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Duplex Wave Migration for Coal-bed Methane Prediction

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SUMMARY

A case study of using migration of duplex waves to trace zones of near-vertical fracturing in coal formation is described. As a rule, coal-bed methane traps are connected with these zones, however, identification and tracing of them based on the standard seismic exploration techniques are practically impossible. It is shown that the joint analysis of structural interpretation and seismic facies investigation data and of the results of duplex wave migration improves efficiency of coal-bed methane prediction. The work has been carried out based on 3D seismic survey conducted at one of the coalmines in the Donets Basin (Ukraine).

Introduction

The coal fields can as well be the methane reservoirs. In many regions of the world (USA, Canada, Australia and others) methane production at coal fields is a commercially viable. Methane is originated during coalification of rocks, i.e. when plant deposits are transformed into coal. Methane is accumulated both in coal beds and in sealing them rocks. The gas could be in the occluded, water-dissolved and free state. Occluded state of a solid solution is typical for coal beds and enclosing them rocks that contain dispersed and concentrated organic material. Being in this state, methane is practically not recoverable from a rock. A water-dissolved and free gas is concentrated mainly in porous and fractured rocks like coal itself and enclosing it rocks.

The most important condition for gas migration from gas-produced rocks like coal or organic deposits of enclosing it rocks is natural and man-induced (technogenic) fracturing. Because of fracturing, gas transforms from a bound state into a free state and acquires ability to migrate along fractured zones towards traps. Therefore most coal-bed methane traps are confined to fractured zones.

Basic seismic exploration techniques aimed at prospecting for fractured zones are based on study of azimuthal anisotropy of reflected wave velocities and amplitudes. The most efficient methods of prospecting for such zones are based on 3D-3C seismic exploration technology. Shuck et al. (Shuck et al., 1996) have shown an example of successful mapping of the zone of an increased coal fracturing and an increased pore pressure in reservoirs of Cedar Hill Field (USA). Their work was based on the integrated study of the structure of the reflectors' boundaries, azimuthal AVO and wave polarization characteristics.

Peng et al. (Peng et al., 2006) have shown a case study of using 3D seismic exploration for investigation of methane accumulation zones. They also have analyzed specific features of appearance of AVO-effect in prospecting for coal-bed methane in comparison with AVO-effect in prospecting for natural gas in classical reservoirs (for example, in sandstones). Other similar works are also available.

3D seismic exploration techniques are efficient in the case of pronounced HTI-environment that leads to effective azimuthally-dependent anisotropy. Large observation apertures are required to ensure both wide azimuthality and large angles of incidence of waves to the boundary. However, in case when coal gas saturates some fractured zones (the thickness of which does not exceed several tens of meters) isolated by non-disturbed rocks; azimuthal anisotropy at accessible for seismic exploration frequencies does not practically manifest itself. This paper focuses on the opportunity of identifying and tracing near-vertical reflecting objects responsible for zones of gas-saturated fracturing. For this purpose we use duplex wave migration (DWM) (Marmalyevskyy et al., 2005, Marmalyevskyy et al., 2006). It is shown (Khromova, 2008) that wells debits in a fractured reservoir at one of the fields in Russia with a coefficient equals to 0.94 correlates with seismic image amplitudes generated on the basis of DWM. This gives grounds to assume that fractured zones which could be supplying channels and coal-bed methane traps as well can be found on the basis of DWM analysis.

A case study of identifying potentially gas-saturated fractured zones based on DWM method given in this paper is based on 3D seismic exploration data obtained in the Donets Coal Basin (Ukraine).

Method

We have developed a Kirchhoff depth migration that is based on the Green's function using the kinematics of duplex waves. A primary event (that must be deeper than the vertical boundaries we wish to image) is defined in depth by the user. It is assumed that a conventional pre-stack depth migration (PSDM) has been run prior to running DWM; therefore we use the depth model generated from that process as a starting point. The depth model can be either isotropic or TTI anisotropic.

The DWM algorithm is designed to image the duplex waves that will arrive at a time greater than that of the primary base boundary. A beam tube construction eliminates the migration noise that would result from including the base boundary primary reflections in the migration summation. Tight control of the aperture is also a key to suppression of artefacts from primary reflections. Each DWM run produces four separate and distinct views (images) of the vertical boundaries based on two possible bounce orders – base boundary then vertical boundary or vice versa and traces input to the migration are either to the right of the shot or to the left of the shot.

Results of the sub-vertical imaging by DWM

Duplex wave migration was performed within two depth intervals and two reference boundaries were selected respectively to these depths. The first one was at the level of horizon C_8, which corresponds to the top of Vise coal formation, and the one was at the level of horizon c1, which corresponds to the bottom of this formation. Image cubes of near-vertical objects have been obtained for these reference boundaries. Figure 1 shows stratigraphic slice of the first of these cubes at the level of 70 m above horizon C_8.

Figure 2 shows location of faults obtained by DWM and depicted at the structural map along horizon C_8. The faults are designated by numbers. The exploration area is divided by big fault of approximately 200 m with lowered north flank. The north part is of practical interest from the point of view of prospecting for methane as the whole coal formation at this area is within the zone of methane content, whereas coal formation in the south part of the area is above the zone of methane content. 37 faults were identified by the results of the standard interpretation within horizon C_8. They can be grouped into three systems: of northeast strike, southwest strike and parallel to the mentioned big fault. These faults divide the area into blocks within which tectonically hidden traps are identified. These blocks delineate the anticline structure that was identified earlier, before conducting 3D seismic exploration. From Figure 2 one can see that parallel with the above mentioned faults additional near-vertical boundaries of north-south strike and east-west strike are identified by the results of DWM.

The very fact that these faults were not identified as a result of the standard interpretation means that they are among small faults and probably they are fractured zones which are of great interest in respect for methane prospecting. This is explained by the fact that tectonic stress leading to the occurrence of faults with significant amplitudes, evident by boundary displacement on seismic data. It results not only in collector losing tightness but also in de-sealing of a reservoir followed by area degasification. At the same time, tectonic stress leading to formation of fractured zones usually does not destruct cap rock that ensures the safety of accumulation. Figure 3 shows DWM cube cross-section along line Y=800 where one can see near-vertical boundaries associated with the predicted fractured zones.

Analysis of seismic facies maps (which are not shown here) indicates that faults of northwest and southeast strikes are sedimentary faults. Such faults are generally tight and screen hydrocarbon accumulations. The second factor that defines accumulation is a presence of a supplying channel which role can fulfill fractured zones. Thus, the best conditions for accumulation of a coal gas must be in tectonically screened traps limited by sedimentary faults and intersected by fractured zones identified by DWM data. One of the examples of such trap is shown in Figure 2 where it is designated by C letter and is intersected by the predicted fractured zone 5.

Figure 4 gives stratigraphic slice of the second DWM cube obtained with the base boundary at the level of horizon C_1. Predicted fractured zones of north-south and east-west strikes are also identified here. Independent identification of near-vertical boundaries of the same direction on 3D seismic images obtained at different levels considerably improves probability of prediction of their presence. Furthermore, some images of near-vertical boundaries at the level of horizon C_1 practically fully coincide with the images of near-vertical boundaries obtained at the level of horizon C_8. This fact may indicate that these are the single fractured zones having practically vertical dip and intersecting coal formation. Such supplying channels are the most efficient as they have considerable drainage area. We may predict that the zone under consideration is not only a supplying channel but also a reservoir for hydrocarbons by similarity with similar zones described in (Khromova, 2008, Marmalevskyi et al., 2007) based on the drilling data.

The linear anomaly extraction procedure result for the DWM cube C_1 is shown in Figure 5. The procedure targets the automated detachment of connected volume picture elements (voxels). The connectivity parameters are amplitude diapason, types of contact (by a face, by an edge, by a vertex), and a minimal size of the connected voxel associations to extract. As you can see in Figure 5 some additional bow-shaped in sub-horizontal slice objects were extracted. They correspond to the probable fracturing zones. Such objects mostly located in the elevated South block are highlighted by arrows. Probable origin of those objects can be the big upcoming pressure also formed the anticline structure.

Conclusions

Presence of fractured zones in the formation increases probability of the existence of a free-state coal methane that allows its commercial production. Prospecting for fractured zones by standard seismic exploration techniques is usually difficult. Use of duplex wave migration makes it possible to solve this problem on the basis of 3D standard seismic studies. Joint analysis of structural interpretation data, seismic facies studies and the results of duplex wave migration allows to expect improving efficiency of coal methane prediction.

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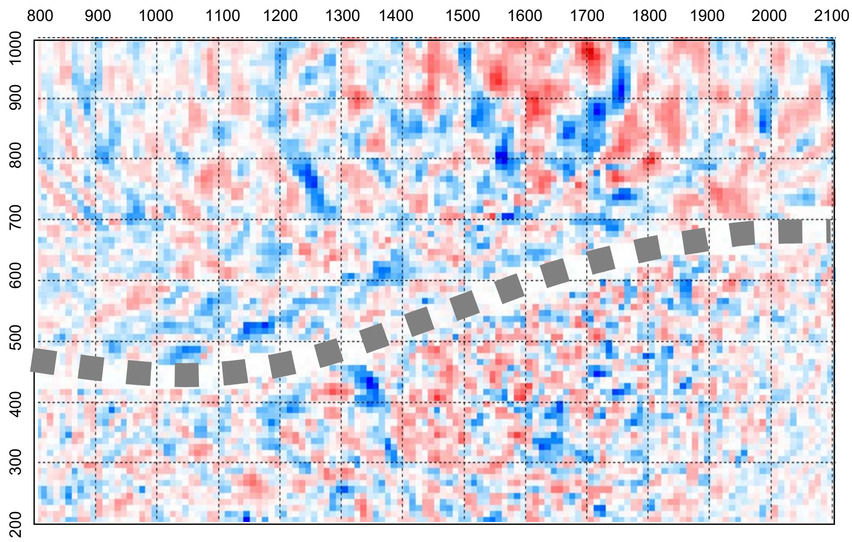

Figure 1 Stratigraphic slice of DWM 3D cube for base horizon C_8.

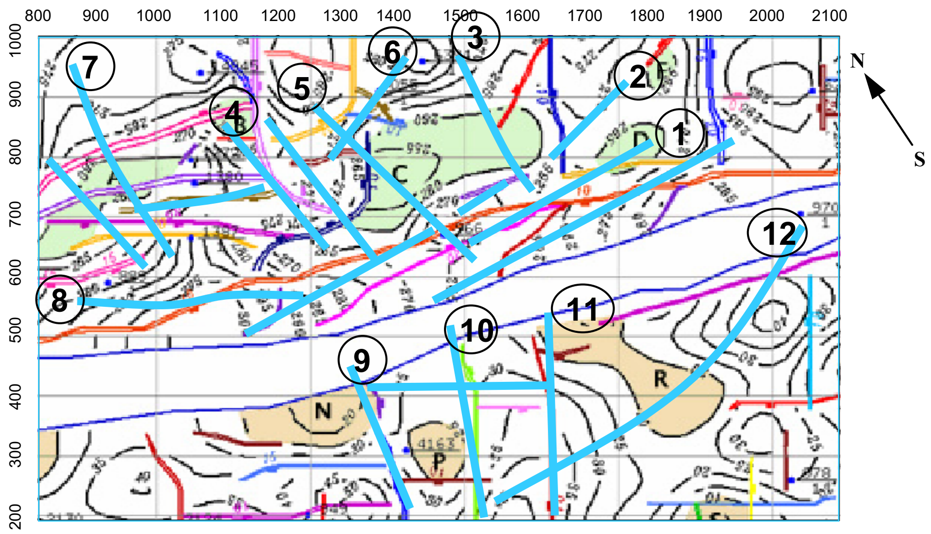

Figure 2 Location of faults obtained by DWM and depicted at the structural map of horizon C_8.

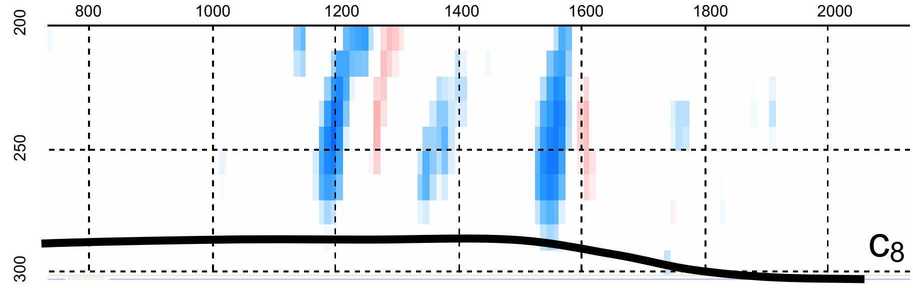

Figure 3 Cross-section along line Y=800 of DWM 3D cube for a base horizon C_8.

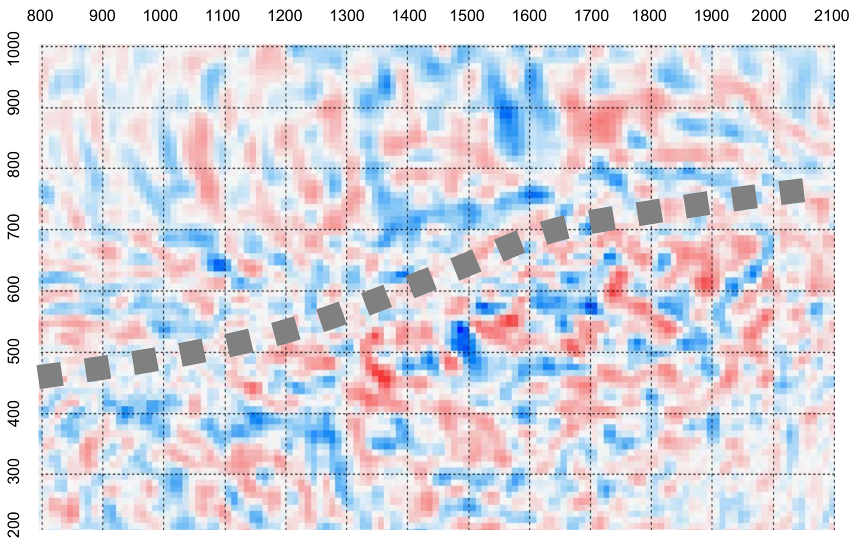

Figure 4 Stratigraphic slice of DWM 3D cube for base horizon C_1.

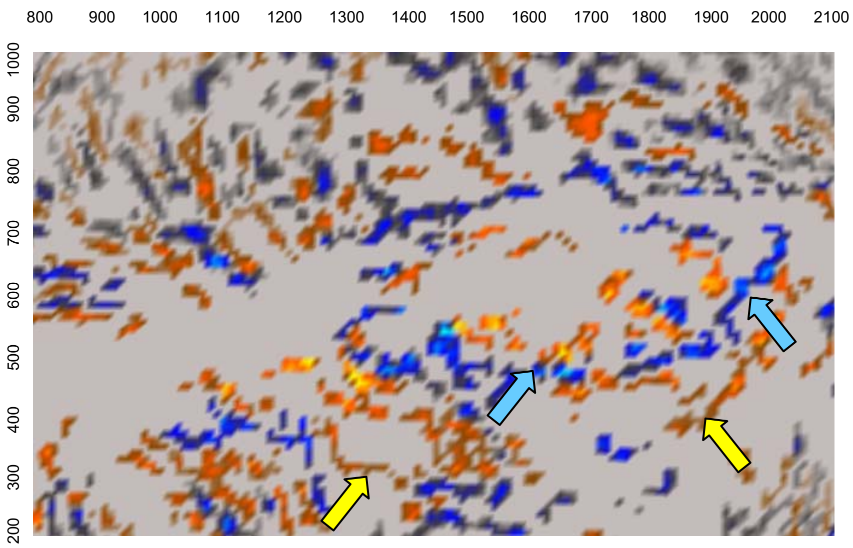

Figure 5 Stratigraphic slice of DWM 3D cube for base horizon C_1 after the linear anomaly extraction procedure.