Mapping of fracture zones and small faults using VSP and Cross Dipole Sonic in Eastern Siberia Carbonate Reservoirs, Yurubchansky Field, Russia.

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SUMMARY

Zero offset VSP, two Walkaway lines, ultra sonic and cross dipole sonic were used to interpret fracture zones and small faults in the vicinity of a deviated well drilled through carbonate reservoirs of the Yurubchansky giant oil and gas field, Russia. The fractures and small faults are the main flow conduits and storage of the hydrocarbons within mainly low porosity carbonate reservoir of the Proterozoic age. The wells are only successful if they intersect these "sweet spots" in the reservoir. This is a challenge in developing the Yurubchansky field. The 3D seismic over the field has low resolution, strong heterogeneous reservoirs, varying degrees of anisotropy, multiples contamination and therefore cannot be used to map the "sweet spots" reliably.

An incoherency attribute was used to guide fracture and fault interpretation. Two major fault zones and small faults were interpreted from VSPs. One of the fault zones within the reservoir corresponds to fractured core, intensive fracture zones interpreted from the logs and hydrocarbon shows. This demonstrates the effectiveness of high resolution VSP data in mapping fractured zones. Other geological features including unconformity at the top of the reservoir were also interpreted from VSPs.

Key words: field development, VSP, fractured reservoir, carbonates.

INTRODUCTION

Fractures in carbonates often form fracture zones or clusters that become conduits and storage of the hydrocarbons. Information about distribution of the fracture zones is crucial for the successful development of the carbonate reservoirs. The usage of 3D seismic data for fracture mapping has become quite common in recent years and is offered by many geophysical contractors using various developed techniques. The main uncertainty in all these methods is that the scale of detection of the fracture zones is often beyond the scale of the 3D data. Although VSP data are limited spatially near a borehole, it is much higher resolution and can provide reservoir property information using the VSP and the sonic compressional (P) and shear (S) wave.

The Yurubchansky giant oil and gas-condensate field in the East Siberia (Figure 1) is at the Baikut regional high and within the Siberian Craton margin with sedimentary rocks from the Riphean (Upper Proterozoic) to Ordovician age (Kontorovich, *et al.*, 1996, 1994, Ulmichek, 2001). The sedimentary section primarily consists of carbonates, shales and salt rocks (Figure 2). The field is a structurally controlled anticline with some stratigraphic traps within the closure. The area of the field stretches 80 km in length and 50 km in width with a gas and oil column up to 45 m. The main reservoir is vuggy and fractured dolomites of the Riphean age. Matrix porosity (0.1-1%) and permeability of the dolomites is very low and not productive, and secondary porosity (up to 5.5%), consisting mainly of vugs and fractures, is unevenly distributed. The challenge is to delineate and intersect these high productive "sweet spots" by the wells. A 3D seismic survey acquired in 2009-2012 has low resolution, multiples contamination, varying degrees of anisotropy and strong heterogeneous intervals due to mostly carbonate lithology at the reservoir level and cannot be used to map these features reliably.

During November-December 2015 a land zero offset VSP; two walkaway VSP profiles were acquired with UBI (Ultrasonic Borehole Imager), Sonic Scanner data and the full suite of wireline logs in the Yurubchansky Yur-90 deviated development well. The TD 3200 m MD was 800 m away from the well head. The objectives were to acquire data for 1) accurate P, S velocities, 2) high resolution VSP imaging near the borehole, 3) VTI estimation and AVO measurements 4) validation of surface seismic results and 5) integrated interpretation. Other objectives were: anelastic attenuation (Qp), VTI anisotropy, phase analysis and tying 3D seismic to the well. Two inline walkaway VSP lines (16 levels VSP tool) with a maximum offset of 3500 m from the wellhead and cover a 700 -1000 m and 2200-2500 m depth interval with receiver spacing of 20m was carried out with explosives as a seismic source. It took 21 days to drill 245 shot holes in a remote location (800 km from Krasnoyarsk) in extremely harsh conditions where the temperature changed from -35 to -50 degrees C. A rich VSP data set was utilized to estimate the surface statics, geometrical spreading, Q factor, VTI anisotropic parameters and compute high resolution Pp, Ps VSP images. The true amplitude processing workflow was applied to zero offset VSP and walkaway VSP-P and VSP-S using a calibrated anisotropic model (Leaney, *et al.*, 2003, Morice, *et al.*, 2003, Tcherkashnev, *et al.*, 2015).

SEISMIC INTERPRETATION AND RESULTS

The integrated interpretation of the cross dipole sonic and the VSP processing results included shear wave azimuthal anisotropy analysis, Stoneley permeability (Dobrynin and Stenin, 2009), sonic fracture porosity estimation (Bayuk and Ruzkov, 2010), UBI breakouts, fault analysis, 3D seismic, VSP structural, attribute analyses and mapping small faults and fracture zones within the reservoir around the well.

As a rule, leading service companies provide only acquisition and processing VSP data for clients. In this project, the contractor additionally provided geological interpretation of the VSP data and integrating them with the well logs and 3D full stack seismic data. Initially, an incoherency attribute was used for VSP seismic sections to map the faults and fracture zones. Manual mapping was used as the next stage to map structures accurately. The results were compared with fracture zones from core, interpreted UBI and Sonic Scanner data as well as hydrocarbons shows.

There are no obvious conventional indications of the faults as displacements and discontinuity of the reflectors on the migrated VSP-P and VSP-S images (Figure 3 and 4, left). We interpreted two major sub-vertical fault zones A and B on the zero offset VSP-S data section. They both have a strong incoherence attribute which is obvious on the VSP-S section (Figure 4, right). These faults look like deformation zones 100-150 m wide on the VSP seismic section (Figure 4, left). It may indicate the shear nature of these faults with intensive fracturing along the fault plane. There are no indications of these faults on 3D seismic (Figure 5). Fault A is very encouraging as it is located within Riphean reservoir. If the fault zone were to continue upward, it would intersect the well path with two intensive fracture zones interpreted from UBI and Sonic Scanner well data as well as fractures observed from the core data (Figure 4, left). The lower zone also has oil shows in the core. These types of results bring confidence in the VSP interpretation.

Zero offset and walkaway VSP-P and VSP-S images were used to map smaller faults and fracture zones (Figure 3, 4 and 6). Most faults are sub-vertical with apparent 5-10 m throw. The incoherence attribute shows clustering around small faults on the VSP-P migrated images. These fracture zones are defined by loss of continuity of the reflectors on the VSP sections. The confidence in interpretation of the small faults is not as high as in faults A and B.

VSP S and P waves provide different dynamic information of the rocks. The VSP-S data provides mainly rock matrix properties (density, fractures, porosity) and is not influenced by fluids while VSP-P data includes matrix and fluids components. For this reason, it is likely that a deformation zone around large faults, with likely intensely developed fractures, can only be seen on VSP-S and not on VSP-P data. The high amplitude zones adjacent to the faults also indicate changes in the matrix properties - possibly density and/or porosity change (Figure 4, left).

Additional geological information from zero offset VSP was interpretation as an unconformity at the top of the Iremekenskaya Formation (Figure 7). Riphean unconformity is known in the area from regional geology but cannot be seen on the 3D seismic (Figure 5). Interestingly, the patterns of these reflectors within this formation look like a “prograding” sequence.

CONCLUSIONS AND RECOMENDATIONS

The Yur-90 zero offset VSP and walkaway VSP-P and VSP-S images are higher resolution than 3D seismic data. The VSP data provided a revised structural model that allowed the interpretation of faults and fracture zones that are the main flow conduits and stores of hydrocarbons in the fractured reservoir. An incoherency attribute can be used as a supplementary tool for fault and fracture zone interpretation. The confidence in mapping of small faults and fracture zones are lower than the mapping of large faults.
Time migrated VSP P and S waves provide different rock property and therefore geological information. This can be used in seismic inversion, AVO calibration and modelling reservoir properties.

Traditionally VSP provides the velocity and imaging information after the well has been drilled. Geological interpretation of shallow walkaway VSP data, predictions of fracture intensity and orientation and placing the lateral wells in the best areas can bring an economically viable opportunity to drill the wells within fractured reservoirs. We recommend acquiring and processing walkaway VSP data before the well enters the reservoir. With today’s technology, processing and interpretation of the walkaway VSP data can be done within a short period of few weeks. These results can be used to steer a well trajectory into interpreted geological features or “sweet spots” in the reservoirs. Alternatively, VSP can be done in a pilot hole and then side track the well based on the VSP interpretation in areas where structural geometries are poorly imaged on surface seismic.

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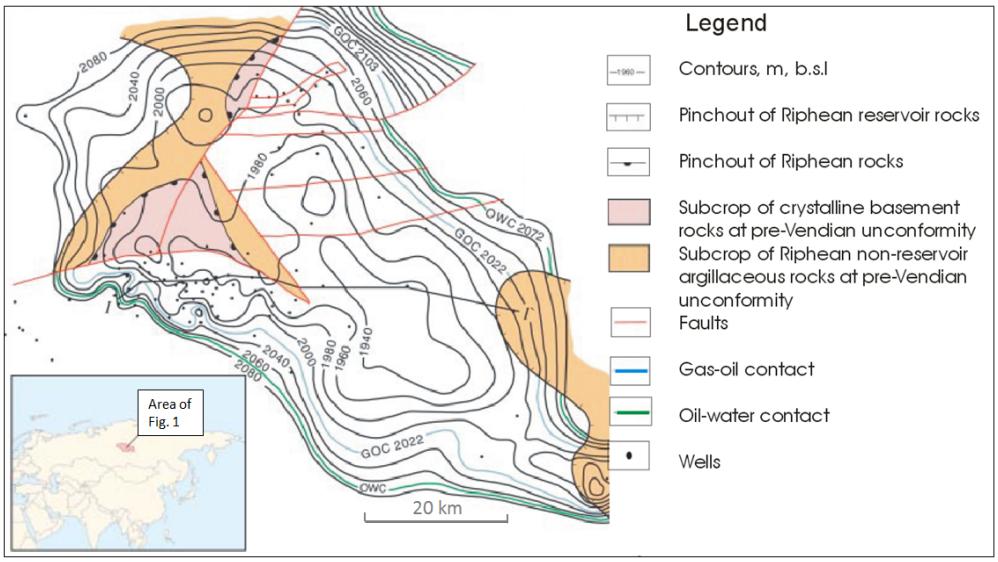

Figure 1: Contour map of the Yurubchansky field. Modified from Kontorovich and others (1966). Contours are the top reservoir and the erosional surface of Riphean rocks.

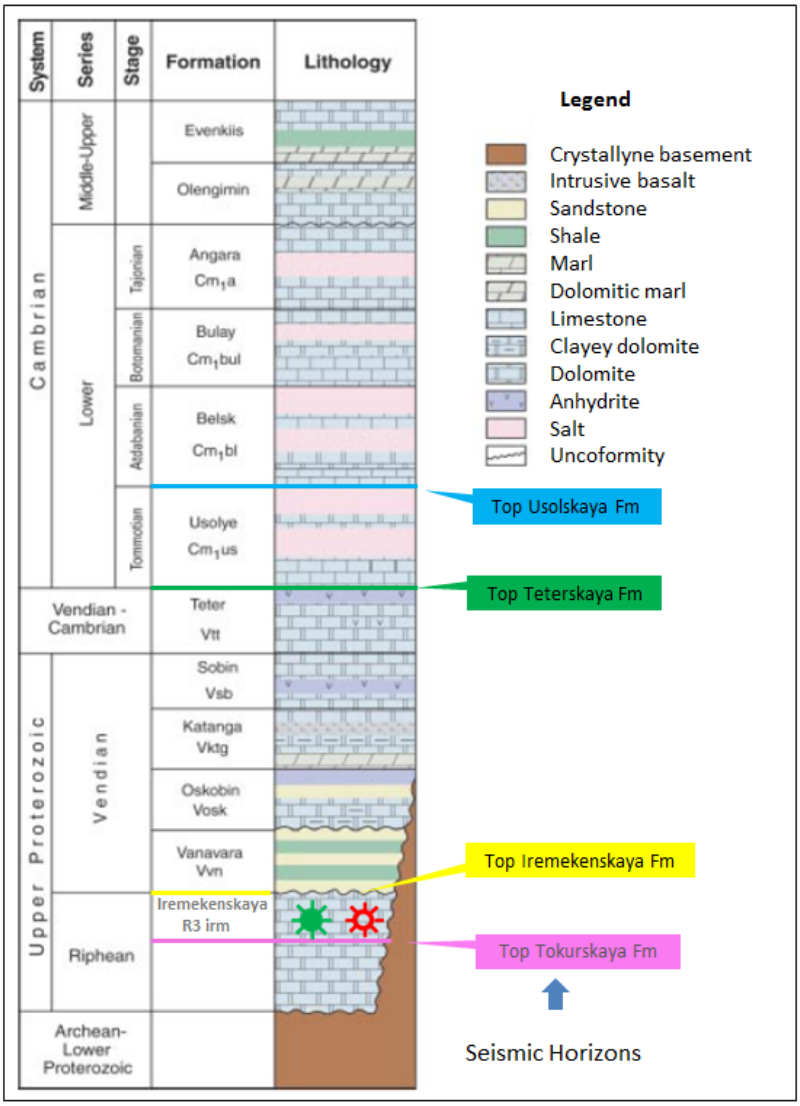

Figure 2. Generalised stratigraphy of the Baykit regional high. Principle seismic horizons and main reservoir are shown.

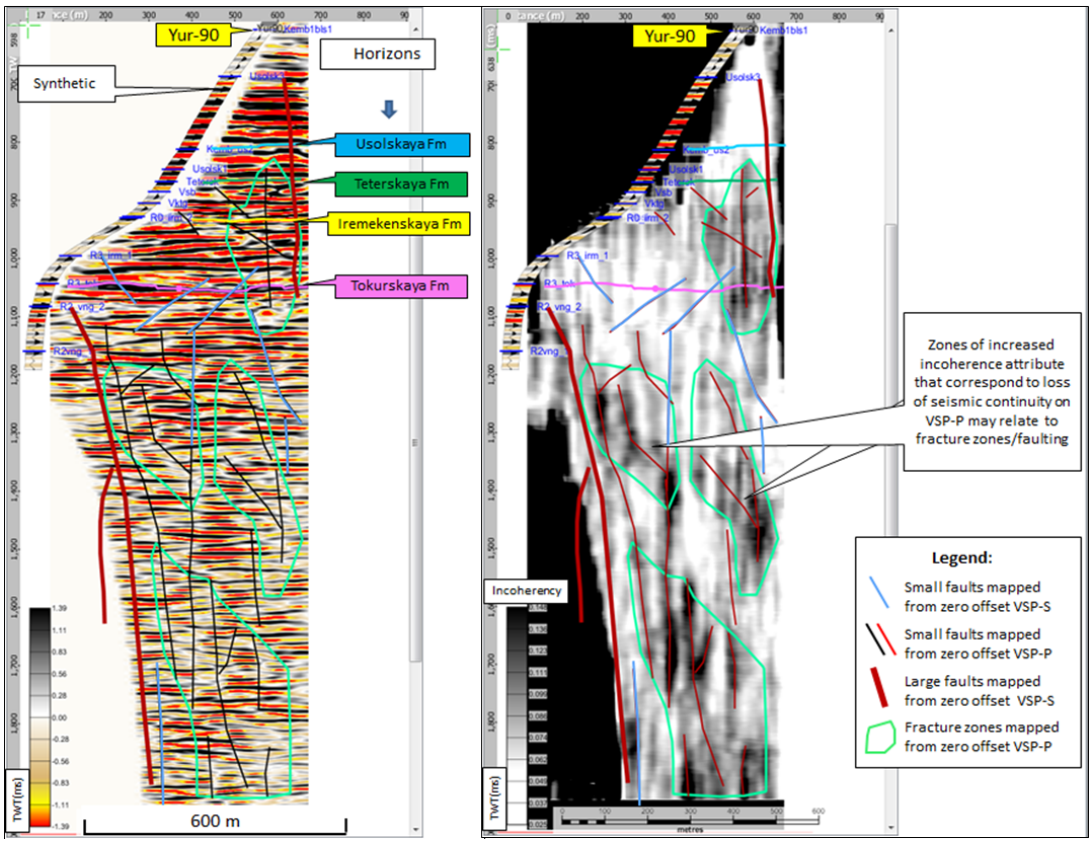

Figure 3. Zero offset VSP-P time migrated profile with interpretation (left). Incoherency attribute of VSP-Ps profile with faults and fracture zones interpretation (right).

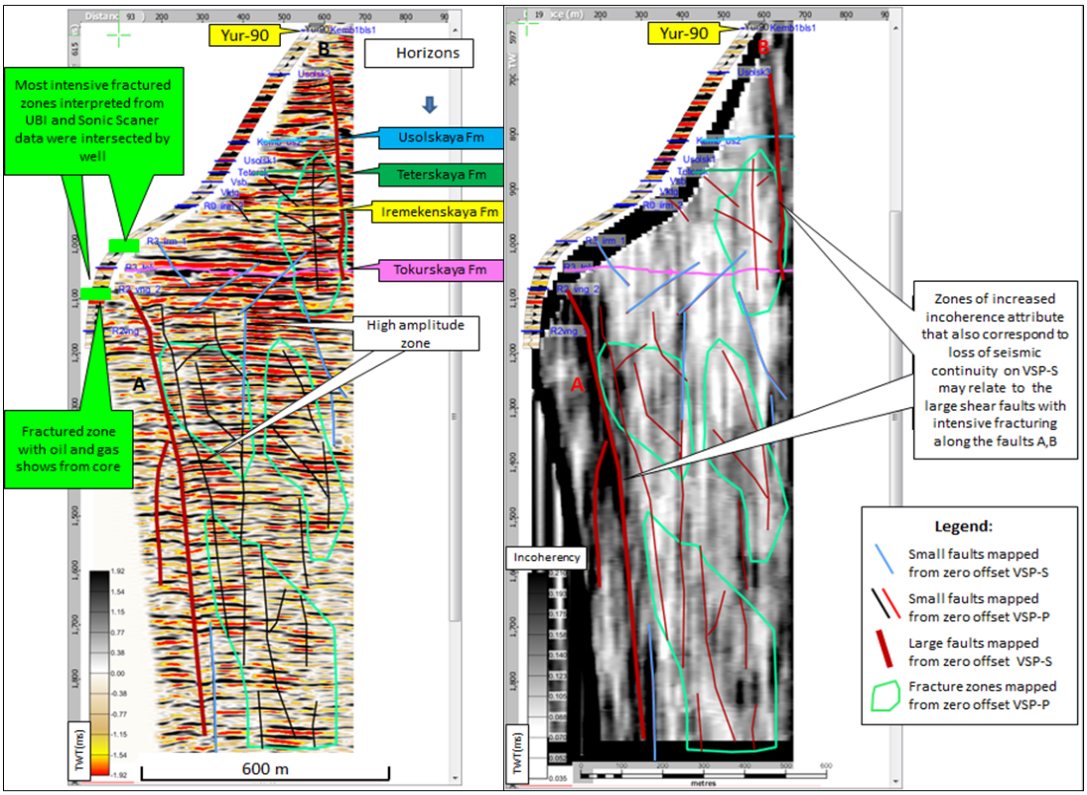

Figure 4. Zero offset VSP-S time migrated profile with interpretation (left). Incoherency attribute of VSP-S profile with faults and fracture zones interpretation (right).

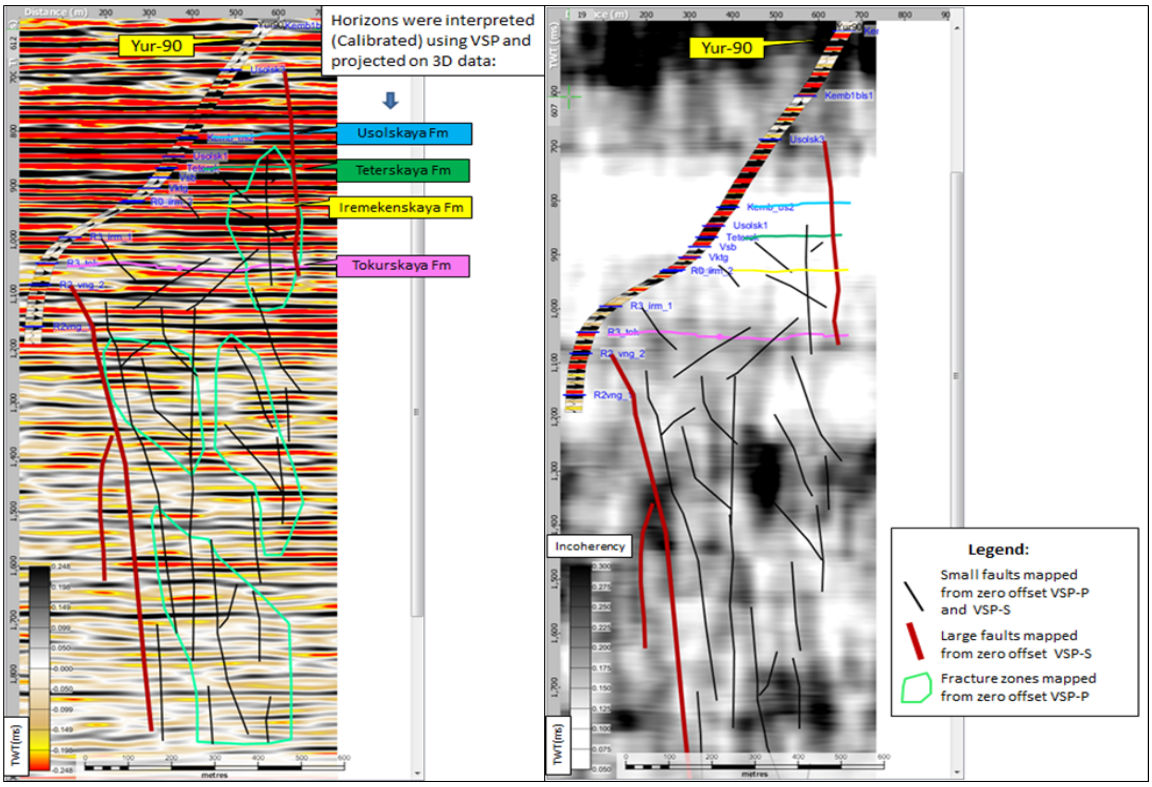

Figure 5. 3D seismic and incoherency attribute from 3D. Faults and fracture zones interpreted from VSP.

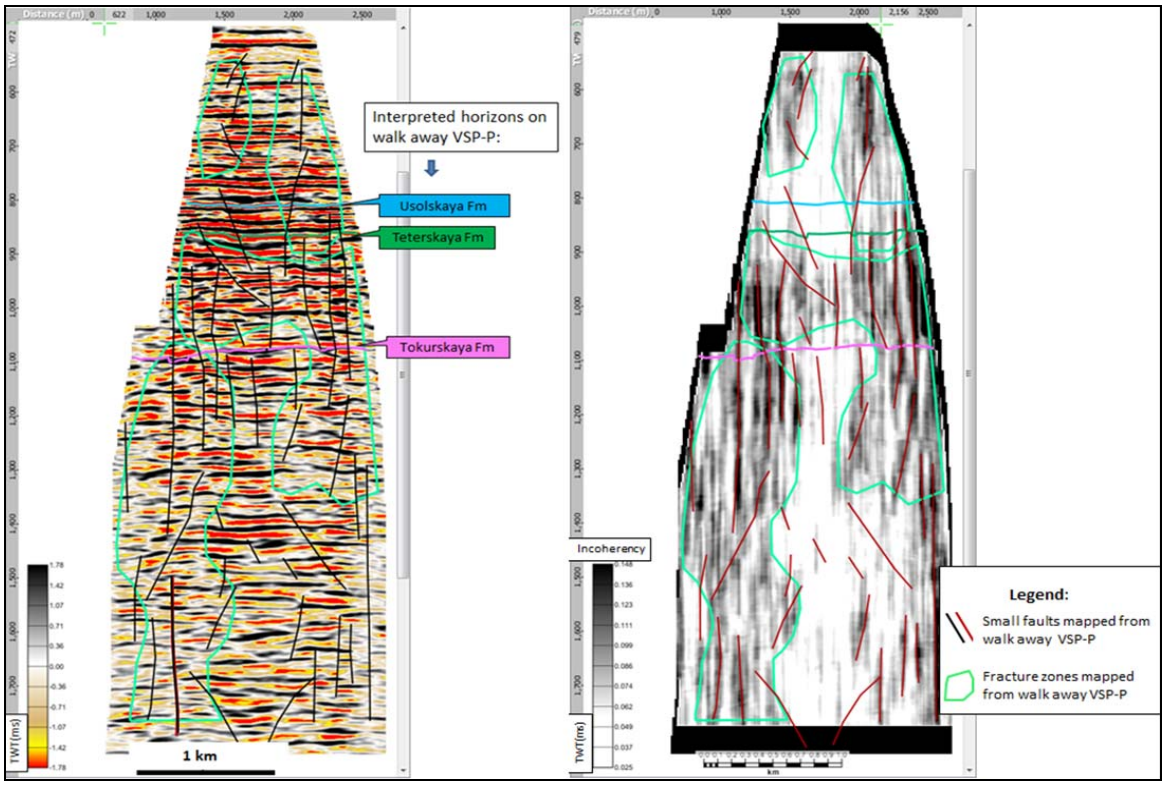

Figure 6. Migrated Walkaway VSP-P image (left) with the interpreted fault zones and incoherency attributes (right).

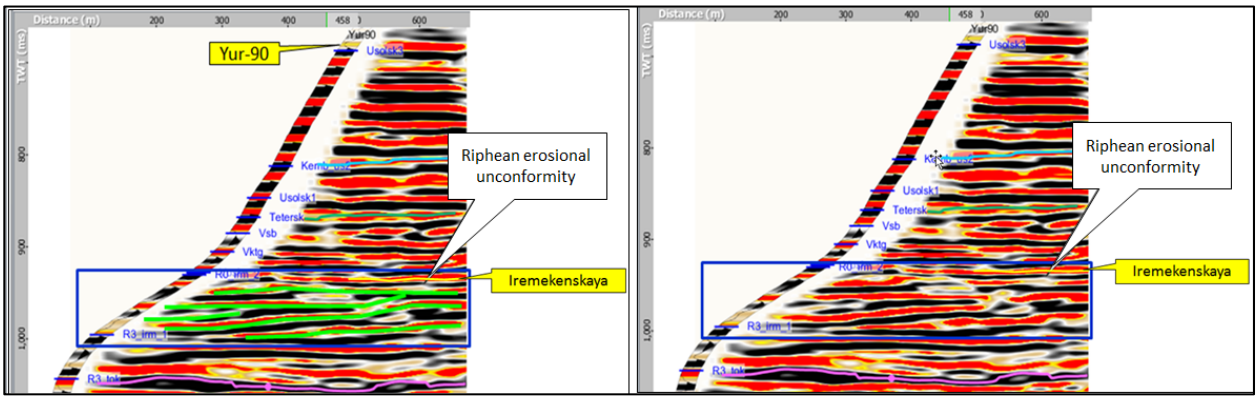

Figure 7. Riphean erosional unconformity interpreted from VSP-P profile.