Seismic Azimuthal Anisotropy: an Important Tool for Detection of Coal Bed Methane, an Unconventional Source of Energy- a review

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Abstract

Methods of measuring seismic azimuthal anisotropy are being used increasingly to detect fractures in reservoirs. Coal reservoirs are usually more abundant in fractures than any other ore bodies. However, not all the fracture nets have the same feature, neither can they lead to the same permeability and the same anisotropy. In coal exploitation, research on fractures is of vital importance in guiding the layout of working faces, mining and driving, the exploration and development of coal bed methane, the maintenance of roadways and the prevention of water and gas bursts. Therefore, to be able to forecast the direction and density of fractures in coal seams is of great importance for safe production and high efficiency of coal mining. This suggests that estimates of seismic anisotropy can be used for detecting cleats in the coal bed methane (CBM) reservoirs. In this paper we are going to present a review work of the application of azimuthal anisotropy estimated from a small 3D, shot over an area in Western Canada known to contain significant coal beds, and shows that significant seismic anisotropy is associated with them. This suggests that estimate of azimuthal anisotropy can be used for optimizing CBM reservoir management in the future.

Introduction

This paper is an estimation of seismic azimuthal anisotropy and the possibility of applicability to exploration and development. CBM is an important fuel resource in the USA (Figure 1) and there are substantial reservoirs available within NORTH AMERICA, 60 TCF within the US lower 48 alone according to the energy information Administration (Hower, 2003).

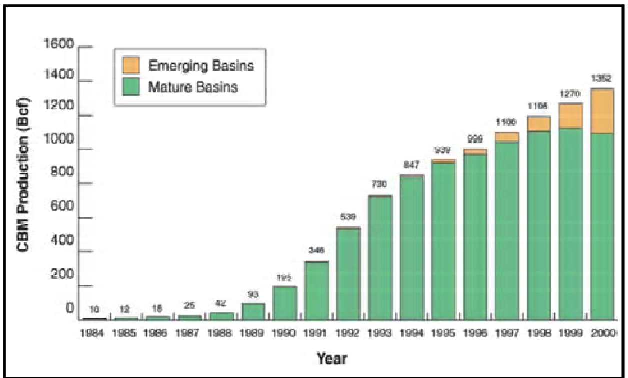

Fig. 1 CBM production in the U.S. Lower 48 (www.eandpnet.com/cbm).

CBM is produced through a system of fractures in the coal beds that are known as "cleats". If the system is entirely coal, as the water is removed from the cleat system the reservoir pressure declines and methane is desorbed from the coal into the cleat system causing the gas production to begin in these cleats. It is thought that the cleats provide the pathways that allow for the methane to be reported to generate from the coal beds. Many autohers have reoported that fractures prouduce azimuthal anisotropy in seismic data (GREY at. el. 2002 and GREY at.el.2003). Since coal cleats can be considered to be fractures in the coal bed, they should also be observable by seismic anisotropy estimate.

Azimuthal anisotropy estimates have been derived for a 3D seismic survey acquired in an area of Alberta that is known to contain extensive coal beds (Figure 2). Significant anisotropy has been seen at the same depth in the sections as the coals of cretaceous Manville formation (Dong, 2004 and Dong and Yang, 1999). The coal cleats are most likely cause of observed anisotropy. This suggests that seismic azimuthal anisotropy may indicate the distribution of coal and/or the location of preferred permeability zones within them.

Fig. 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. (Source: Gray 2006)

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 below the seismic wavelength. Coal cleats meet these criteria and so swarms of seismic cleats may be observable through seismic anisotropy (Liu, Crampin, Queen and Rizer, 2000). Cleats tend to occur in pairs with a dominant set of “face cleats” providing directional permeability and a secondary set of “butt cleats” that truncates against them. Dominant and secondary cleats exchange permeability roles (Liu and Wei, 1999). There is a strong possibility that seismic azimuthal anisotropy will be observable since this dominant cleating direction anisotropy sees fluid filled and gas filled fractures (Qu, Ji and Wang, 2001).

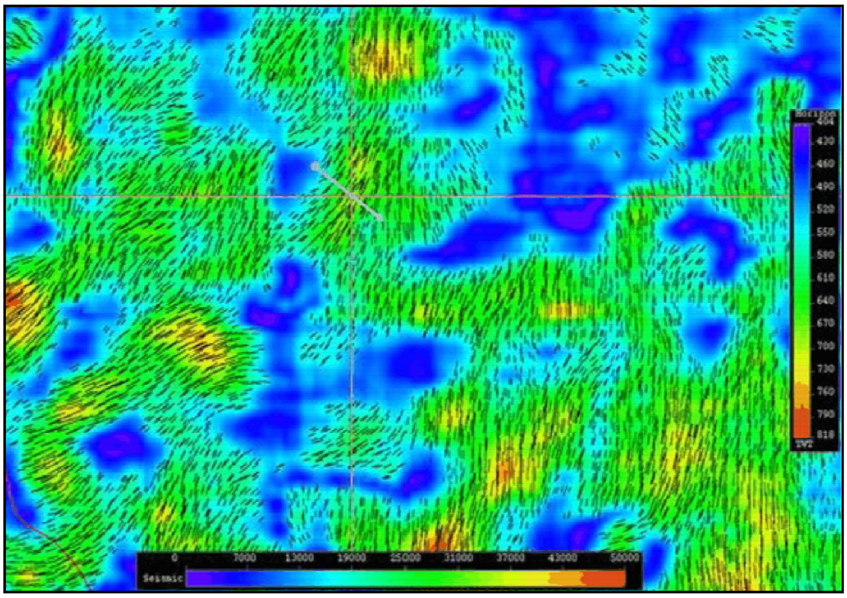

Fig. 3 Detail map of AVAZ intensity and strike indicating the relative fracture density and strike at this location in the reservoir. Note the well path marked in white, which crosses this level at the cross-hairs indicating moderately intense fracturing with a strike of NNE-SSW at the well location.
(Source: http://www.cggveritas.com/default.aspx?cid=3660&lang=1)

Seismic anisotropy has been observed in all mode of seismic waves. 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 and velocities (Antonic and Thomas, 1997). 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 (Rüger, 1996) (Figure 3). Because it has a similar resolution to the standard seismic data, one may able to detect anisotropy associated with these seismically thin layers.

Method

The Amplitude versus angle and azimuth (AVAZ) method is used to detect HTI (Horizontal Traverse Isotropy) anisotropy. It has been applied to seismic gathers in Erskine 3D seismic survey to generate an estimate of seismic amplitude anisotropy (Zhang and Dong, 2006) . The Erskine 3D was shot over a part of Manville Formation that is known to contain coal beds (Jenner, 2001). The coals can be seen on the density logs from wells within the area of 3D (Pelletier and Gunderson, 2005). We can compare the location of the coals as indicated on the logs to the zones of high anisotropy within the Manville formation to see if they correlate. If they do, it is a strong indication of azimuthal anisotropy in seismic amplitudes. If so, then seismic anisotropy may be a tool to find areas of better permeability within the coals.

Results

Figure 4 clearly shows that seismic amplitude anisotropy is associated with the coals of the Manville Formation. Significant seismic anisotropy starts in the section where the density log deflects to left, indicating Upper Coal (U&C). Another zone of high anisotropy appears to be associated with middle coal, although the anisotropy is not exactly associated with this coal. Tuning of the seismic wavelet with the thin coal bed can cause this.

In the Manville section the coal has highest level of anisotropy in the clastic section above the Paleozoic, where carbonate lithologies are encountered. Carbonates are frequently fractured or have anisotropic porosity like aligned vugs (Vetri, Loinger, Gaiser, Grandi and Lynn, 2003). These probably account for the increase in anisotropy observed in Paleozoic. Grey, Jenner and Gunderson (1999) have observed anisotropy in Paleozoic carbonates. The most likely cause of the anisotropy observed in the Manville section is the cleats in coals. The azimuthal anisotropy associated with the coals shows some lateral variations in the coals.If the cleating in the coals is consistent,then the anisotropy indicates the distribution of coals.Also since the method measures HTI, the zones of high anisotropy indicates the areas where there is a preferred direction of anisotropy.

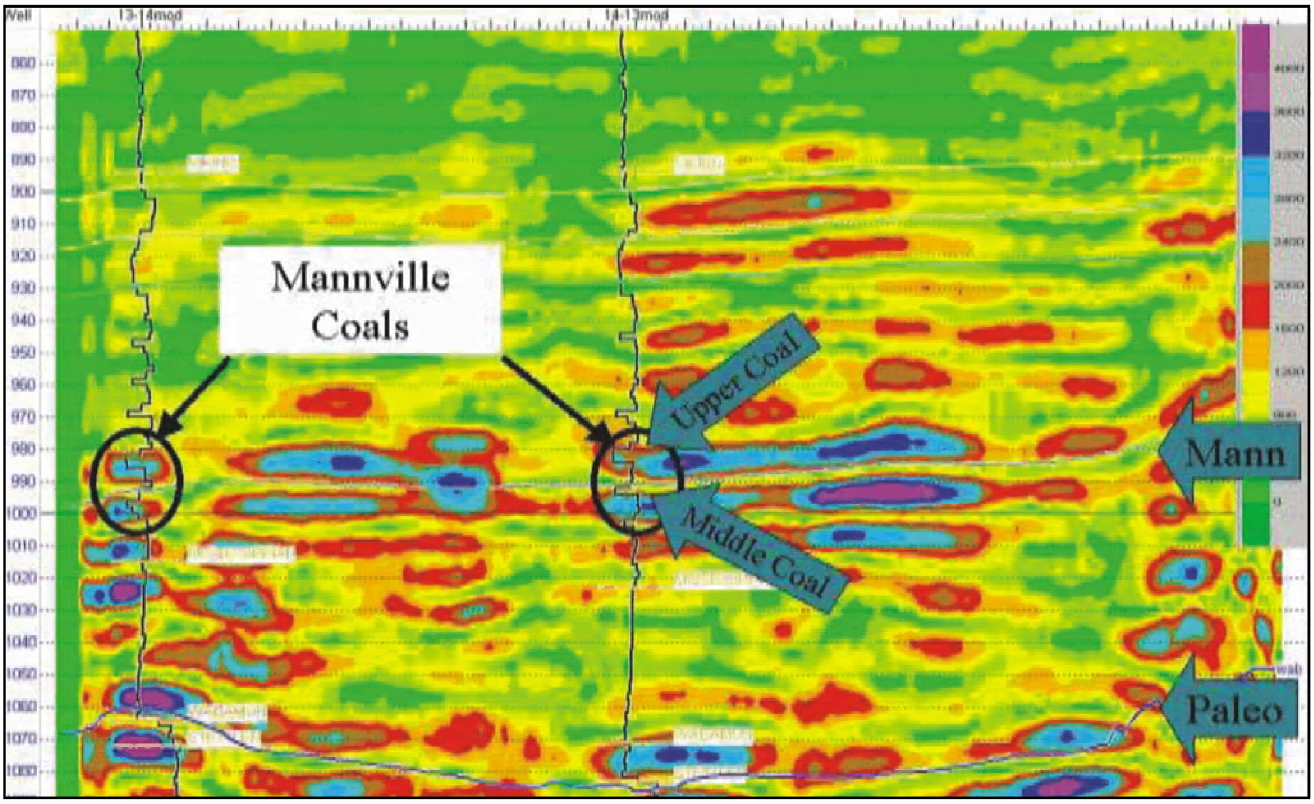

Fig. 4 Observations of seismic anisotropy associated with the coals of the Mannville Formation, Erskine, Alberta Canada. The color represents the intensity of seismic anisotropy. The logs overlaying the section are density logs in which low values (deflections to the left) indicate the location of the Mannville coals (Source: Gray 2006).

Conclusions

The amount of azimuthal anisotropy of the seismic amplitudes in the Manville section is significantly higher than in the other clastic formations surrounding it. The anisotropy level in the Manville are similar to those seen in the carbonates of the Paleozoic section which has been previously associated with fractures. Several authors have observed that fractures in both sandstone and carbonates rocks cause significant anisotropy in the P- wave seismic data (Dong and Yang, 1999).

The strong azimuthal anisotropy observed in the seismic data of the Manville section occurs at the depths of the coal in the formation (Figure 5 and 6). Coals are known to have cleats, which can be considered as fractures within the coal seams. Therefore the most likely cause of the observed seismic anisotropy in the Manville section is the cleats in the coals. The observed seismic anisotropy varies within each coal and from coal to coal.

The study suggests that there is significant variation in the permeability and perhaps in the distribution of these coals. If this is indeed the case, then anisotropy should be useful in finding where the cleating is more prominent. Therefore, it is suggested seismic anisotropy be used to optimize the development of CBM reservoirs (Subhashis, Kenneth and Laurent, 1998).

Further work needs to be done to correlate seismic anisotropy with cleats observed in the core and logs from existing reservoirs in order to fully substantiate these conclusions (Ebrom and Sayers, 1997). We can conclude with the following results:

1) Seismic azimuthal anisotropy can be significantly used for the detection of fractures in coal reserves (Dong and Yun, 2006) .

2) The observed seismic anisotropy varies from coal to coal indicating variance in the permeability and perhaps the distribution of these coal. Hence, if this is the case anisotropy should be used to find where the coal are and where the cleating is more dominant (Liu, Zhou and Zheng,1998).

3) AVAZ is more effective as it deals with amplitude hence it's resolution is more and gives idea about fractured reservoir and unbreached caprock (Antonic and Thomas, 1997).

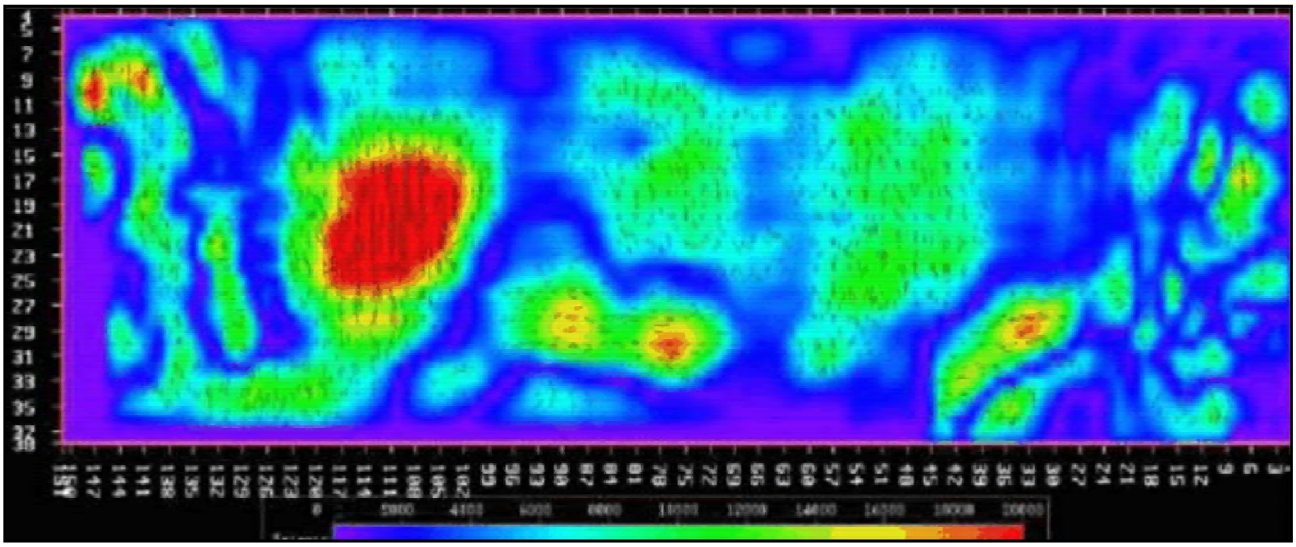

Fig. 5 Map of seismic anisotropy in the Upper Coal indicated in figure 4. Hot colors indicate higher level of seismic anisotropy. The lines on the image indicate orientation of the anisotropy. North is to the top of the figure (Source: Gray 2006).

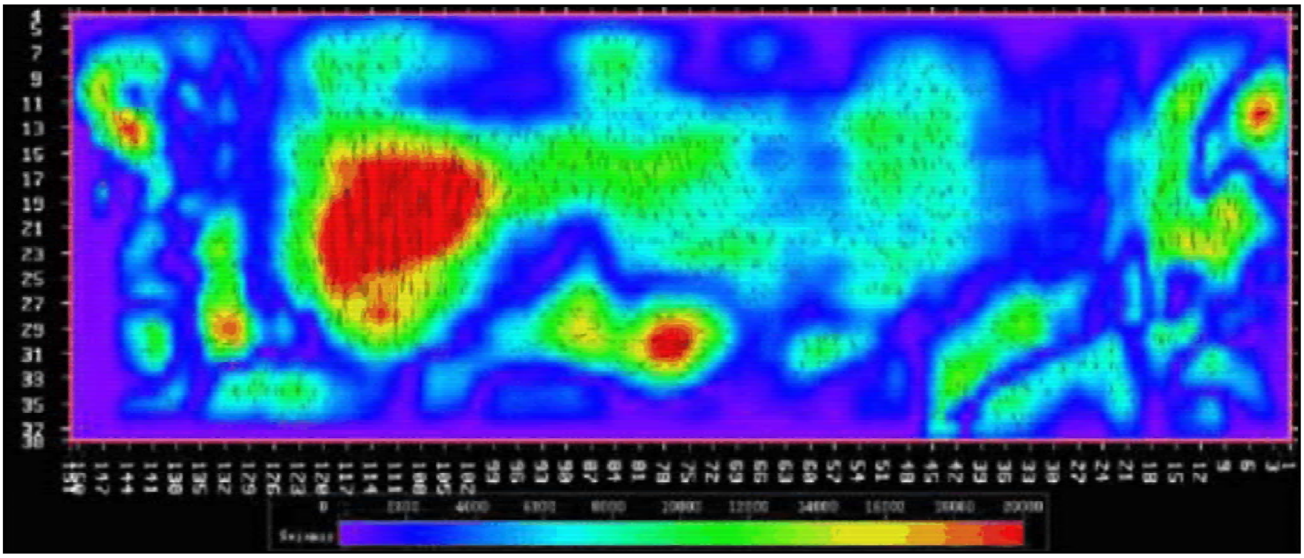

Fig.6 Map of seismic anisotropy in the Middle Coal indicated in figure 4. Hot colors indicate higher level of seismic anisotropy. The lines on the image indicate orientation of the anisotropy. North is to the top of the figure (Source: Gray 2006).

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