Fracture Delineation Case History from Russia and implications for plays in North America

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Summary

This paper describes examples of mapping fracture zones in carbonate reservoirs using duplex wave migration (DWM). This method is used following conventional pre-stack depth migration with a new and very different type of pre-stack depth migration called DWM plus interpretation. The theoretical basis of the DWM process enables its ability to provide accurate and detailed detection of the position and properties of vertical boundaries and of the fracture zones confined by them. Fracture zones revealed using the DWM process are compared with available well information that verifies the existence or absence of anomalous permeability, its direction, and most importantly, information about the intensity of open fracturing in productive wells. The locations of open fracturing are verified by the productivity factors and interconnection of these wells. Also, the DWM results are compared with the results of standard methods for seismic data interpretation, which are widely used for mapping of small-scale faults and fracture zones. Hydrothermal dolomite (HTD) plays in North America also involve the need to identify lateral in-homogeneities in carbonates. The applicability of DWM to HTD plays will also be illustrated.

Introduction

In this paper, two fields are examined which contain oil in carbonate reservoirs of a thickness equal to or greater than the seismic wavelength. Considerable differences in productivities of the wells drilled within these oil-fields give evidence about an extremely heterogeneous permeability of the reservoirs (Lower Permian in the first case and Lower Devonian in the second case), despite the fact that porosity is almost constant. Numerous thorough investigations have shown that the formation of permeable heterogeneities within these oil-fields was governed by tectonic events rather than by sedimentation or post-sedimentation processes.

The high-scale fracture zones of tectonic origin are often high-permeable corridors and the strategy of field development is guided by the movement of fluids along these corridors. As a physical model, such zones may be considered vertical layers of relatively low density embedded in a homogeneous medium. To form seismic images of such zones, even when their elastic attributes differ considerably from those of the surroundings, is quite a challenging problem, which cannot be solved satisfactorily with convention migration methods. Waves reflected only once from these objects do not reach the observation surface. However, seismic images of salt stock flanks (Marmalyevskyy et al., 2006) and fracture zones (Marmalevskyy et al., 2007; Khromova, 2008; Kostyukevych et al., 2009) may be formed using duplex wave migration (DWM) (Marmalyevskyy et al., 2006).

Method

Duplex waves are the waves that have reflected twice: firstly, from a sub-horizontal surface, and then from a target sub-vertical surface, or vice versa. Due to their double reflection, these waves can reach the observation surface. They are characterized by a relatively weak energy, as compared with the single reflections, but have specific travel path kinematics (Marmalyevskyy et al., 2006). During conventional processing, the duplex waves are considered a type of noise and are suppressed on seismic images.

In Kirchhoff integral-based DWM, the Greens function is calculated in accordance with the kinematics of duplex wave energy propagation. This type of migration may be compared a with conventional migration with its impulse response rotated by 90^0. DWM uses the same input data and depth-velocity model as conventional depth migration. In addition, a depth map of a reflection surface below the bottom of the reservoir under study is used. As a rule, this information is all available for use by the DWM process after conventional PSDM has been completed.

Examples

In the first field, Lower Permian carbonates of shallow shelf formed a 100m thick layer, which was bent in a bar-like structure at the Triassic-Jurassic boundary under the impact of global tectonic processes (the Northern Urals and the Paj-Khoj region orogenies). The structure is complicated with en echelon shift dislocations. The layer integrity was not practically broken. However, high tangential stresses caused the appearance of linear zones, inside which rocks could not stand breaking off forces and formed broken up, deconsolidated mass. The wells that

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encountered such open fracture zones at the depth of 1.3-1.5km are characterized with many times higher productivity factors relative to the nearby wells that did not penetrate such zones. All the attempts to map these zones with the help of standard methods for processing and interpretation of seismic data have resulted in very approximate schemes (Figure 1, top). These schemes give only a rather common notion about the directions of these zones, as their location contradicts real data from the field development observations and the results of hydrodynamic investigations.

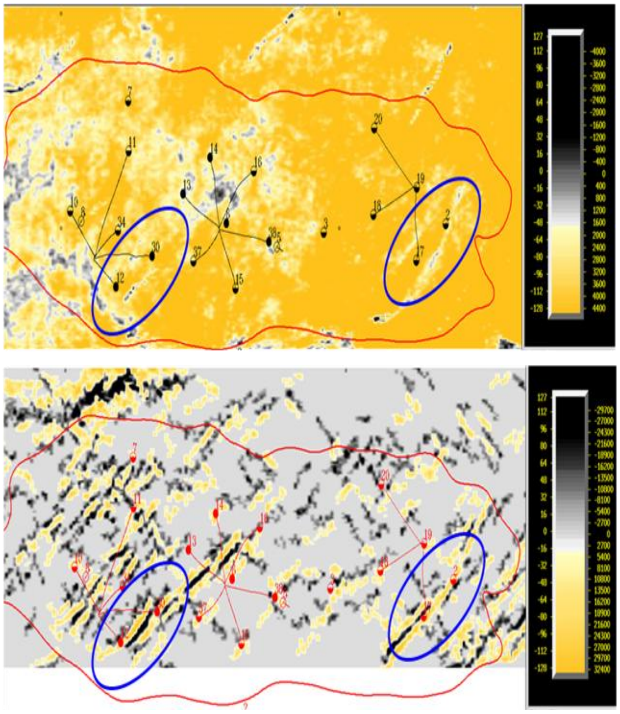

Figure 1: Comparison of an amplitude map of single-reflected waves from horizon Ia at the top of a reservoir (top) with that after duplex wave migration for the same horizon (bottom). The red contour shows the oil-bearing area. The most productive wells are outlined with blue ovals. These wells, according to the results of both pressure interference tests and pressure build up tests, are interconnected with permeable corridors. On the top map, linear anomalies are laterally miss-located relative to highly productive wells 12, 30, 17, and 2. At the same time on the bottom map, these wells coincide with intense multiphase reflections interpreted as open fracture zones.

With the help of DWM, a detailed map of an orthogonal macro fracturing network was obtained. The correct location of the fracture zones identified is confirmed by all available well information (Figure 1, bottom).
In the second field under consideration, five shallow-shelf carbonate layers form a 160-200m Lower Devonian reservoir at a depth of 3.8 - 4.5km. These carbonate layers are separated by argillite inter-beds and bent in a bar-like structure. Most inter-beds have porosity 1.5-3.0%; however some are as high as 6-8%. Nevertheless, the oil production rate of high productivity wells reaches up to 600m^3/day. For investigation of such a thick reservoir, two cubes of sub-vertical boundaries, namely, for the upper two layers A+B (the upper object) and for the lower three layers C+D+E (the lower object) were built with DWM. In spite of a common similarity, the maps of duplex wave amplitudes at the roofs of the two objects are essentially different in details. Linear zones shift laterally, changing insignificantly their configuration. However, their locations on both maps agree well with borehole data. Thus, if an intensive inflow is obtained in a well from the lower object (Figure 2), then the point of crossing of the lower object by this well is located within a linear anomaly on the lower object map. At the same time, a linear anomaly within the upper object is located away from the well. Such a shift is a result of intersection of a non-vertical fracture zone and horizons at various depths.

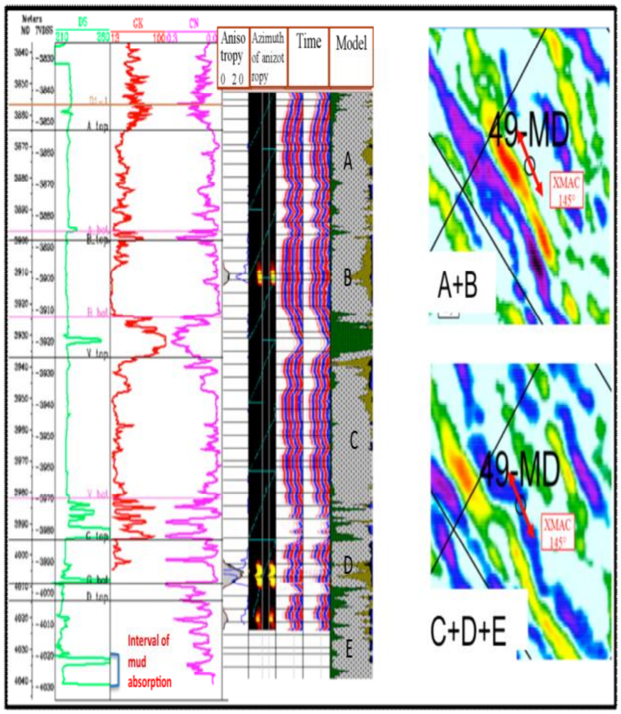

Figure 2 After production logging in well 49-MD, all the inflow was obtained from an interval within the lower object, where intensive mud absorption occurred while drilling. In the other part of this borehole, according to XMAC data, any significant anisotropy of the rocks is absent (see the well log data on the left-hand side). On the amplitude map of duplex waves for the upper object (level A+B, top), an intensive multiphase amplitude anomaly is located away from the well at a distance of 50m. On the

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same map for the lower object (level C+D+E, bottom), this well precisely coincides with a linear anomaly interpreted as a fracture zone. The double-sided arrow on the well symbol designates the direction of anisotropy measured with XMAC.

The comparison of the results of mapping zones of fracturing by conventional methods with the DWM method is illustrated (in Figure 3) in the area of pressure interference tests between the two wells 47 and 49. Pressure interference tests results showed that these wells are interconnected by a highly conductive corridor. The distance between the wells is 2 Km and response to pressure change is noted after 16 hours. On the map of the amplitudes of duplex waves, these two wells are located within a single linear seismic anomaly. Such connected zones could not be identified on the maps of the curvatures, coherence and azimuthal anisotropy.

Figure 4 a, b, and c illustrates a hydrothermal dolomite (HTD) example in which conventional PSDM fails to adequately identify the significant lateral heterogeneity associated with the oil filled porosity. DWM clearly delineates the strong change in relative lateral acoustic impedance in the limestone interval.

Conclusions:

Utilization of DWM in several oil-fields from Northern Russia permitted us to map networks of vertical conducting corridors in each of the cases. Comparison with existing borehole information about anisotropy attributes and direction of fracturing (obtained with full-wave acoustic well-logging XMAC) and, most importantly, with the results of hydrodynamic investigations of wells, has shown a high accuracy of prognosis of fracture zone locations. The results of DWM are superior to the results of standard techniques because DWM produces more detailed images of fracture zones better coordinated with borehole data, which allows new similar zones in well-absent places to be revealed and mapped.

The DWM technology has been successful carbonate fracture plays Russia, China, and Ukraine. In North America we struggle with the difficulty of identifying lateral in-homogeneities in carbonates in hydrothermal dolomite (HTD) plays. We will also demonstrate how the lessons learned in Russia may lead to success in North America by significantly reducing the risk associated with exploration for oil and gas deposits in structurally controlled HTD plays.

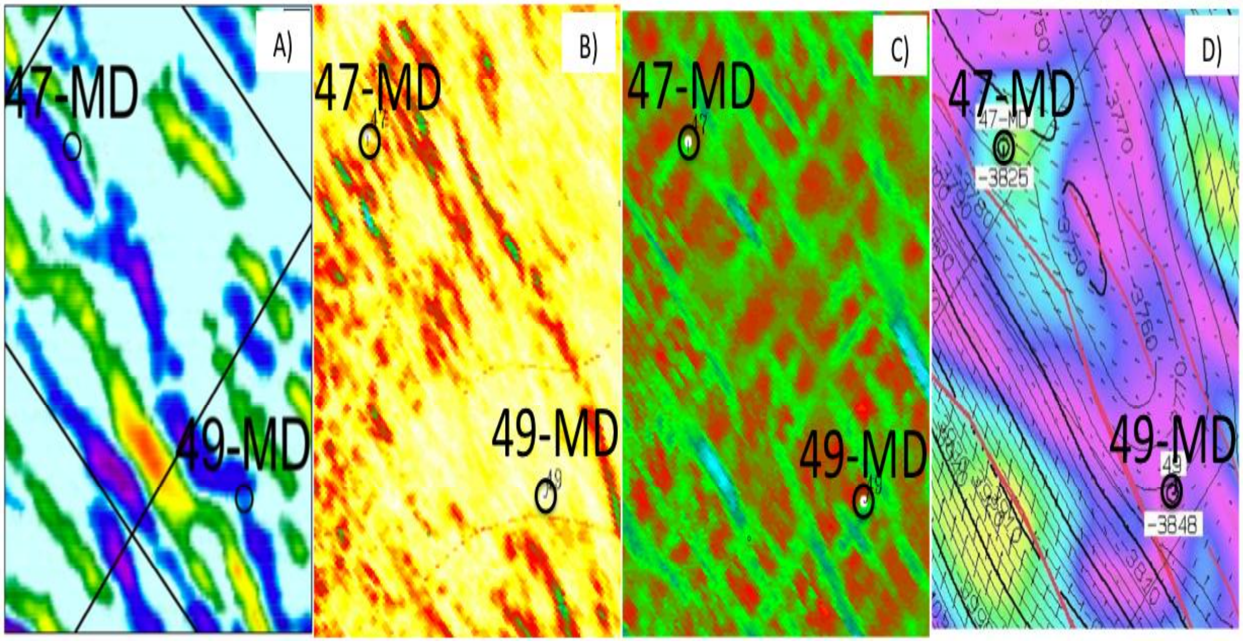

Figure 3: Top of reservoir amplitude maps calculated by A) Duplex Waves Volume B) Cube of Coherency, C) Most Positive Curvature by top of reservoir D) Map of Azimuthal Anisotropy. All methods define similar direction of anomalies, but DWM more accurately delineates the position and configuration of fractured zones than conventional methods.

Fracture Delineation Case History

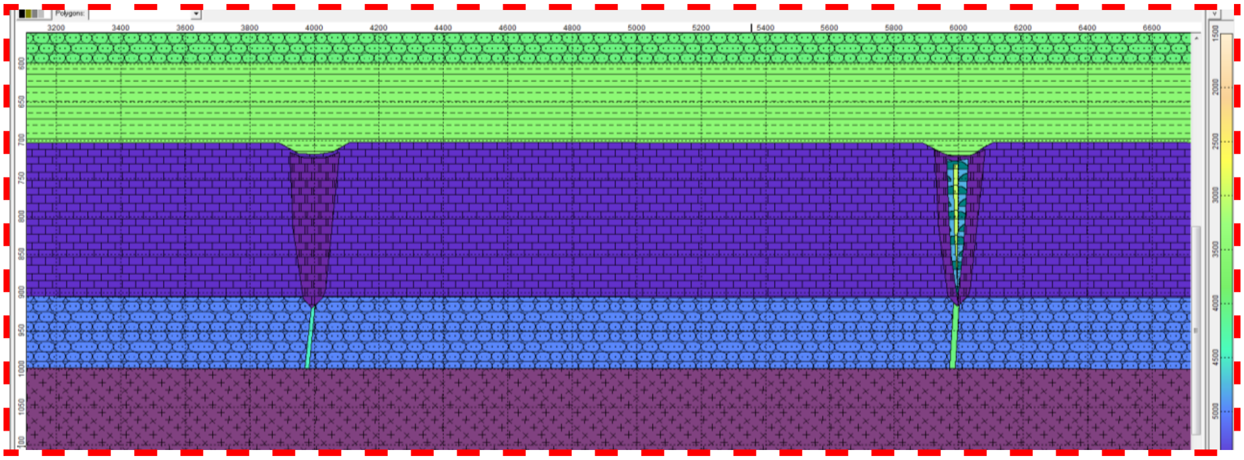

Figure 4a: Model of tight dolomite HTD on left and oil porosity filled dolomite HTD feature on the right

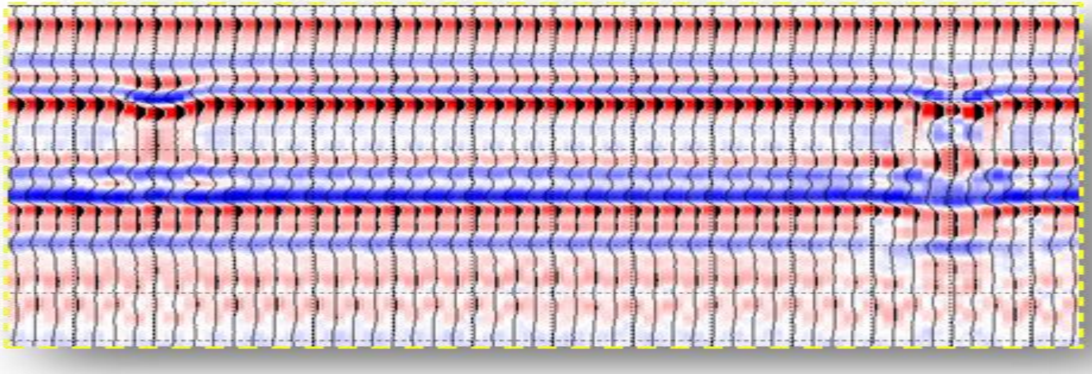

Figure 4b: PSDM imagine of these features shows very little image differentiation.

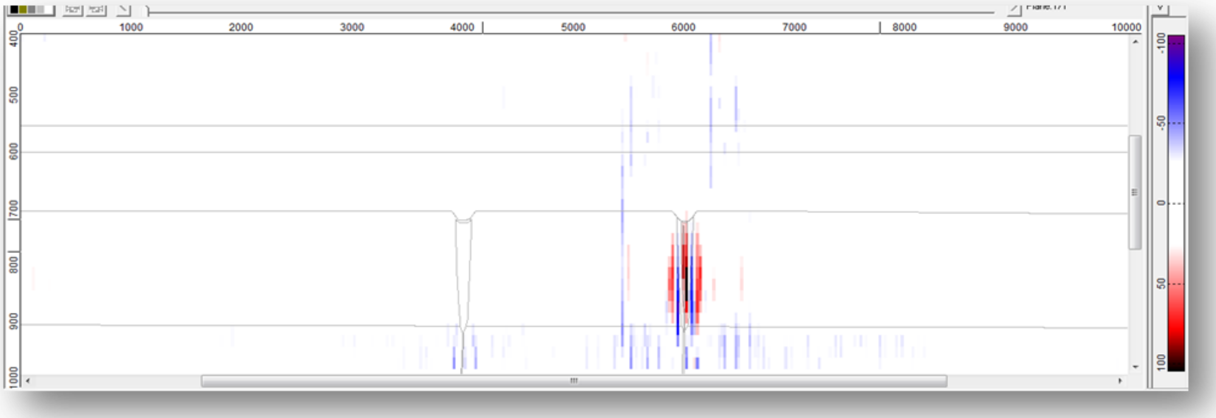

Figure 4c: Duplex wave migration imaging of these features – relative strength of lateral heterogeneities is clearly identified. Also, signature of vertical wrench fault that acts as a conduit for hydrothermal fluids is indicated

EDITED REFERENCES

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