Pyritization effect on well logging parameters in Jurassic reservoirs within S-E Western Siberian oil fields

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Abstract. Authigenic sulfide mineralization in hydrocarbon-saturated reservoirs distorts the electrical and density properties of rocks. The correlation between volumetric density, electro-conductive minerals and open porosity in 300 samples were determined. This fact made it possible to develop a nomograph in evaluating oil saturated reservoirs and could be applied in well geophysical survey data interpretation.

1. Introduction

Determining the reservoir fluid content (saturation) during exploration and hydrocarbon, reserve estimation is based on the interpretation of production well logging data. Formations with low resistivity (R_{por} = 3.5-5.5 ohm.m.) are identified as water-saturated ones [4, 7, 9]. Nevertheless, according to induction logging data (Fig.1),there are cases of cumulative oil inflow from Upper Jurassic reservoirs, namely, from water-saturated intervals within Tomsk Oblast oil fields.
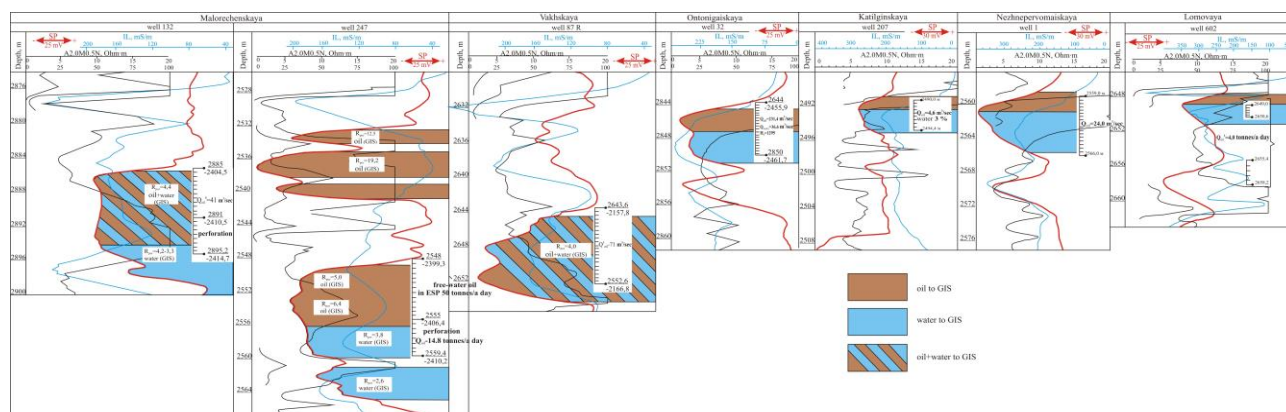

Figure 1. Examples of oil – saturated Upper Jurassic low-resistivity

Similar reservoirs were also exposed in Shirotni Prioby(Tumen Oblast) oil fields within NezhneVartovsk, Surgut and Nojabrsko-Pursk oil-gas bearing areas. This fact was established in the 90s of the last century by engineers of the Petrophysics Laboratory, Siberian Research Institute of Petroleum Industry (F.J. Borkun and others) in collaboration with the Department of Geology and Oilfield Development, TPU (A.V. Ezhova and others) [3]. These anomaly field geophysical characteristics of oil-saturated formations being determined as water-saturated due to low electric resistance values were the result of semi-conductor mineral occurrences in the rocks, such as sulphides, titanium and ferrum oxides. This mineral quantitative correlation indicated a well-defined predominance of sulphides. Titanium and ferrum oxides were only 1-2% and found in water-bearing horizons or water-saturated sections within hydrocarbon reservoirs, while sulphides were pervasive, including from 4 to 14 %.

Sulphides (FeS_2 compounds) are crystalline formations (pyrite and white iron pyrite) and powdered black matter (melnicovite). Pyrite and white iron pyrite have identical chemical composition (Fe – 46.6 %, S - 53.4 %), color (in reflected light-metallica, goldish), petrophysical properties (specific electric resistance – $10^{-5}–10$ Ohm.m·, density- $4.88–5.2$ gr/cm^3) [10]. These minerals differ only in their crystal structure: pyrite-cubic (i.e. cubic syngony), while white iron pyrite has tabular and / or spear-like crystals, as well as

concretions with radial structure (rhomboid syngony) [2]. Melnicovite (collodial bisulphide iron) is a finely-dispersed matter with specific gravity of 4.1 gr/cm^3 and composed of fine pyrite and white iron pyrite grains (which was identified by X-ray diffraction analysis) [2].

The sulphides in oil-saturated reservoirs are finely-dispersed, having pseudomorphic and idiomorphic crystals, spherulites, irregular formations, veins and seams. The cement- basalt, porous and film-like. Sulphide formations as fines on grains and oils, as well as peripherally to the hydrocarbon-filled pores are of more interest.

Taking into account the fact that the petrophysical properties of both pyrite and white iron pyrite are identical and only their crystal structure differs makes it possible to solve the stated target without considering these two factors. Thus, for avoidance of any doubt, concerning the name of the above-mentioned minerals, one and the same name-pyrite is used according to Betekhin classification, in which pyrite group is included in the sulphide class [2].

Pyrite crystallization is probably due to iron oxide and sulphate reduction in formation water. Increasing SO_4^{-2} ion content (37−113 gr/liter) to (3.7−2.0gr/liter or less) is observed in formation water of Upper Jurassic sediments with anomaly geological description (31 and 49, respectively).

Oil and pyrite association is confined to the lower section of the layers where connate water content is increasing. Pyrite and connate water inclose oil occurrences and develop well-closed path transmitting electric current. Specific electrical resistance decrease can be registered on electrical logging diagrams.

2. Results and discussion

Survey results of geophysical parameters and well samples from SE Western Siberian petroleum province revealed the fact that identifying oil-saturated reservoirs based only on resistivity logging images is relatively unreliable. In this case, additional geophysical methods should be applied to determine other petrophysical rock properties, which, in its turn, would establish the electrically-conductive minerals within these rocks.

According to potential induced polarization values, electrically-conductive minerals are reliably identified. Measurements are conducted in Borkun samples [3] after extraction, i.e. hydrocarbon extraction. Electrical resistivity of semi-conducting minerals sharply increases at growing temperature within formation conditions [8]. In this respect, proposed Borkun nomograph determining reservoir saturation behavior, including electrically-conductive minerals and based on potential induced polarization measurement data [3], should be correlated to well logging. However, it should be stated that this method is not applied.

Another informative method in well logging identifying rock density properties is gamma-ray density logging. It is well-known [1] that in existing host rocks with density of $(2.4-2.7) \cdot 10^{-3}$kg/m³,sulphides and other ores with a density of $(4.5-5.1) \cdot 10^{-3}$kg/m³ reflect decreased radiation intensity on logs.

Volume density, electrically-conductive mineral content and effective porosity relationship identified in 300 samples provides data to plot an evaluation nomograph of the reservoir saturation parameters (Fig. 2).
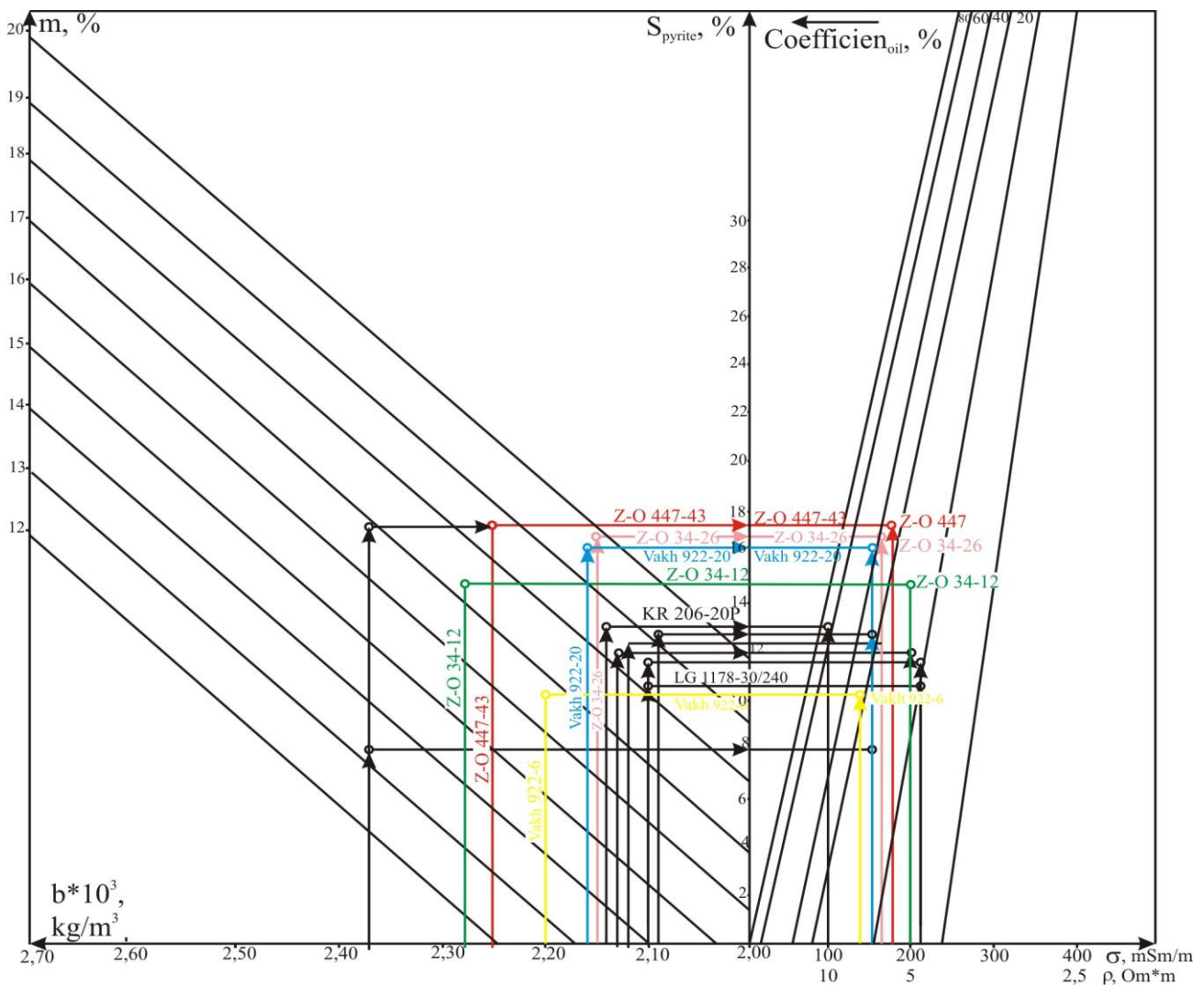
Figure 2. Nomograph of evaluating oil-saturated Upper Jurassic low-resistivity reservoirs

The first section of Borkun nomograph [3] plotted for Upper Jurassic reservoirs of Surgut anticline fold involves a relationship diagram of rock electric conductivity (σ), rock saturation coefficient (K_{sat}) and pyrite content in rock (S_{pyrite} %). Electric conductivity in wholly water- saturated sample without electrically-conductive minerals is 266 mS/m (R_{por} = 3.75 Ohm·m) at formation temperature of 90°C. Electric conductivity of pyrite at above-mentioned temperature is 1.5 Ohm·m.

The left nomograph section plotted by A.V. Ezhova [5] is a diagram indicating the content of electrically-conductive minerals based on rock volume density data (δ) including rock porosity (m) [5].

Application procedure of nomograph:

– rock volume density is determined based on gamma-gamma ray logging data on density;

– rock porosity coefficient is determined based on radioactive logging data;

– from point, corresponding to rock volume density (δ), a perpendicular is erected extending until it intersects the projection of the horizontal line, corresponding to rock porosity value (m). The projection of this point on Y-axis determines the pyrite content in rock (S_{pyrite} %);

– based on inductive electric- magnetic logging data, rock electric conductivity(σ) is determined by erecting a perpendicular extending until it intersects the projection of the horizontal line through Y-axis (S_{pyrite} %). Located point on the slanting line indicates oil saturation behavior in investigated reservoir beds.
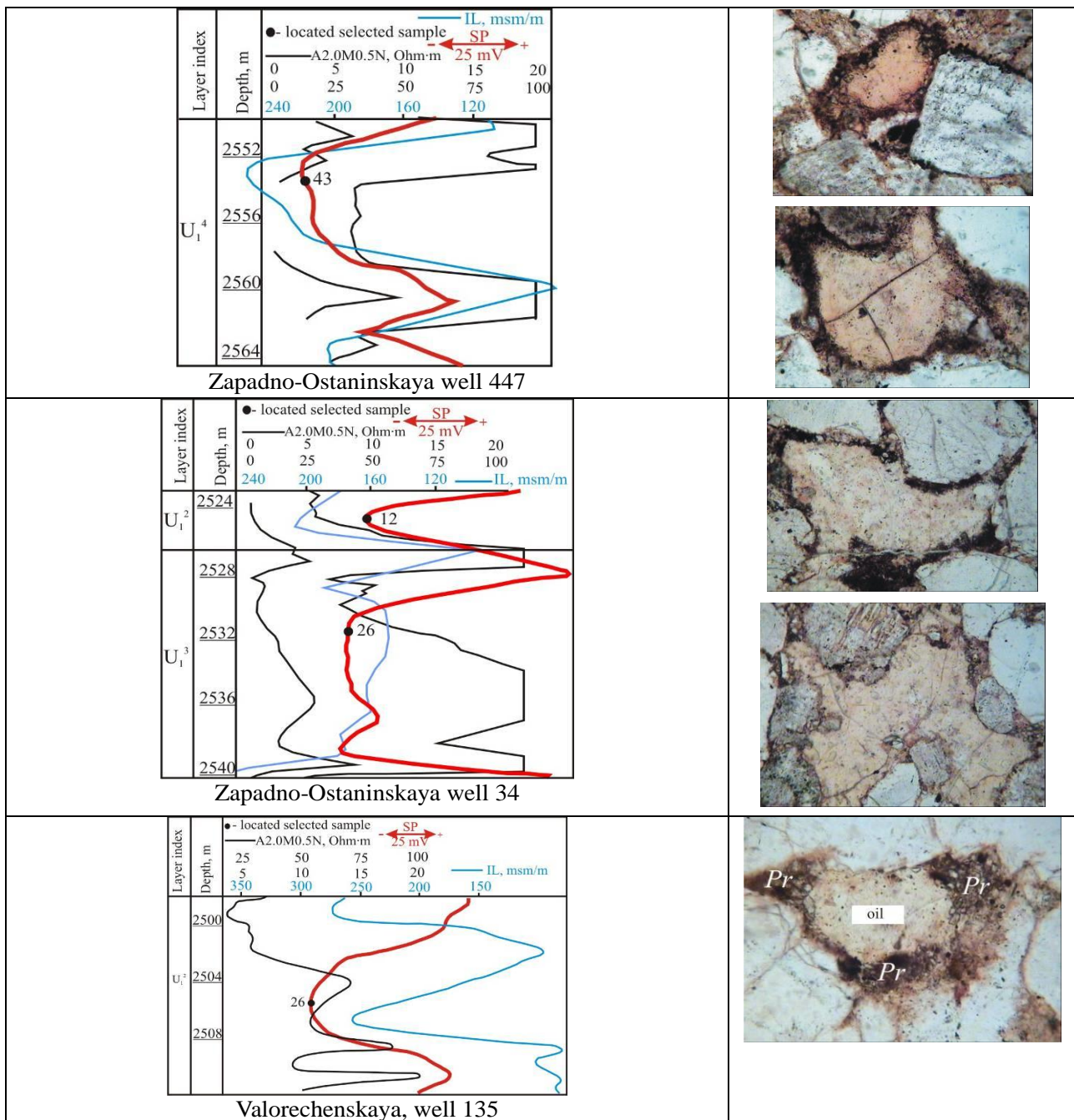
Figure 3. Geophysical characteristic anomalies and photos of thin sections, oil-saturated reservoirs

3. Conclusion

Nomograph example is based on the data of several investigated rock samples. According to geophysical data these selected samples were from water-saturated reservoirs. Occurrence of oil substance within pores was observed in thin sample sections (Fig. 3). Nomograph could be applied in GIS data interpretation to identify oil saturation degree in low-resistivity reservoirs [5].

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