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The possibilities of well logging data methods for studying fracturing

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Abstract. This article covers the main methods of geophysical well studies aimed at studying fractured zones. Examples of the results of a quantitative evaluation of fracture parameters and examples of their use when working with seismic data and constructing hydrodynamic models are given. The emphasis is made on the need for a cross-cutting technology to study the type of pore space from seismic data, geological and technological studies, core, geophysical studies of wells, field geophysical studies, hydrodynamic studies.

Keywords: fractures, reservoir, well logging, field geophysical studies, permeability, watering

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Over a 25-year history of the Pomor-GERS LLC, wealth of experience has been gained in the field of geophysical well logging in different regions: Timan-Pechora petroleum and gas province, Volga-Ural petroleum and gas province, Siberia, Kazakhstan, Uzbekistan, etc. The great scope of our work is associated with extremely complex objects for which standard techniques are not suitable. Each region has its own characteristics, but issues such as pore volume and tectonics are acute in all regions. During these years, the company's specialists have developed techniques for studying non-standard reservoirs with a focus on the type of pore volume.

Our techniques have been tested at more than 20 fields, and at more than 500 wells. We have gone from a selection of fracture zones at a qualitative level to the quantitative geophysical assessment of such complex parameters as density, opening, fracture capacity, their permeability, etc.

The main idea that we are trying to communicate to subsoil users is as follows: what matters are not separate, even very advanced and expensive technologies, but systematic works on studying the type of pore volume. There is a need for end-to-end technology to verify and complement regional seismic, geological modelling, etc., which is only possible after well drilling.

The main stages of obtaining information that should not "live" independently, but constantly overlap and complement each other: **geotechnical survey, sludge, core, open-hole well logging, well testing, geotechnical survey + field-geophysical research, closed hole well logging, field operations results.**

A constantly updated document is required in which the presence or absence of fractures, caverns should be noted from the first days of work. Perhaps in some cases it will sound even odd: "we looked for cracks and caverns using methods (seismic, geotechnical survey, open-hole well logging, field-geophysical research, etc.) – are absent". This is important both for the possibility of obtaining the inflow of the expected hydrocarbons, and for the prevention of advanced flooding. The fractures problem of is also of ecological importance, since disposal of wastes may lead to regrettable consequences.

When studying rocks, especially carbonate rocks, one should proceed from the assumption that there are always fractures (or there were). It is important to know the genesis of fractures, what they are and how many. Photos of a core with various type of fractures are given in Fig. 1-5.

In this article we will focus only on some points in the chain of studies based on the methods of geophysical exploration of wells, which allow us to move to a new level of areal and regional studies that are crucial for building a hydrodynamic model.

High-resolution scanning methods

An important group of relatively new methods for the study of complex sections is high-resolution scanning methods, both electrical and acoustic. The previous research methods included the use of tiltmeters that have been used for a long time, but due to the limitation or lack of computer technology, has not been properly

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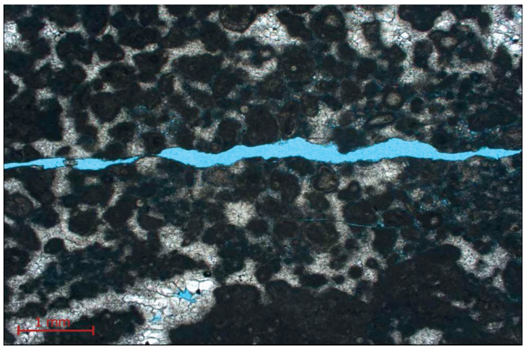

Fig. 1. Microfractures (thin section)

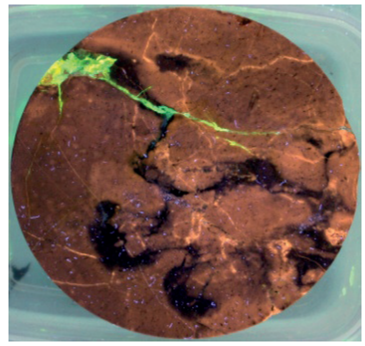

Fig. 2. Caverns along the fractures, (with bitumen)

Fig. 3. Meso-fractures

Fig. 4. Macro-fractures

Fig. 5. Tectonic fractures (with calcite)

developed. Modern equipment production technologies, and most importantly computer imaging technologies and possibility of multivariate processing of the received data, have given a breakthrough in the development of this area of well logging. An important advantage of these methods is the ability to visually and clearly not only for geophysicists to correlate an image of the physical properties of the rock with a real rock. Examples of such visualization are given below (Fig. 6, 7).

The possibilities of the method are not limited to the photographic display of the section.

For the analysis of the structure of the reservoir as a whole and fracturing on the scale of the field, statistical processing of the results of scanning methods is of great importance, which allows to divide the groups of fractures in azimuth and inclination angle. Fracture opening analysis, the capacity of the caverns along the fractures for each system, gives an insight into the hydrodynamic characteristics of the studied part of the section at initial stages of the investigation.

The following are examples of scanner processing results (Fig. 8), an example of construction of the map of fracture distribution over the area (Fig. 9) and an example of a comprehensive analysis of seismic data and well logging (Fig. 10).

The full-waveform logging has gained considerable prominence in the study of fracturing. Recently, new generation devices are used extensively, both domestically produced (AVAK tool), and proposed by Western service companies (DSI, XMAC, SonicScanner, etc.). The use of such devices provides a number of important advantages in comparison with simpler devices of the previous generation:

• Reliable separate recording of waves of different types (S and P waves, and so-called Lamb-Stoneley waves);

• High quality of recording of the amplitude parameters of all waves;

• Anisotropy recording with a cross-dipole sensor.

This provides new opportunities for studying the fractures parameters (fracture capacity, opening, quantity of fractures per meter (fracture density), permeability, spatial orientation) (Fig. 11-14).

One of the major parameters in the study of rocks is permeability. It is extremely important to separate the permeability associated with the traditional granular reservoir and the permeability due to the fracture system. The main method for determining the permeability is acoustic logging, but on condition that the Stoneley wave is obtained from the wavetrain. It should be borne in mind that the appearance of the Stoneley wave depends not only on the properties of the rock, but also

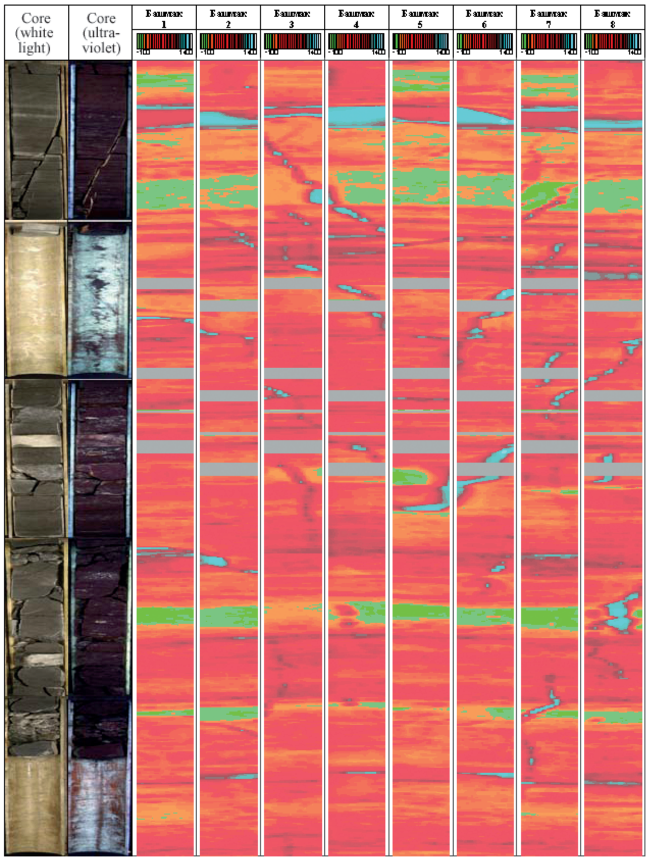

Fig. 6. Photo of core and processing of FMI primary data (“POMOR-GERS”) for further analysis with a high evidence base

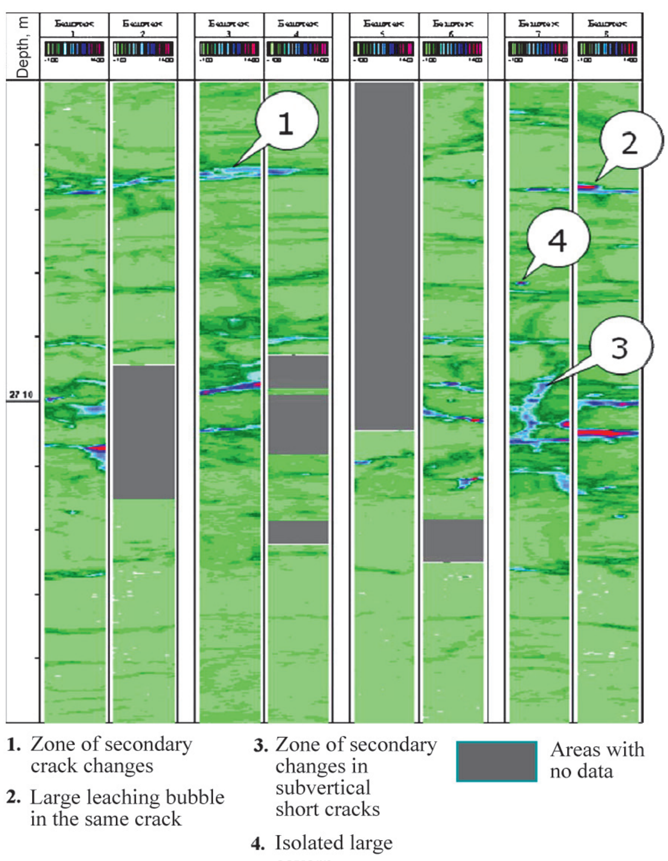

Fig. 7. Selection of objects on microimages

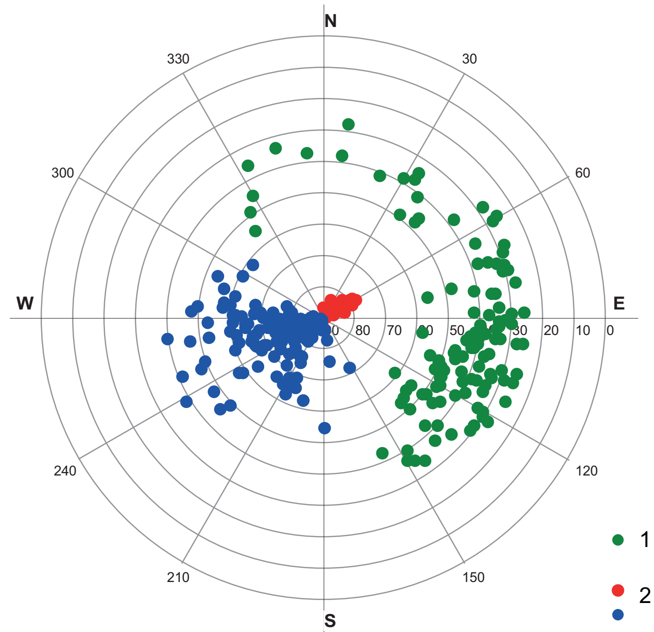

Fig. 8. An example of determining the occurrence of fractures and fracture typing according to the occurrence peculiarities: 1 – a group of sub-vertical fractures, 2 – a group of inclined diagonal fractures with transverse strike azimuths

on the conditions of logging, since it is affected by the mud composition, the composition of the fluid in the near-wellbore area, the cavern porosity of the wellbore. It should not be overlooked that one of the tasks in the drilling process is to prevent drilling mud filtration into the formation, while sometimes mechanical impurities, gelling additives are used, which greatly changes the properties of the near-well area, i.e. changes the permeability and propagation conditions of acoustic waves. Of course, there are limitations, but this is the only well logging method that has a direct correlation with permeability.

Figure 13 provides further options for calculating the permeability by different techniques:

• traditional permeability calculation depending on porosity, i.e. this is permeability, associated mainly with traditional granular reservoir (increase in porosity – increase in permeability);

• permeability, determined by the Stoneley wave, which is significantly higher than permeability 1, and in the top of the section has the highest permeability, which should be attributed to the fracture permeability, or vuggy-fractured system (in this area the total porosity of the rock is less than 5%);

• differential permeability, determined in the process of testing the object according to the field-geophysical and hydrodynamic research (methodology developed in “POMOR-GERS”).

Figure 14 gives an example of determining the permeability of sediments with the absence rocks with a porosity of more than 5%. The inflow was only in

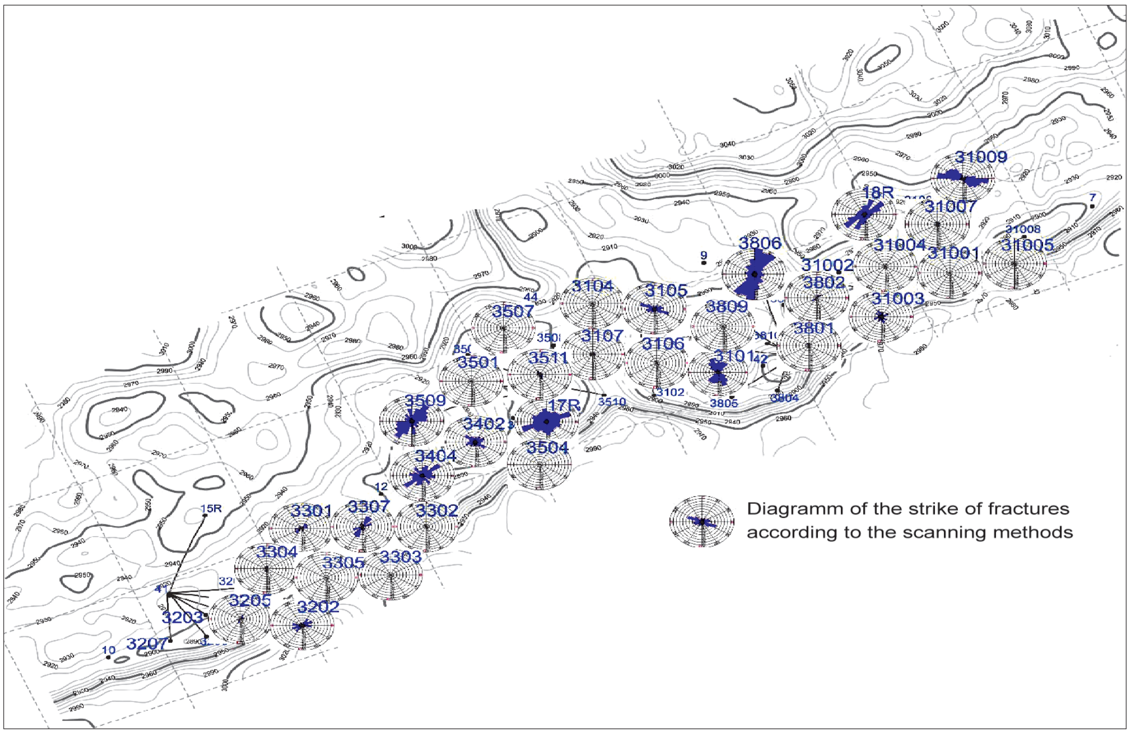

Fig. 9. Evaluation of the dominant direction of the strike of fractures in the studied reservoir along the horizontal

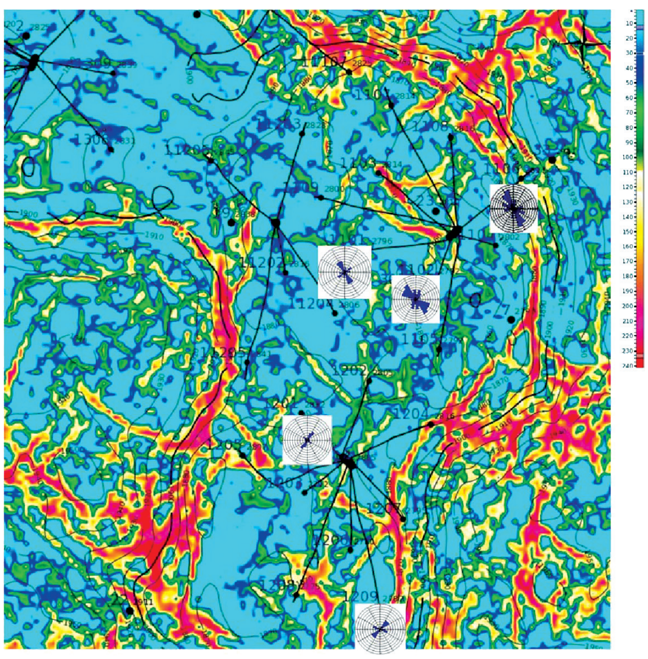

Fig. 10. Azimuths of the strike of fractures against the background of filtered coherence (PetroTrace Global LLC). Full-wave acoustic logging (capabilities)

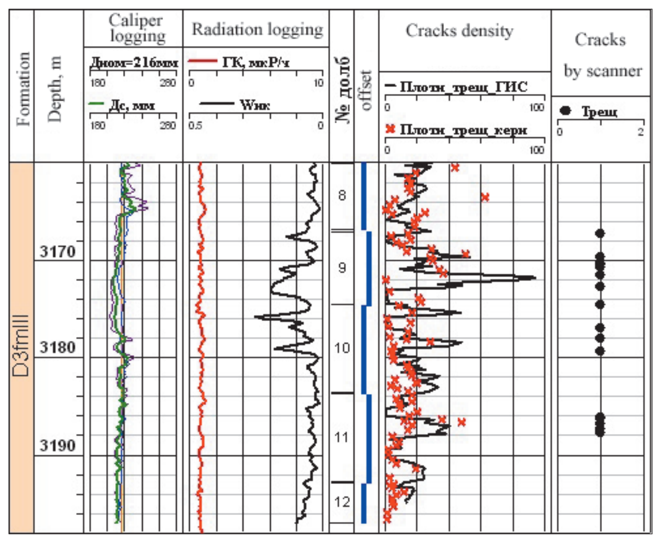

Fig. 11. Comparison of fracture density, defined according to the sonic log data and on a core column

the intervals where, according to the acoustics data, the cavern and fracture capacity was determined, and where an increase in permeability was noted above the boundary value for the Stoneley wave.

Figures 11, 12 show examples of calculation of fracture porosity (capacity). Given the many restrictions that all well logging methods have, the question arises about the reliability of the quantitative evaluation of this parameter, which is determined by hundredths of a percent. It is a complex issue, and it is difficult to find an effective response to it. Of course, it is an essential parameter, and quantitative estimate is important when calculating hydrocarbon reserves associated only with fractures. However, this option is extremely rare, and against the background of the granular and even cavernous capacity, the fracture capacity makes little difference. For the bulk of the studied fields, the very fact of the presence of such a capacity is important, since it is this capacity that will control filtration flows, and the possibility of differentiating this capacity at a quantitative level allows this parameter to be embedded in a hydrodynamic model.

Below are distribution maps of fracture capacity in two fields. On one of the maps, a detailed gradation

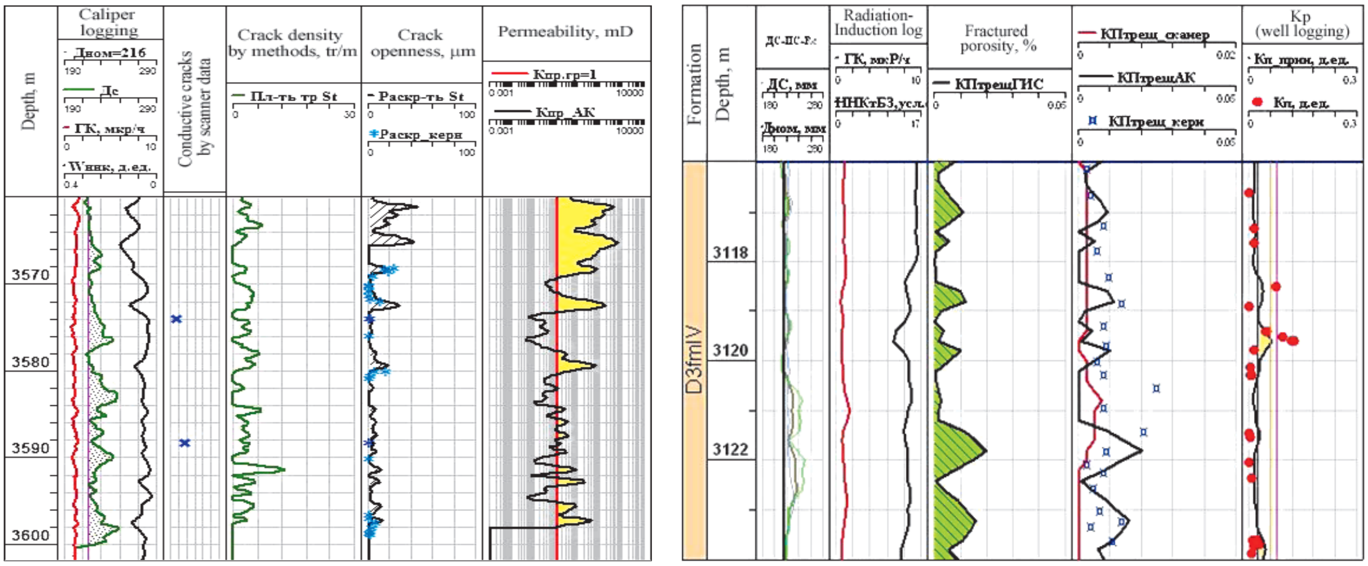

Fig. 12 Comparison of fracture opening and density, defined according to the sonic log data and on a core column

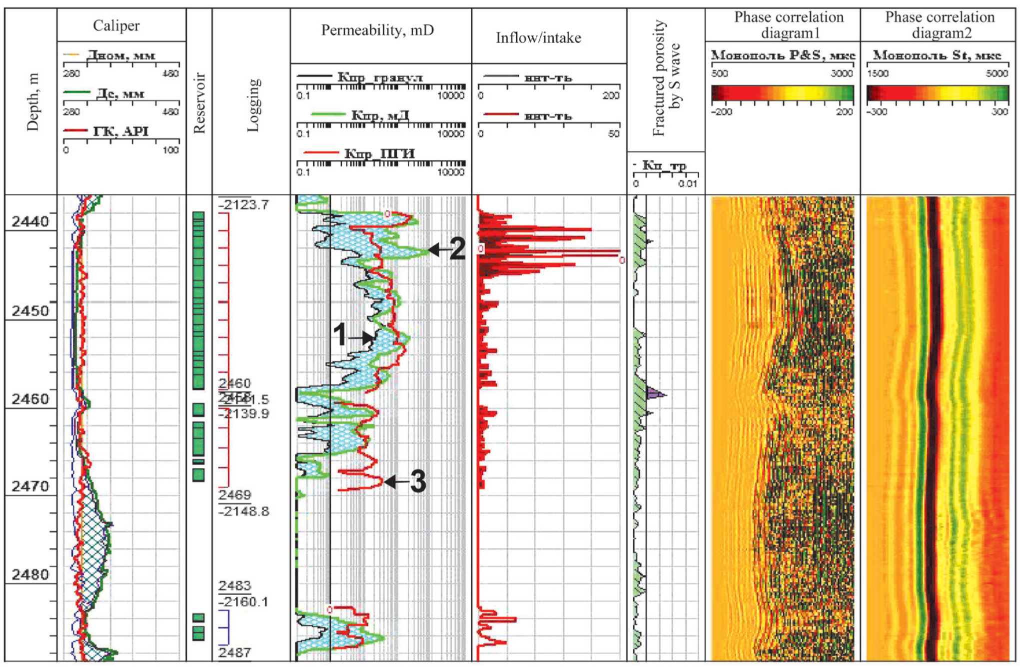

Fig. 13. Examples of determination of capacity and permeability associated with the fracture system, comparing different methods of porosity calculation

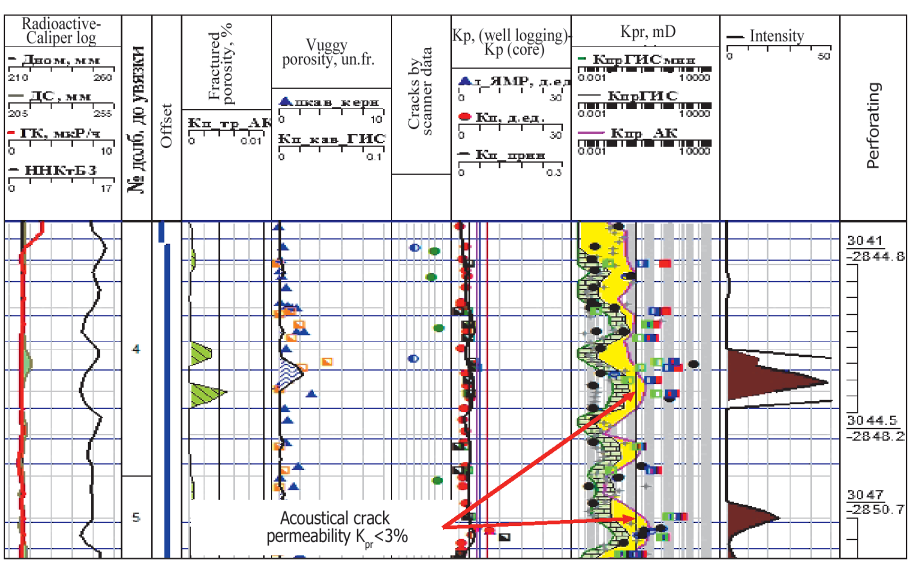

Fig. 14. Examples of determination of capacity and permeability associated with the vuggy-fractured system

of fracture porosity is given, on the other map, the separation is only according to three gradations: > 0.01%, 0.005-0.01%, <0.005. (Fig. 15)

Despite the fact that today it is preferable to use equipment such as AVAK11, KhMAK, etc., it is not necessary to abandon the more common devices of broadband acoustics such as SPAK-6 and information accumulated over previous years if the wavetrain is stored only on paper. Generally, mass studies provide more valuable information than a single high-level record. Good results could be obtained by combining the entire spectrum of information.

Experience has shown that acoustic logging is the most informative method to date, and we have yet to discover the full range of its capabilities.

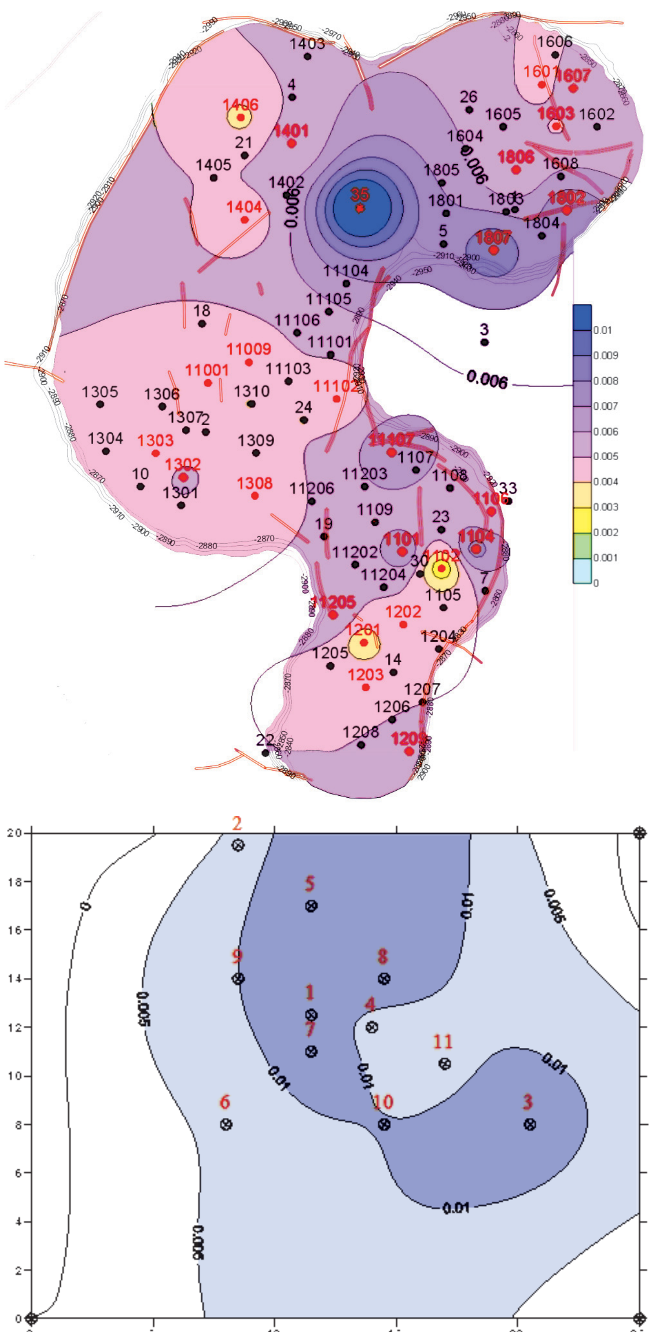

Fig. 15. Schematic maps of fracture capacity distribution

Verification: Theory and Practice

It is difficult to say where theory ends in our work and practice begins, which should test the theory. For geophysical exploration techniques recorded in an open hole, the practice is a well operation, which is controlled by another set of well logging techniques – a combination of field-geophysical and hydrodynamic research methods.

Figures 13, 14 give an example of calculating the inflow intensity and permeability using the field-geophysical and hydrodynamic research complex in comparison with open-hole well logging methods. The open-hole geophysical study complex does not always satisfy our expectations, as a rule, the wavetrain is absent, or it allows to single out fracture development zones only visually at the “many-few” level.

Figure 16 shows an example of such a well, where only fracture zones are indicated. Permeability is calculated from the results of core studies and standard well logging methods depending on porosity (average, minimum, maximum). The minimum permeability, as a rule, corresponds mainly to a granular reservoir, which we see from the results of field geophysical studies in the central part of the section in the area of the highest porosity (K_p = 25%). Despite the very high porosity, the main inflow of oil is observed in the top from intervals with signs of high fracturing in the acoustic logging, and specifically in this interval rapid flooding with a sharp oil production decline was obtained.

There are many such examples, and this is the main reason why regulations are needed to control the amount of research.

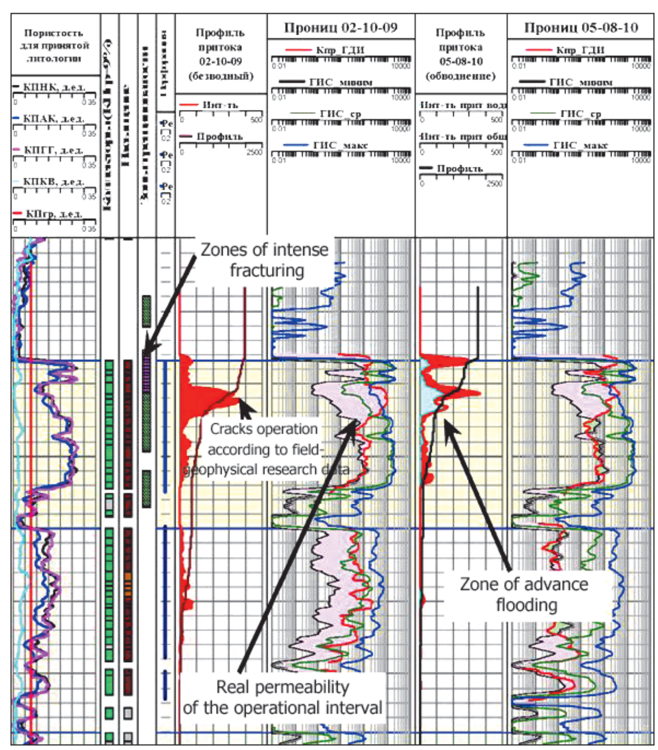

Fig. 16. An example of fractures

Conclusion

This article covers only a small range of possible studies. A cluster of studies, conducted during the formation drilling (geological and engineering surveys) hydrodynamic studies, tracing issues still have to be reviewed. Joint work with seismic specialists to study stress and shear zones can therefore constitute a major stage. And, in our considerations, we should be mindful of the proven methods of fracture zones allocation on such widespread complexes as radioactive logging, lateral log, and micro-laterolog.

There are many examples of rapid flooding, examples of financial losses due to lack of knowledge of the type of pore space. As a rule, the study of the impact of fractures at the field begins after receiving extremely negative consequences (Ostrich policy) and this is the main reason why the regulations controlling the amount of research are necessary.

There should be a report on research and findings, which is passed to the state structures controlling the subsoil study and, most importantly, which will be sent to a new subsoil user in case of a change. Perhaps it is necessary to create polygons, where methods of working with such rocks will be practiced, including geophysical well survey techniques. At a minimum, it is useful to have three polygons with the presence of fractures, conditionally divided into types: 1 – low porosity; 2 – variable porosity; 3 – bitumenosity, organic.

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