THE APPLICATION OF BIOGEOPHYSICAL STUDIES IN THE SEARCH FOR OIL FIELDS

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Abstract. The article gives an analysis of qualitative and quantitative indices of biogeophysical anomalies (BGPh-anomalies) recorded over oil deposits, obtained as a result of experimental and methodological work on the oil fields studied in detail. By the degree of intensity and complexity of the BGPh-anomalies registered in digital form with special equipment developed by the authors, a set of qualitative and quantitative features has been developed that make it possible to determine the genetic type of the structural trap of the identified oil deposit, and, under favorable conditions, the depth of its occurrence.

BGPh-anomalies of the “tectonic fault” type, their influence on the “oil deposit” type of BGPh-anomalies have been studied. The limiting values of the watercut in the exploited oil reservoir are determined, when exceeding, the oil reservoir ceases to create a BGPh-anomaly such as “oil deposit”, which can be used for the areal monitoring of oil fields. The minimum thickness of the oil-saturated reservoir is determined, which creates an anomaly of the “oil deposit” type. Based on this analysis, it is assumed that the BGPh-anomalies arise only over oil deposits, potential for industrial development.

Keywords: biogeophysical method, oil deposit, tectonic fault, seismuc structure
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Academic Note

In the academic journal, the millennium was marked by the discovery of a large silver field in Germany by dowsers, after which a thaler with a frame was released (Maksimov, 1970). Acknowledgment of dowsing merits in the XVIII century was the decree of Catherine II to include divining rod in the Petrozavodsk’s coat of arms (Frantov, Glebovsky, 1987).

The beginning of publications about the possibility of using the divining rod method for the water search in the USSR refers to the beginning of the twentieth century. Here the work of Professor I.A. Kashkarov of the Tomsk Polytechnic Institute should be noted, as well as the works of V.A. Guskov, I.I. Ginzburg.

In 1973 the International Society for the Study of Instrumental Research of Biofields was organized, where the questions of dowsing were also considered.

The Ministry of Geology of the USSR organized in 1967 a meeting at the All-Union Institute of Mineral Raw Materials on dowsing with the participation of eight institutes, where the terms BPhE(biophysical effect) and BPhM (biophysical method) were approved.

The first All-Union seminar on BPhE was held in 1968, the second – in 1971, in Moscow, the third – in 1976 in Tomsk, the fourth – in 1979 in Riga, the fifth – in 1981 in VSEGINGEO. The results were 445 publications in the collections of the library of the Academy of Sciences of the USSR; a bibliography on BPhE was compiled. In the 1980s, the effect of the biolocation method was fully recognized by the USSR Academy of Sciences.

A letter from Academician O.A. Ovchinnikov, vice-president of the Academy of Sciences of the USSR, notes: “The Academy of Sciences of the USSR have considered issues related to the dowsing method and finds that the application of this method will yield appreciable savings in the national economy, and the need for its further study does not cause doubts” (Sochevanov, 1984).

In the work “Biogeophysical method of prospecting and exploration of oil fields”, a working hypothesis of the origin of Biogeophysical (BGPh) anomalies over oil deposits is given, based on the electromagnetic nature of this phenomenon (Mardanov et al., 2015).

In the work “Electromagnetic field as a cause of the emergence of the biophysical effect”, references are given to the connection of BPhE with electromagnetic fields and ionization of air (Sochevanov et al., 1975).

Introduction

At present, the seismic survey method, aimed at finding positive structures, is the most generally recognized and reliable method for searching for oil

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fields. However, seismic exploration has one significant drawback: in identified seismic structures, oil may not exist, and the seismic structures themselves may be false, caused by velocity anomalies in the overlying sediments. Therefore, recently there has been an increased interest in methods aimed at direct search for oil deposits. Such methods include the biogeophysical method.

Biogeophysical method, which in previous centuries was called "Divining rod method" was widely used in the Middle Ages, in particular, most of the ore deposits of gold, silver, copper, lead, antimony, iron, coal in Western Europe were discovered thanks to the application of this method (Maksimov, 1970, Sochevanov et al., 1987). In ancient times the BGPh method was called dowsing, this phenomenon was known more than 4000 years ago. It boils down to the fact that some people, when passing over aquiferous or ore zones, observe a deviation or rotation of a clamped woody branch in the hand.

Recent studies show that biogeophysical anomalies can be detected not only over ore deposits, but also over oil fields (Mardanov et al., 2015).

For direct searches for heavy oil fields, JSC "Tatneft" in May 28, 2014 received patent No. 2551261 "Method for mapping structural uplifts in the upper part of the sedimentary cover and predicting heavy oil deposits". Summary of the invention: Electromagnetic waves emit and receive signals reflected from the interfaces of the sounded medium. Herewith structural maps of the uplift, as well as temporary seismic sections of the reflected boundaries of the upper part of the sedimentary cover are preliminarily constructed; geophysical studies of the wells, core materials are studied.

Another method of direct searches for hydrocarbon deposits is the overvoltage prospecting method, patent No. 2391684 dated April 22, 2008. "Method of geoelectric exploration of oil and gas fields with the forecast of hydrocarbon saturation".

In contrast to the biogeophysical method, the radar method of patent No. 2551261 has a significant drawback – a narrow field of application, requiring detailed study of the field by drilling, seismic survey, and the patent No. 2391684 drawback is a low resolution for all electrical survey methods, low reliability.

1. Methods and technology of the BGPh method

At present, the authors have developed and applied the original technique and technology for the production of BGPh-studies of oil, which allows recording anomalies using a semi-automatic digital recorder combined with a GPS sensor. Depending on the intensity of the biophysical field, the frame in the hands of the operator performs a rotational motion with a certain force. The recorder converts this rotational force into millivolts, which allows the resulting material to be digitized and processed promptly using a specially designed computer program. With the use of the developed technology, it became possible to digitally quantify the level of intensity of BGPh-anomalies. Since the intensity of the BGPh-field is not obtained directly by measuring electromagnetic or other geophysical parameters, but indirectly, on the resultant maps, the intensity is denoted in conventional units (cu). This allows not only to identify and delineate oil deposits, but also to distribute the studied area according to the degree of prospects into several categories. The most promising can be considered those areas where the identified intense GGPh-anomalies such as "oil deposit" coincide with the positive seismic structures of the target oil-bearing horizons.

2. Interpretation of the results of BGPh-studies

With the increase in the number of areas studied by the BGPh-method in the search for oil deposits, the authors made significant progress in interpreting the results of the field survey. During the last six years, experimental, methodical and production work was carried out at 57 facilities located mainly in the Volga-Ural oil and gas province.

In order to resolve the interpretation issues in 2014-2015, the BGPh-method was carried out in two detailed areas of the Alekseevsky and Bavlinsky oilfields located on the south-eastern slope of the South-Tatar Arch.

2.1. The first polygon for solving the problems of interpretation of the BGPh-anomalies was the experimental and methodological work on the central part of the Alekseevsky oil field, which is being developed for more than twenty years (Fig. 1).

The unified oil deposit, which is in operation for more than 20 years, according to the data of the BGPh-study is divided into two parts; the division occurs along a tectonic fault line 150-250 meters wide, coinciding with the riverbed of the Kuehlga River, with a steep northern side.

All wells, of which industrial oil is currently produced, are in the outline of the BGPh-anomaly such as "oil deposit". Wells that, because of the water cut in the reservoir, have been transferred to the reservoir pressure maintenance regime, are located behind the outlines of the BGPh-anomalies.

In the central part of the BGPh-anomaly such as "oil deposit", a zone with an intensity of 60-80 cu is allocated; this zone corresponds to the contour of oil deposits in the carbonate Devonian sediments D3*fm*, which are located under the reservoir in the Tournaisian sediments C1*t*.

Only in one well No. 6440, which is located outside the BGPh-anomaly such as "oil deposit", oil is produced with a flow rate of 4m^3/day and it is located near the tectonic fault. This corresponds to the hypothesis of the

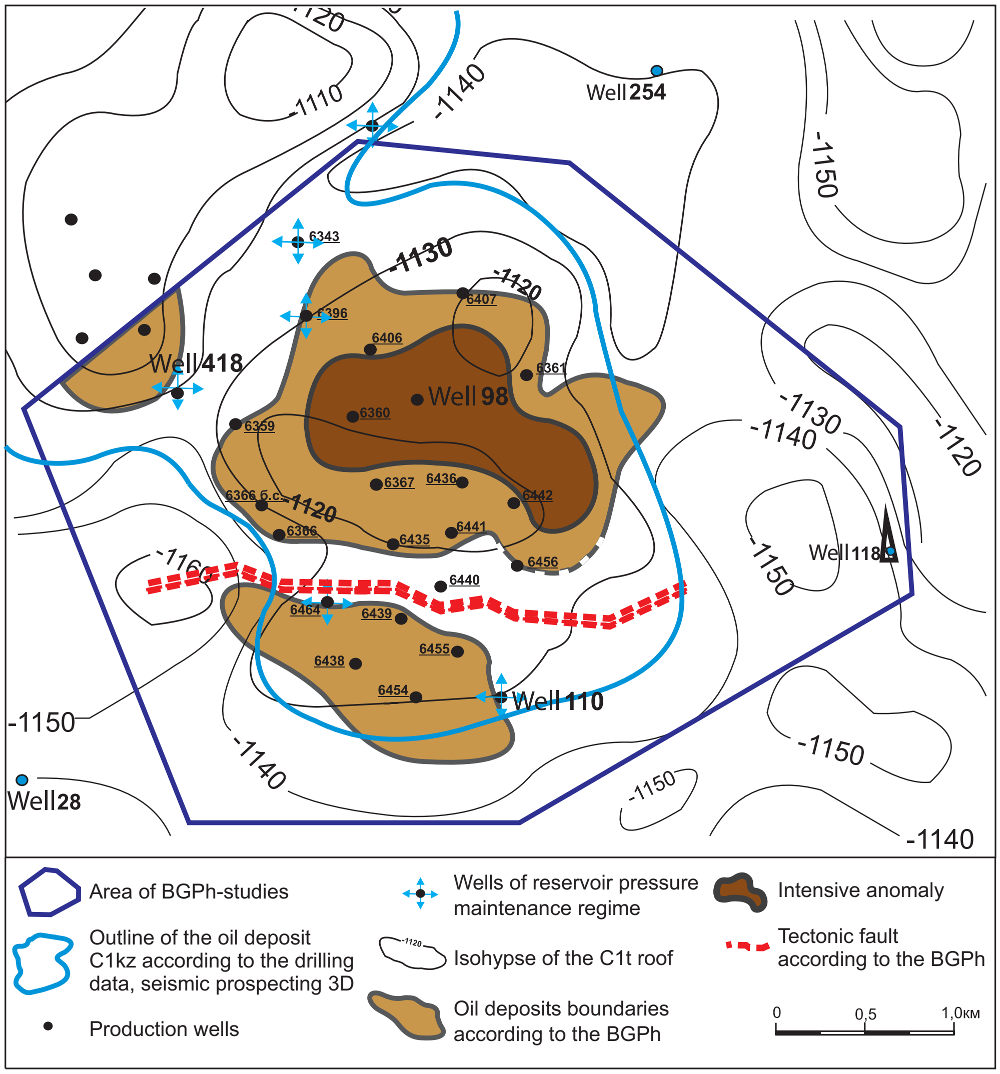

Fig. 1. Results of BGPh-studies at the Alekseevsky oil field.

origin of BGPh-anomalies over oil deposits, according to which the BGPh-anomaly from the tectonic fault breaks the BGPh-anomaly over the oil deposit (Mardanov et al., 2015).

2.2. The second polygon for solving the problems of interpreting the BGPh-anomalies was pilot works at the Sabanchinsky oil field developed since 1974. The map compiled on the basis of the results of the BGPh-studies is shown in Fig.2.

On the area of BGPh-studies, according to the available geological information, it was assumed initially that there is one vast oil deposit with a complex configuration. As a result of the work, six BGPh-anomalies of the "oil deposit" type of various sizes were identified.

In the central part, an extensive BGPh-anomaly with an intensity of 30-50 cu was found, within which one zone with an increased intensity of values and two zones of absence of the BGPh-anomaly of the "oil deposit" type was identified. After applying the revealed contours of anomalies to the development map of the field, it was found out that zones of anomaly absence within the deposit can be caused either by the absence of industrial oil (insignificant thickness of oil-saturated reservoir, with low reservoir properties – as in wells 2196, 1749, 2159, 2158) or the presence of "washed" productive zone in the area of wells 2163, 2165. 20 years ago, at the beginning of operation they produced oil up to 5t/day, but then, due to watering, they were transferred to the reservoir pressure maintenance regime. In the center of "oil-free zone" there are wells 2163, 2165. In the well 2161 the water-cut is 83%; in the well 2172 the water-cut is 92.4%.

A zone with an increased intensity of 50 to 70 cu was found in the area of well 2168, and in the very center of this zone the intensity of the BGPh-anomaly reaches a maximum value of 90 cu. After the conducted pilot works, the following features were emerged:

- zone with an intensity of 50-70 cu is caused by an oil deposit of increased thickness in the Tulskian-Bobrikovian deposits C1;

- zone with an intensity of 90 cu refers to a deeper, terrigenous Devonian D_3. Its dimensions are small – 200x200 meters. At the same time, it is known that several producing wells from the terrigenous Devonian deposits are exploited in this region, and the

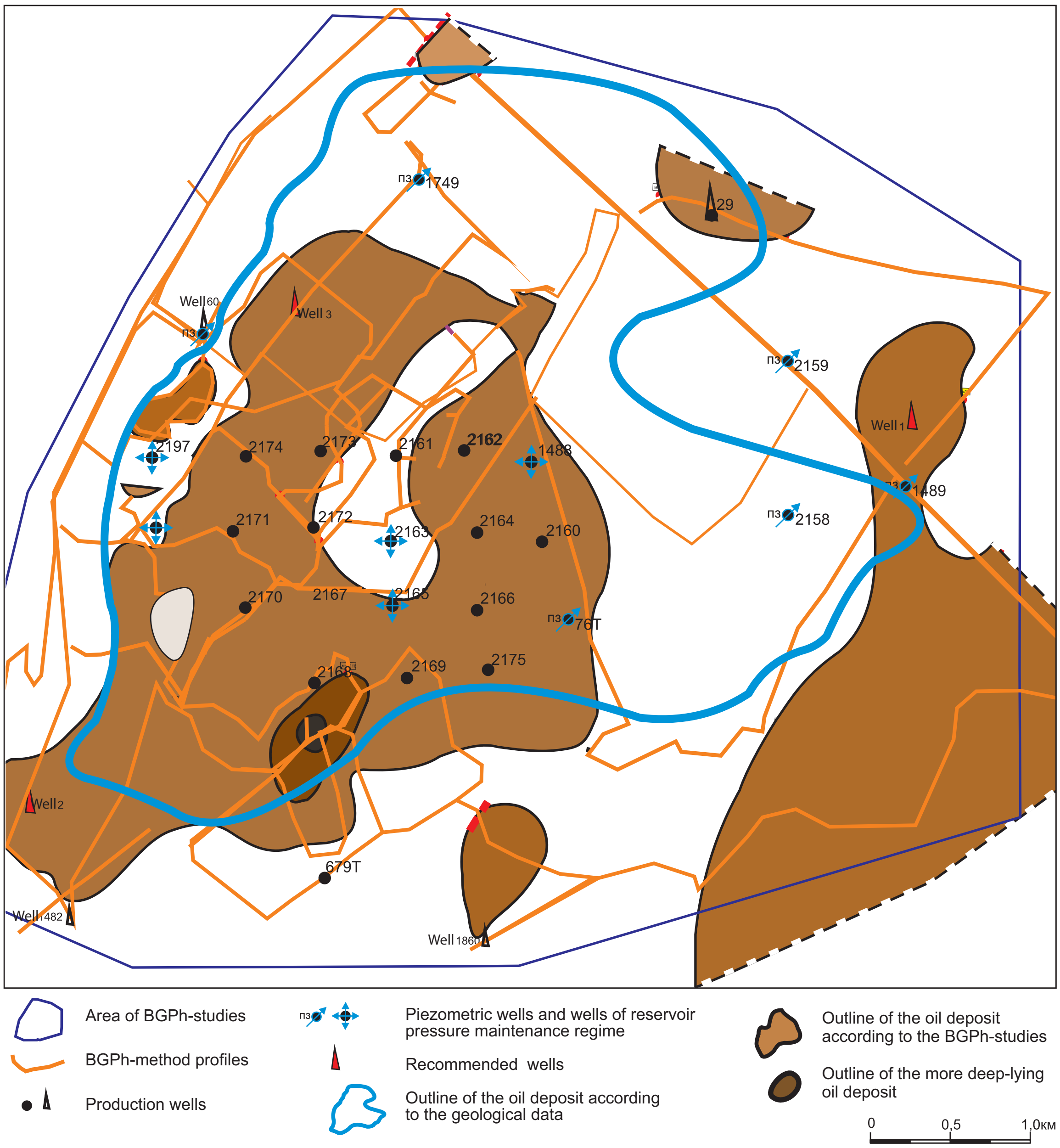

Fig. 2. Results of the BGPh-studies at the Sabanchinsky field

BGPh-studies, however, only note medium-intensity anomalies related to the lower Carboniferous. The explanation of this phenomenon is that these wells have been producing oil for many decades, and the water cut of the production reaches 98-99%. With such a water-oil ratio, the operator of BGPh-studies does not reveal the oil deposit.

As a result of the pilot production works conducted at the Sabanchinsky field, the following was revealed:

- BGPh-studies conducted on the area of old deposits, identify areas with industrial oil, where the water cut of the products does not exceed 75-80%;

- The BGPh-method under favorable conditions makes it possible to determine the presence of a second, more deep-lying oil deposit under the upper deposit and to contour it;

- The presence in the geological section of several oil-saturated reservoirs with an interval of several hundred meters leads to the formation of a high-intensity BGPh-anomaly.

3. Determination of the quality of oil reservoirs

In 2015, BGPh-studies were carried out at Shuganskoy, Komuninsky, and Pokrovsky uplifts of the Muslyumovsky section of OJSC Mellyaneft to clarify the contours of the developed deposits and identify new oil deposits. All the tasks were successfully solved. It is interesting to consider the results of drilling a horizontal well 186g, the horizontal part of the trunk of which is beyond the boundary of the BGPh-anomaly of "oil deposit" type (Fig. 3). According to the logging conclusion, the oil saturation of the C1*tl* reservoir in the horizontal part of the trunk with length of 130 meters is in the range of 55-60%, clay content – from 4.5 to 7.5%. As a result of the well tests, it was possible to obtain only a small amount of technical water, there is

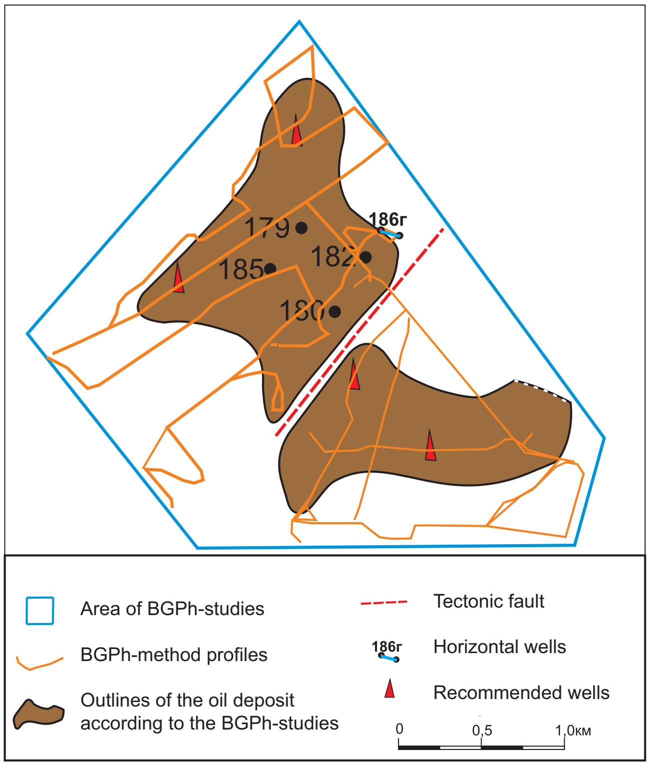

Fig. 3. Results of the BGPh-studies on the Pokrovsky uplift

no inflow of reservoir fluid. At the same time, it is known that production wells No. 179, 180, 182 and 185, located in the central part of the oil deposit, have penetrated the oil-rich reservoir C_1tl with clay content not exceeding 3.5%, and oil has been successfully produced for a long time. Thus, we can assume that the BGPh-method allows to indirectly determine reservoir properties of the formation.

The fact that within the oil reservoir of the structural type, identified by seismic prospecting and drilling, the BGPh-method identifies zones of BGPh-anomaly absence, can be explained by a change in reservoir properties – in terrigenous rocks by increased clayiness, in carbonate reservoirs – by dense areas.

After analyzing the results obtained and comparing them with the geological structure and hydrodynamic parameters of the studied sections of the fields, the following conclusions can be drawn.

1. At present, the technical level achieved at LLC NPF LOZA allows to register the BGPh- anomalies in digital form, continuously along the working profile. The intensity of the BGPh-anomaly is measured in conventional units (cu), in the range from 0 to 100 cu. As experience shows, gradation is enough in five intervals with values: 0-20; 20-40; 40-70; 70-90 and above 90 cu.

2. BGPh-anomaly such as "oil deposit" appears almost vertically over the outer contour of the oil deposit, with an accuracy of 50-100 meters.

3. In a detailed study of an oil field in long-term operation, local zones with high water cut (over 80%) are allocated as zones of absence of an "oil deposit" anomaly.

4. If the injection well is located inside the oil reservoir contour, the area that is "washed" by injected water is allocated as a zone of absence of an "oil deposit" anomaly.

5. The fact that within the oil reservoir of the structural type, identified by seismic prospecting and drilling, the BGPh-method identifies zones of absence of the BGPh-anomaly, can be explained by a change in reservoir properties – in terrigenous rocks by increased clayiness, in carbonate reservoirs – by dense areas.

6. If the thickness of the oil-saturated reservoir is less than 1.5-2 meters, it is not allocated as an "oil anomaly".

7. In some cases, inside the BGPh-anomaly such as "oil deposit" with an average intensity of 30-40 cu, zones are allocated with an intensity of 60 cu, and sometimes up to 90 cu. This happens in those cases when one or several oil deposits are located under one deposit, several hundred meters deeper. For example, in the case of a fragment of the Alekseevsky field (Fig. 1), discussed above, a zone with an intensity of 30-50 cu refers to the contour of the oil deposit in the sediments C1*kz*, and the anomaly with an intensity of 60-80 cu along the contour coincides with the contour of oil deposits in the carbonate sediments of the Upper Devonian (D_3fm).

4. Identification of tectonic faults

When searching for oil deposits by BGPh-studies, anomalies such as "tectonic fault" are often detected. This occurs as follows: an anomaly of the "oil reservoir" type disappears, after some distance an anomaly of the "tectonic fault" type appears. The width of the zone of the tectonic fault is from several meters to hundreds of meters. Quite often the anomaly "oil deposit" ends on a tectonic fault. If the oil anomaly is extensive, an anomaly of the "oil deposit" type appears again after the "tectonic fault" anomaly. The width of the absence zone of "oil deposit" anomaly along the tectonic fault in most cases coincides with the steep slopes of ravines.

The explanation of this phenomenon is possible: it is well known that ravines and rivers occur in places of tectonic faults. Anomalies of the "tectonic fault" type are mainly confined to ravines and river valleys. It is generally believed that a zone of destruction is formed along the inclined (subvertical) plane of the tectonic fault, where, due to the displacement of the rock layers, fragmentation occurs, and the rock cracks become more fractured. Hydrothermal streams circulate for a long time along this subvertical zone of destruction, which cause secondary mineralization in the near-fault zone. Ultimately, this leads to the formation of an inhomogeneously densified subvertical plane. The presence of such an anomalous object screens the anomaly emerging above the oil deposit (Fig. 1, 3). Since destruction and secondary mineralization in the tectonic fault zone does not occur in the same way everywhere, a

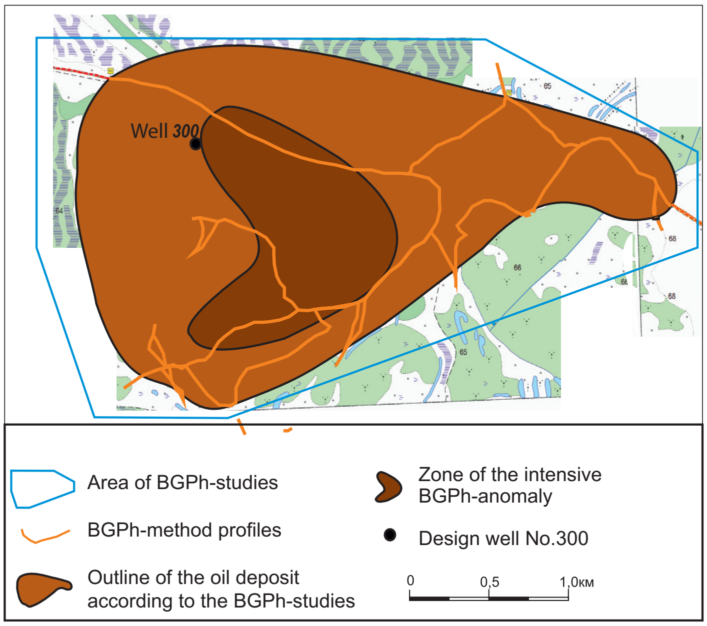

Fig. 4. Results of the BGPh-studies at the Tlanchi-Tamaksky section. Note: Well No. 300 was drilled in the spring of 2014, the oil deposit in C1bb was penetrated. The total capacity of oil-saturated reservoirs is 10 m

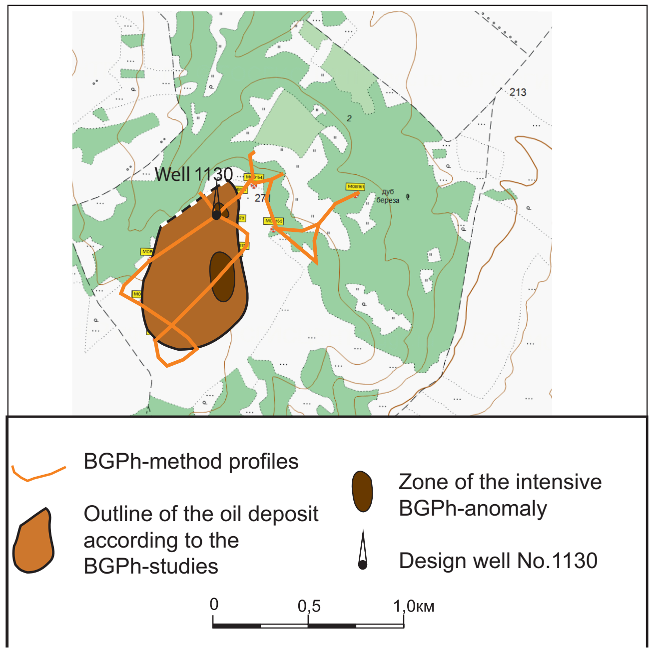

Fig. 5. Results of the BGPh-studies at the Petrovsky section. Note: Oil-saturated reservoirs in C_{1kz} *and in carbonate Devonian sediments were identified in 2015 as a result of drilling*

screen that prevents the formation of a BGPh-anomaly also arises of different qualities. Therefore, the zone of absence (screening) of the oil anomaly along the tectonic fault varies in width.

In the scientific literature devoted to the study of tectonics in the Volga-Ural oil province, the identification and tracing of tectonic faults within oil deposits has not yet been systematized and described. Modern seismic exploration does not notice small faults as a result of multiple summation of traces. This can be clearly seen from the time cuts applied to seismic records, where tectonic faults from seismic exploration, above the terrigenous Middle Devonian, are practically not distinguished. Geochemistry gives some scatter of data that is "spread out" over the area. It is known that discrete methods of fixation cannot uniquely identify small faults, especially when there is no vertical displacement of the seams. The BGPh-method allows to continuously trace the nature of the change in the anomalies of the "tectonic fault" type and as a result, it makes it possible to isolate both large tectonic faults having a deep origin, and neotectonic ones having a local character.

5. Effectiveness of the use of BGPh-studies

To illustrate the effectiveness of the use of BGPh-studies in forecasting the prospects of seismic structures, a few more examples are given below.

Tlanchi-Tamaksky section is located to the west of the village of Tat.Suksi in the Aktanyshsky district. In 2013, as a result of the studies carried out by the BGPh-method, one large anomaly of the oil deposit type was singled out with the aim of predicting the oil prospect of the Tlanchi-Tamaksky section. The size of the detected anomaly is 4x2 km, in the central part of the anomaly there is a section of increased intensity, with a high degree of prospects, with dimensions of 1x1.5km. The design well No.300 is located within the anomaly (Fig. 4).

Petrovsky section of the Bavlinsky field is located to the south-west from the village of Petrovka in the Bavlinsky district. In 2014, as a result of the research carried out by the BGPh-method, an anomaly of the "oil deposit" type with two intensive areas and a size of 0.6x1.0 km was singled out for the prospective evaluation of oil prospectivity by the design point for well No.1130. The design drilling point is located within the intensive zone of the oil anomaly (Fig. 5). A forecast was made about the prospects for identifying oil-saturated reservoirs in the Lower Carboniferous and Devonian sediments.

In addition to the above examples, there are still a significant number of studies that confirm the high efficiency of the BGPh-method in the search for oil deposits, these works are included in Table 1.

Table 1 includes 97 investigated structures at 37 sites. Based on the results of wells testing, including previously drilled wells, the success rate of 141 wells is 94%. In addition, on the territory of the Samara, Orenburg, Ulyanovsk, Perm, Chelyabinsk and Kurgan Regions and in the Republics of Tatarstan, Bashkortostan, an additional study was conducted on 14 licensed sites, the results of which, for reasons of confidentiality of information, are not included in Table 1.

	Field, area, objective	Results of the BGPh-study	Drilling results	Efficiency(%)
1	2	3	4	5
1	Bavly Oil and Gas Production Department, forecast for the well No. 1130	Oil anomaly was identified in the area of design well No. 1130	In 2015 exploration well No.1130 has penetrated the oil reservoirs C1 and D3	100
2	Andreevsky section, forecast for the well No. 2263	Oil anomaly was identified at 150 m away from designed bottomhole well No. 2263	In 2015 exploration well No.2263 was drilled at 150 m away from BGPh-anomaly, there were no oil-saturated reservoirs	100
3	Korobkovsky section, outlining of the identified oil deposit	Deposits were outlined around well No. 2248 and 2258, three more oil anomalies were identified	All 10 production wells are located in the area of oil anomalies	100
4	Sabanchinsky field, clarifying the contours of the fields	Outlines of the oil anomalies correspond to the current deposit outlines in C1bb with water-cut 80%	There are 26 wells on the studied area. Almost all wells with water-cut not exceeded 80% are located in the outline of oil anomalies	90
5	Yuzhno-Ashalchinsky field, searching for bitumen	3 oil anomalies of the "oil deposit" type were identified in the area of bitumen field	Anomalies correspond to the most perspective field zones	80
6	Tlanchi-Tamaksky section, predicting the oil prospect	Oil anomaly was identified with a size of 4x2km in the area of design well No. 300	In 2014 exploration well No. 300 has penetrated the oil reservoir with thickness Δh=10 m in $C_{1бб}$	100
7	Aznakaevsk Oil and Gas Production Department, Vostochno-Iryasovsky uplift	2 oil anomaly were identified with a size of 0,25x1,0 km and 0,4x0,6 km, well No. 292 is located in the zone a oil anomaly	In 2017 drilling of exploration well No. 292 is planned	
8	Tumutsky field, forecast for the 3 areas for the wells No.40216, 40217, 40218, 20152, 20154	Oil anomalies were identified on the dome areas of seismic structures	In 2017 well No. 20152 was drilled on the BGPh-anomaly boundary, in Terrigenous Devonian oil was produced - $3m^3$/day	100
9	Muslyumovsky section, forecasting the seismic structures on the 8 areas	19 seismic structures were analysed on the total area of 50 sq.km. Among them 18 anomalies were identified on the 12 structures and 7 structures were without anomallies	In 2016 well No. 40099 was drilled with industrial oil. Well No. 186g was drilled beyond the BGPh-anomaly, no fluid. 21 oil-produced wells are located within the oil anomalies	100
10	Domoseevsky section, forecasting the seismic structures on the 8 areas	16 seismic structures were analysed on the total area of 28 sq.km. Among them 12 oil anomalies were identified on the 11 structures and 5 structures were without anomallies	5 exploration wells are located on the studied area. All wells correspond to the results of BGPh-anomalies. Drilling of new wells is at the design stage.	100
11	Arovsky section, Repusblic of Bashkortostan, outlining of the Petryaevsky oil deposit	1 oil anomaly was identified and outlined, transfering the design well No.10 to the center of anomaly was recommended	In 2016 in the well No. 10 oil-saturated interval was identified with Δh=22 m in Domanic horizon. Two hours of testing gave film of oil	80
12	Alekseevsky field, forecasting the seismic structures	12 seismic structures were analysed on the total area of 40 sq.km. Among them 10 oil anomalies were identified on the 8 structures and 4 structures were without anomallies	64 wells are located on the studied area. 62 wells correspond to the results of BGPh-studies. 2 wells with oil production are located beyond the anomalies	97
13	Orekhovsky license section, forecasting the seismic structures	28 seismic structures were analysed on the total area of 120 sq.km. Among them 21 oil anomalies were identified on the 20 structures and 8 structures were without anomallies	35 wells drilled after the BGPh-studies are located on the studied area. Among them 27 wells correspond to the BGph-studies results, 8 wells with oil production were drilled beyond the anomalies	77

Table 1. Results of the BGPh-studies on identification of objects that are promising for oil reserves

Conclusions

The scope of the research allows us to substantiate that the biogeophysical method makes it possible to identify and outline oil deposits with high reliability.

1. The application of the BGPh-method at the reconnaissance stage allows choosing perspective areas for setting up seismic operations, thereby reducing the financial costs and terms of work.

2. The use of the BGPh-method in the area where seismic operations have already been conducted, seismic structures for prospecting and evaluation drilling have been identified and recommended; it is possible to classify these structures as promising (where there are anomalies such as "oil deposit") or in the category of unpromising, where such anomalies are absent.

3. BGPh-studies conducted on the area of old deposits, identify zones with industrial oil, where the water cut of the products does not exceed 75-80%. Therefore, the areal monitoring of the developed field can be conducted in order to identify "washed" zones, as well as isolated areas ("bypassed oil"), which are not affected by operation.

4. The BGPh-method, under favorable conditions, makes it possible to determine the presence of a second, more deep-lying oil deposit under the upper deposit and to delineate it.

5. If the thickness of the oil-saturated reservoir is less than 1.5 meters, it is not detected by the BGPh-method.

6. The BGPh-method allows to determine the quality of the reservoir within the oil deposit.

In conclusion, the BGPh-method can be also used as an express analysis of the prospects of licensed areas for hydrocarbon raw materials put up for auction by the Ministry of Natural Resources of the Russian Federation.

The BGPh-method can be stated as one of the most promising methods of prospecting oil fields, which includes the ability to carry out works at any time of the year, the absence of costs for farmland waste, the speed of work, and the high accuracy of reservoir boundaries allocation.

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