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Application of Seismic Anisotropy Caused by Fissures in Coal Seams to the Detection of Coal-bed Methane Reservoirs

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Abstract Coal-bed methane is accumulated in micro-fissures and cracks in coal seams. The coal seam is the source terrace and reservoir bed of the coal-bed methane (Qian et al., 1996). Anisotropy of coal seams is caused by the existence of fissures. Based on the theory of S wave splitting: an S wave will be divided into two S waves with nearly orthogonal polarization directions when passing through anisotropic media, i.e. the fast S wave with its direction of propagation parallel to that of the fissure and slow S wave with the direction of propagation perpendicular to that of the fissure.

This paper gives the results of laboratory research and field test on the S wave splitting caused by coal-seam fissures. The results show that it is feasible to detect fissures in coal seams by applying the converted S wave and finally gives the development zone and development direction of these fissures.

Key words: coal-bed methane, coal-seam fissure, anisotropy, splitting of S wave

1 Introduction

Coal-bed methane is the natural gas accumulated in coal seams, is a kind of natural gas formed with and stockpiled in the coal seams (Dai, 1982). It is a kind of clean energy that is easy to mine and transport with high efficiency and low cost. It plays an important role in improving the composition of energy, protecting environment and insuring safety of coal mines in China. Therefore, it has attracted a great attention from the state and relevant industrial departments of China. China is the largest coal-producing country in the world and rich in coal-bed methane reserves. The exploration of coal-bed methane is being undertaken on a large scale (Qian et al., 1996).

However, coal-bed methane is different from conventional natural gas that is accumulated freely in strata. It exists in micro-fissures and cracks in an adsorption state. The coal seam is both the source bed and reservoir bed of coal-bed methane. Coal seams should be discovered before coal-bed methane is found, but the discovery of coal seams does not mean that efficient coal-bed methane reservoirs are found and further efforts should be exerted to seek development areas of coal-seam fissures and cracks that are favourable for the accumulation of coal-bed methane (Qian et al., 1996). This implies that the conventional methods on geophysical exploration of natural gas is not suitable for the prospecting of coal-bed methane reservoirs. New methods must be applied.

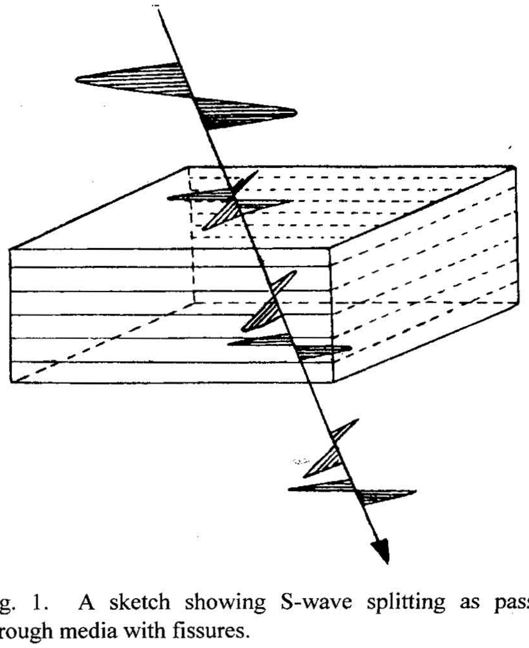

Fig. 1. A sketch showing S-wave splitting as passing through media with fissures.

Anisotropy is due to the existence of fissures in coal seams according to the theory of S wave splitting: an S wave shall be divided into two S waves with nearly orthogonal polarization directions when passing through anisotropic media (Fig. 1). The wave parallel to the direction of the fissure is called the fast S wave and that perpendicular to the direction the slow S wave (Ewen et al., 1996; Crampin, 1998). Thus, the research of seismic waveform features of the coal-seam anisotropy caused by coal-seam fissures is the basis for the detection of coal-seam fissures and further seeking of coal-bed methane reservoirs by means of seismic exploration methods.

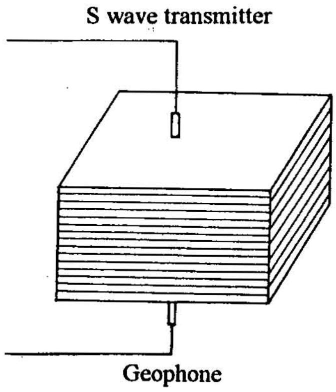

Fig. 2. Physical model of coal-seam fissures.

2 Seismic Wavefield Features of Coal-seam Fissures

Since the state of coal-seam fissures is the main control factor for the accumulation, transportation and development of coal-bed methane, interpretation of development of the fissures (their strikes and densities for example) based on the features of seismic wave fields becomes a top task in the seismic exploration of coal-bed methane.

Figure 2 shows a physical model of coal-seam fissures made in the laboratory. At the beginning of the test, transmission probe and receiver of S wave are located on two sides of the model, perpendicular to the layering (fissure) direction of the model. Then, the transmitter and receiver are rotated in the same direction and at the same step (the beginning point is 0°), and one channel is recorded (once) every 10°. Fig. 3 shows the test record of the fissure model. It is shown from the figure that the velocity of the S wave is the highest, 1510 m/s (travel time 49 μs), when the propagation direction of the S wave is parallel to the fissure direction of the medium (the 9th and 27th recorded channels, i.e. at positions of 90° and 270°), called the fast S wave and that the velocity of wave is the slowest, 1370 m/s (travel time 54 μs), when the turning direction of the S wave is perpendicular to the fissure direc-

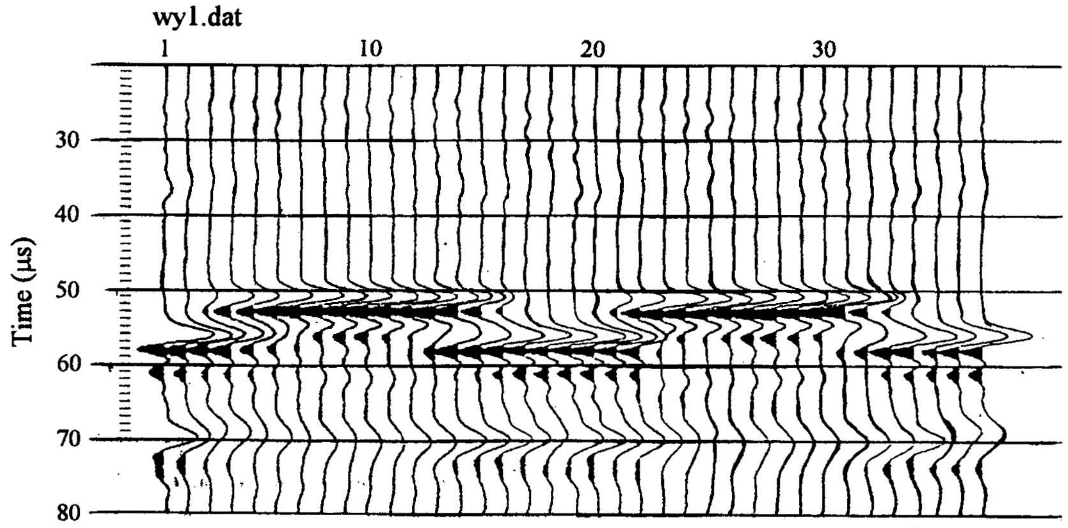

Fig. 3. Test records on the fissure model.

tion of the medium (the first and 18th channels, i.e. at positions of 0° and 180°), called the slow S wave. The results of the above test show that the developing state and direction of fissures can be estimated based on the splitting of S waves when fissures are well developed in coal seams.

3 Field Test

A field test was undertaken in some mining district with flat landform and an area of 5 km^2. The available data show that the experimental area has a simple geological structure and a stable main minable coal seam with buried depths about 700–1000 m. The area is rich in coal reserves and belongs to an area with high content of coal-bed methane. There is obvious impedance difference between the coal seam and its overlying and underlying wall rocks, which tends to cause strong seismic reflected waves.

Within the area of 5 km^2, two 2D lines, crossing the whole area in longitudinal and lateral directions and perpendicular to each other, and six concentric observations were designed. The coal seam is deeply buried in this area and the pure S wave has no enough energy, therefore joint observation of P wave and converted S wave is applied. Compared with the pure S wave, the converted S wave has unique advantages: ① its induction mode is just the same as that of the conventional longitudinal wave and the S wave source is not needed; ② reflected longitudinal and converted S waves can be obtained by the same induction; ③ the converted S wave passes strata only once (one way) and the absorbed energy by strata is just a half compared with the pure S wave, the splitting is converted only once, and vertical and lateral resolutions are relatively high.

Figure 4 shows the converted S wave (P-SV) section of Line N_1 and Fig. 5 the converted S wave section of Line N_2. Fig. 6 is the common-angle-bin stack section arranged in a circle. The circle of 360° is divided into 48 bins and the common-angle-bin stacking section is formed by stacking the data in a bin with NMO and DMO. The first channel is 0°, pointing to the north (N), the second rotates clockwise by 7.5°, the third 15°, ··· and the 12th channel is 90°, pointing to the east (E), 24th channel 180°, to the south (S), 36th channel 270°, to the west (W), and the 48th channel is 360°, i.e. 0°, pointing to the north (N).

Compared with Fig. 3, the common-angle-bin section (Fig. 6) shows a very strong feature of S-

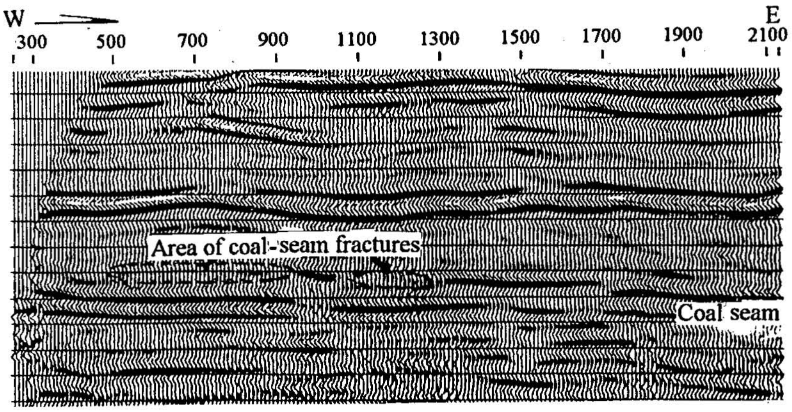

Fig. 4. Converted S wave (P-SV) section on Line N_1.

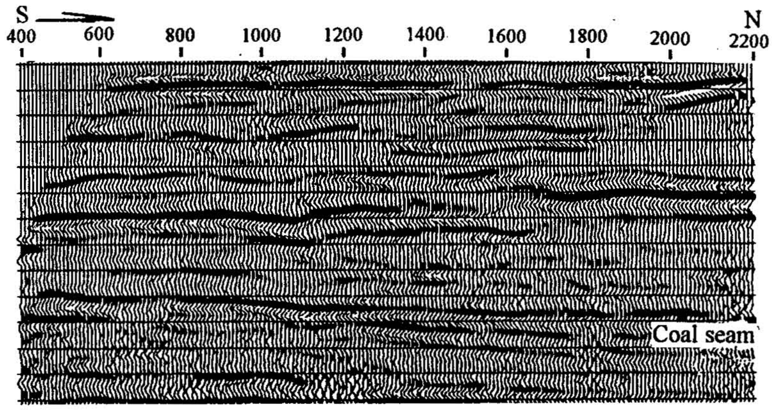

Fig. 5. Converted S wave (P-SV) section on Line N_2.

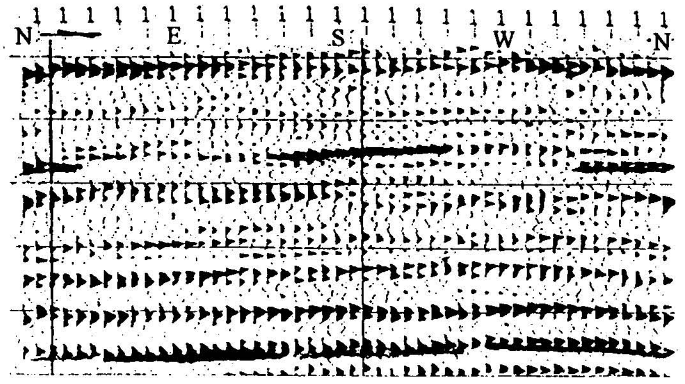

Fig. 6. Common-angle-bin section arranged in a circle.

wave splitting and anisotropy of strata caused by the fissure. Based on the features of the fast and slow waves and the position of the converted point, it is shown that the fissure is located around the third channel (198.5°), i.e. in a north-north-east (NNE) direction.

Comparison of S-wave sections of Line N_1 (Fig. 4) and Line N_2 (Fig. 5) shows that T_0 wave is completely closed at the intersection on the bottom boundary of the new stratum, suggesting that the converted S wave has the same propagation velocity in directions perpendicular to each other without splitting, but the coal-seam reflected wave T_7 at the intersection is nearly 30 ms slower on section N_1 than on Line N_2, which shows obviously that the splitting of S wave occurs in the coal seam. The longer propagation on section N_1 indicates the slow S wave, while the shorter one on Line N_2 the fast S wave, which means that the fissure of the coal seam exists approximately in the direction of N_2, basically the same direction pointed by the circle-arranged section. The development area of fissures, i.e. the area favorable for the exploration of coal-bed methane, can be determined by the neuro-network analysis of the seismic attributes of the P-SV wave section and P-P wave section.

4 Conclusions

Coal-bed methane is generally accumulated in fissures and micro-fissures of coal seams. The main task in the exploration of coal-bed methane is to seek coal-seam fissures and the application of S wave splitting features is the basis for the exploration of coal-bed methane with seismic methods. This test shows that it is feasible to apply the converted S wave in the practice of exploration.

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