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Study of Subvertical Fracturing Zones in Subsalt Carbonates of the Pre-Caspian Basin using Duplex Wave Migration

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Summary (Arial 12pt bold or Calibri 12pt bold)

Fracture prediction methods are based on reflection amplitude, reflection curvature and its derivatives, coherency cube, spectral decomposition, ant-tracking technology, azimuthal anisotropy of Pwave velocity, and relatively recently introduced Duplex Wave Migration (DWM) amplitude cube analysis. This paper will report on the results of study a subsalt deposits located in the southwestern part of the Eastern Near-Slope zone of the Pre-Caspian Depression. The DWM amplitude maps will be shown to illustrate the success of this fracture prediction technique.

Introduction

The object under study represents a subsalt deposit located in the southwestern part of the crest part of the Yenbeksko-Zharkamyssky rise in the Eastern Near-Slope zone of the Pre-Caspian Depression, where up to 90% of subsalt hydrocarbon deposits are located. The sedimentary cover is presented by the three mega-complexes of deposits: subsalt, salt, and oversalt ones.

The oil and gas deposits of the considered field are located within the crest part of the fold within the regional oil-bearing series of subsalt carbonate deposits KT-II, Lower and Middle Carboniferous (C1v3-C2m1). Within the limits of the KT-II series, two sub-series are revealed: KT-II-II (Serpukhovsky deposits, Lower Carboniferous) and KT-II-I (Lower Bashkirsky deposits, Middle Carboniferous). The caprock of the carbonate reservoir rocks is presented by thick series of Lower Podolsky terrigene deposits (C2m2-pd).

For hydrocarbon exploitation, detection of heterogeneities of a hydrocarbon reservoir, and especially zones of increased fracturing that may be linked to the most favorable areas of increased reservoir capacity and permeability, is the most important task.

The preconditions for presence and development of highly fractured zones within productive deposits are, firstly, high density, rigidity, and at the same time, frangibility of carbonate rocks. Secondly, this is an irregular load on the target deposits that is caused by significant irregularity of the salt and oversalt complexes characterized by presence of salt stocks and subsidence troughs. The most important confirmation of the production capacity is presence of wells with sharply differing yields within the same field.

The substantial heterogeneity of the sediments overlaying the deposits causes substantial difficulties in studying by the conventional seismic methods based on analysis of coherency cubes, geometrical attributes, etc. Such complication is caused by the fact that heterogeneities in the upper part of the section cause phase shifts in the seismic images at the level of the target horizon which is practically impossible to distinguish from the shifts related to the disjunctives within such horizon.

In such situation the methods of detection of fractured zones that do not rely on analysis of phase shifts in the target horizons are of advantage. The duplex wave migration (Marmalyevsky et al., 2006) is one of such methods. In the present report, the results of delineating the fractured zones imaged by the duplex wave migration within a carbonate reservoir are shown.

Duplex Wave Migration

The Duplex Wave Migration (DWM) allows forming images of sub-vertical boundaries. Initially a vertical boundary image based on duplex waves (DW) was obtained by McMechan (McMechan, 1983). The theory of the method is developing in the works (Kozlov et al., 2009, Malcolm et al., 2011, Davydenko and Verschuur, 2013 and others). In practice, DW are actively used for creation of images of salt flanks (Broto et al., 2001, Marmalyevskyy et al., 2005, Farmer et al., 2006) and fractured zones (Link et al., 2007, Khromova et al., 2011) and others.

The duplex waves on the source – receiver path experience alternately the reflections from sub-horizontal and sub-vertical boundaries, and vice versa (two acts of reflection). The duplex wave migration considered in this report is based on the Kirchhoff transformation, where the Green function is calculated in accordance to the law of the duplex wave propagation. To describe this law, an auxiliary sub-horizontal reflecting boundary (a single bounce base boundary) and the velocity model identical to the one used for conventional depth migration are employed.

Use of the Kirchhoff integral for creation of images of sub-vertical boundaries gives the possibility to deal with the migration aperture actively. Use of asymmetric apertures (left-side or right-side ones) or symmetric apertures that include the area between the source and the receiver gives the possibility to analyze additionally the azimuths of sub-vertical planes' inclinations that gives some extra information related to fractured zones.

The results of work

The DWM result within the interval of productive layers KT-II-II and KT-II-I was presented by the three cubes: with left-side, symmetric (hexagonal) and right-side apertures. The DWM was performed in two variants: with isotropic and anisotropic (VTI) depth velocity models. In the Fig.1, the comparison of results is shown that were obtained by isotropic (left) and anisotropic (right) DWM. In the figure, the fragments of the stratigraphic slices of the DWM cubes that are parallel to the base boundary of the productive layer KT-II-I are shown. It is clearly seen that in case of isotropic migration, the DW anomalies are absent in the area of the N-001 well, and at the same time an intensive DW anomaly in west-north-west direction is seen near this well after anisotropic DWM. The description of core samples displays intensive fracturing within the whole interval of the core samples. One of the highest values of the fluid yield obtained within this oil field is attributed to this particular well which also testifies the presence of fracturing.

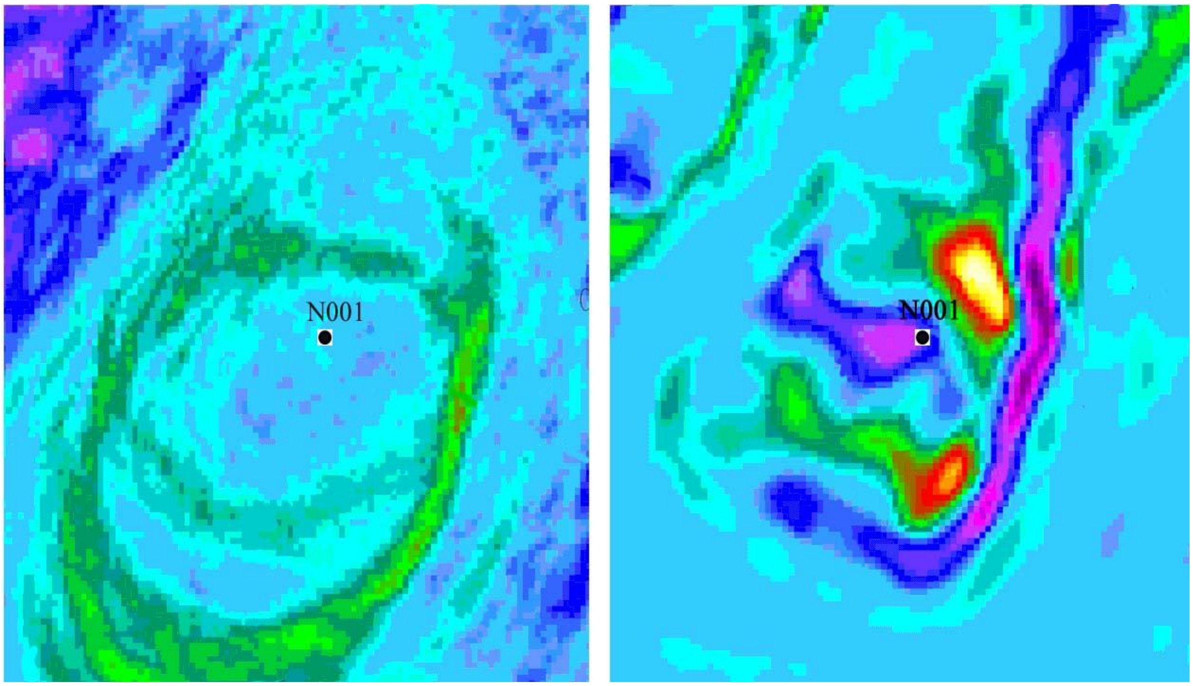

Fig.1 Comparison of results obtained by isotropic (left) and anisotropic (right) duplex wave migration in the area of the well N-001

In the Fig.2, the fragments of stratigraphic slices of the DWM cubes are shown that were obtained in the area of the same well N-001 for the intervals of the two productive layers for different variants of the migration apertures. The upper row refers to the layer KT-II-I, and the lower one to the layer KT-II-II. The analysis of the images produced by the use of different apertures shows that the above-mentioned anomaly passing the well N-001 is absent in the images obtained with left migration aperture. It shows that this fracturing zone has deflection from the vertical to the north-east (normally to the layer surface). It is also possible that in close proximity to the well, an intersection of two orthogonal fracturing systems occurs within the interval of the layer KT-II-II (the strike directions are 110° for the north-eastern dip and 20° for the north-western one); this is also seen by the lineament of the north-eastern strike that may be observed in the images obtained with the left aperture.

An important peculiarity of DWs that is confirmed by numerous real examples is the fact that in case of open fluid-saturated fracturing the DW intensity is far higher than in case of non-permeable healed fracturing. It often allows distinguishing tectonic seals and permeable fractured corridors. In the Fig.3, an example of the joint analysis of the DWM data and the data based on PSDM are shown. The tectonic disjunctive No.3 that is characterized by maximal displacement amplitudes in the structural map (Fig.3A) by the DWM data (Fig.3B, Fig.3C, and Fig.3D) is manifested in the form of a weak anomaly. By this indicant, the disjunctive No.3 may be classified as a tectonic seal. At the same time, the tectonic disjunctive No.2 that is shown in the structural map by insignificant displacement amplitude is imaged by DWM data as a significant anomaly passing the well N-002. Location of the well N-002 within the intensive DW anomaly (Fig.4, right) confirms the assumption that the DW anomalies represent reflections from the boundaries of highly permeable fractured zones that directly reflect the productive characteristics of the wells. The well N-002 has one of the highest yields in the field. It is characteristic that this high-amplitude DW anomaly has its plane inclined to the south-east from the vertical. It is clearly seen by its presence in the cube of DW amplitudes that is obtained with right migration aperture (Fig.4, right) and its absence in the DWM cube obtained with left aperture (Fig.4, left).

It should also be noted that the wells located outside of the duplex wave migration’s anomalies have usually low yields. For instance, such is well NP-2 shown in the Fig.3 (the section passes it) and in the Fig.4.

The experience of the hydrfracturing applied in this field shows that its effectiveness for the wells located close to DWM anomalies exceeds the effectiveness for the wells located at significant distances from such anomalies.

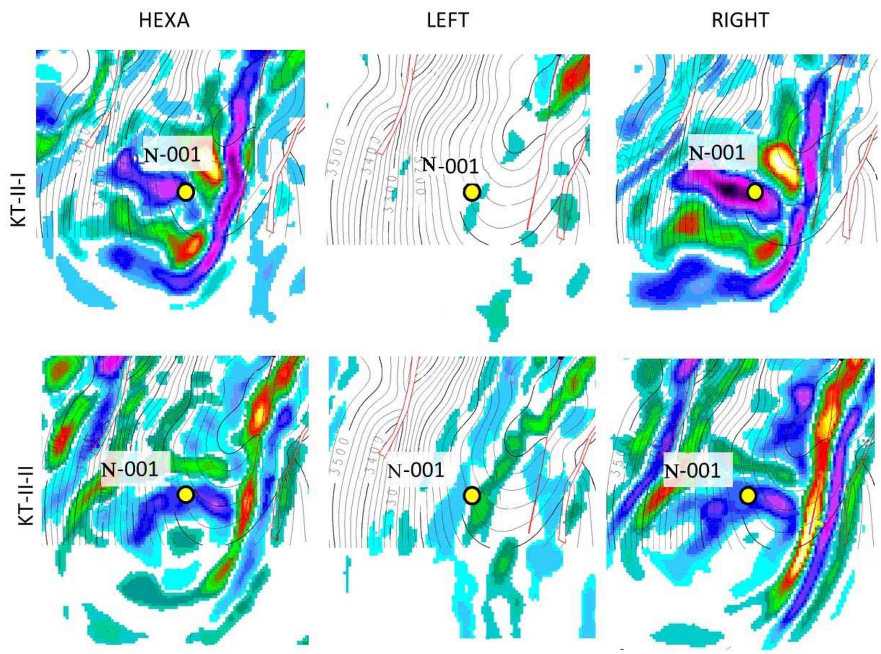

Fig.2. Stratigraphic sections of the DWM cubes in the area of the well N-001:
for the layer KT-II-I (upper row); for the layer KT-II-II (lower row); obtained with hexagonal migration aperture (left); with left aperture (in the middle), and with the right one (right). To the map, the depth isolines and the tectonic disjunctives are superposed.

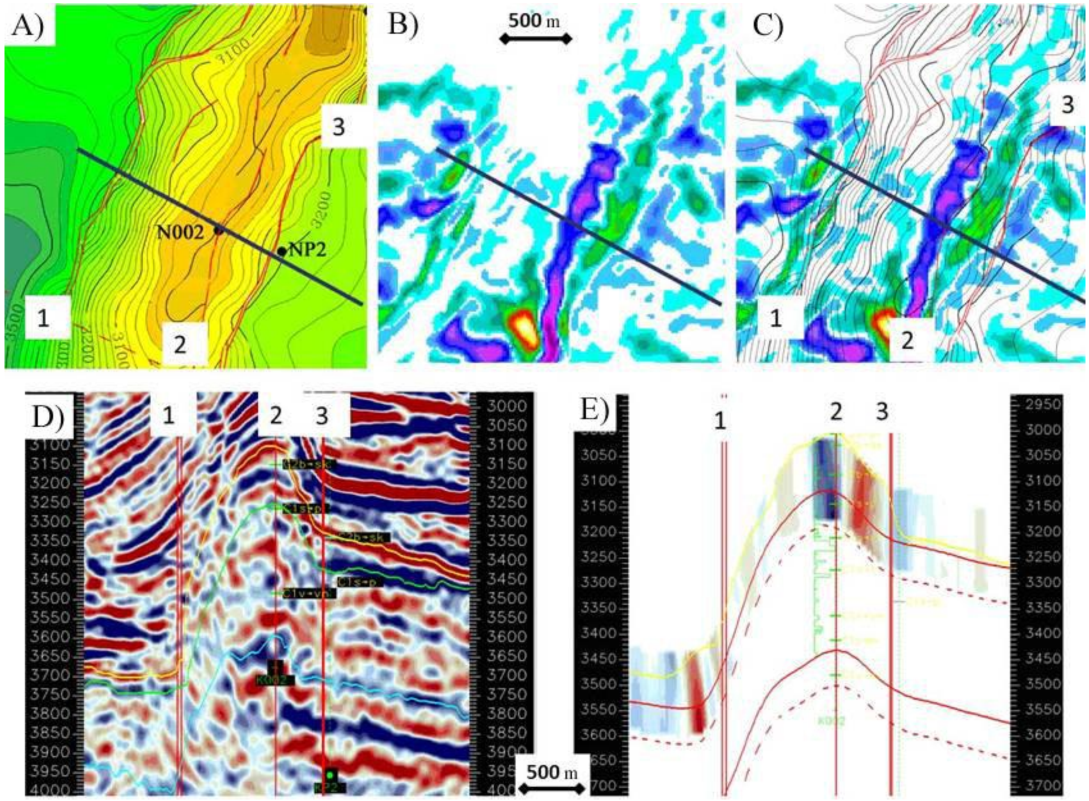

Fig.3. Joint analysis of DWM and PSDM data:

A) Fragment of the structural map for the layer KT-II-1; B) Fragment of the map of duplex waves' anomalies; C) Fragment of the map of duplex waves' anomalies for the same area, with superposed isolines of the KT-II-I layer top and polygons of tectonic disjunctives; D) Depth section of the PSDM cube; E) Depth section of the DWM cube. The Numbers 1, 2, and 3 show the disjunctives

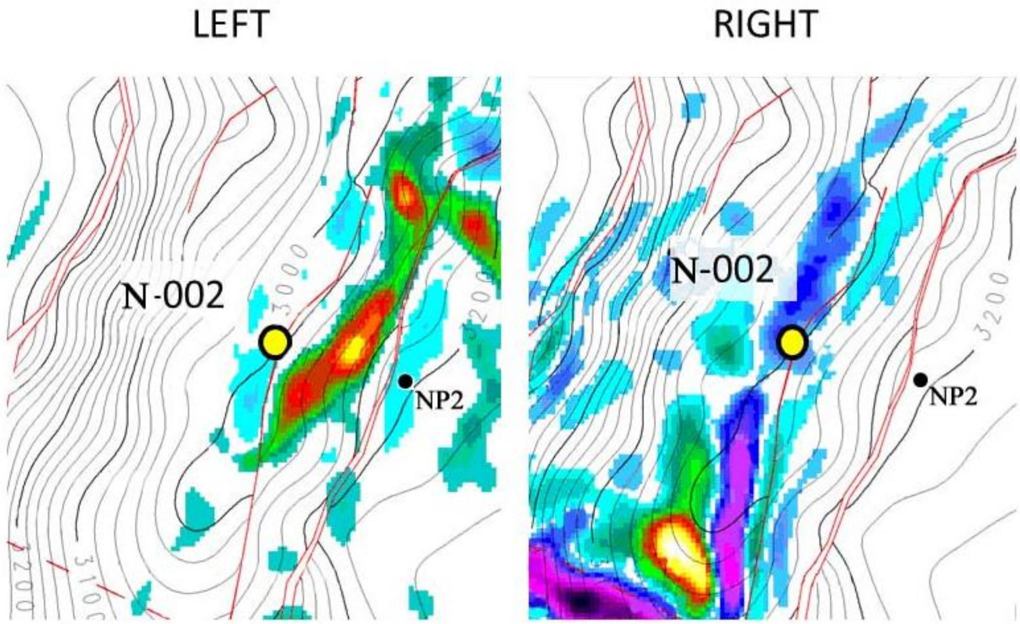

Fig.4. Stratigraphic slices of the DWM cubes in the area of the N-002 well that were obtained with left (left) and right (right) migration apertures

Conclusions

Application of the Duplex Wave Migration for studying of heterogeneities of subsalt carbonate deposits in the field located at the eastern near-slope zone of the Pre-Caspian Depression provided the capability to see that the high-productivity wells are located within intensive DW anomalies. The wells with low yields are located outside of the DW anomalies. Effectiveness of hydrofracturing is directly dependent on the distance from the well to the anomalous zones imaged by DWM results. Using of the anisotropic DWM allowed to reveal some DW anomalies that are practically absent by results of isotropic DWM.

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