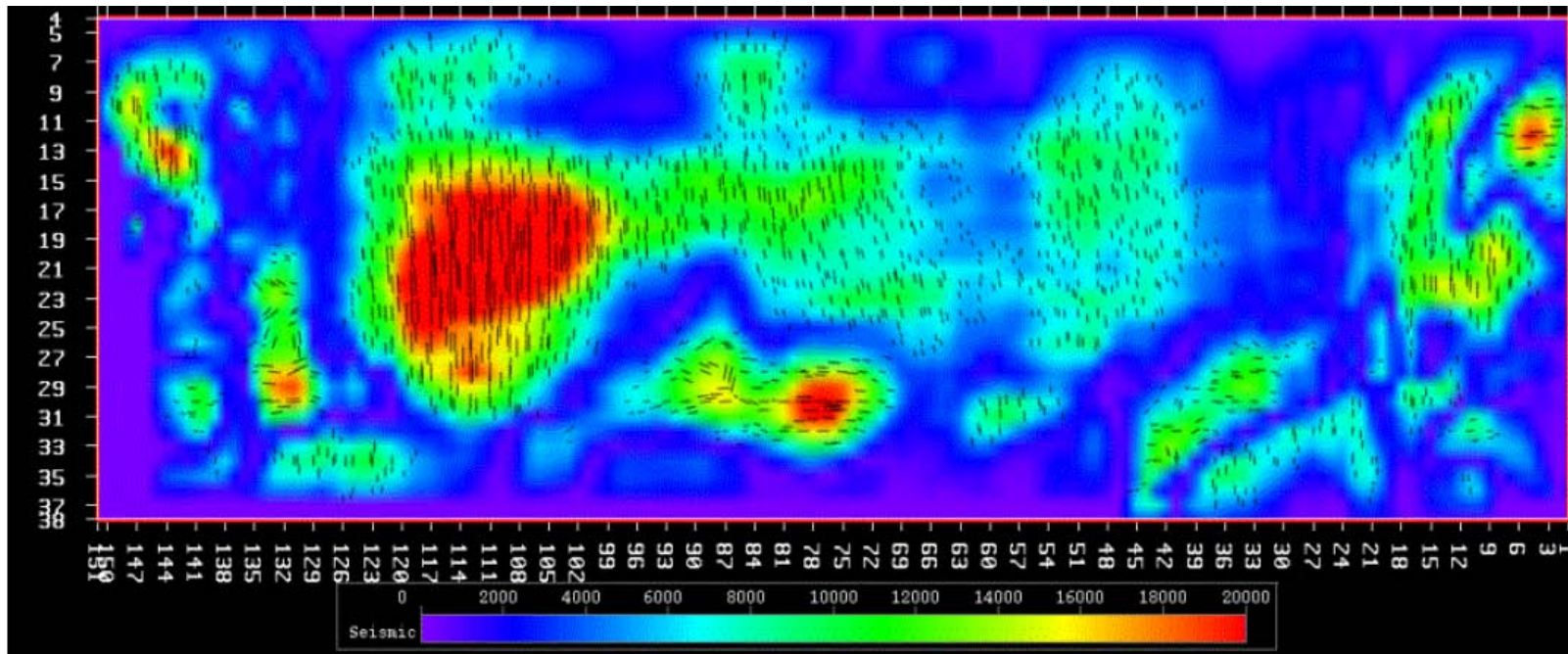
Figure 5. Map of seismic anisotropy in the Middle Coal indicated in Figure 3. Hot colors indicate higher levels of seismic anisotropy. The lines on the image indicate the orientation of the anisotropy. North is to the top of the figure.

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