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RESEARCH ARTICLE

Results of the Application of Direct-search Mobile Technology in the Exploration Blocks of Shakal and Halabja (Kurdistan)

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ABSTRACT

Using experimental studies of mobile exploration technology, which includes modified methods of frequency-resonance processing, decoding of satellite and photographic images, vertical electron resonant scanning of the geological section, and the method of integral assessment of oil and gas content, the authors identified the potential of large prospecting blocks and licensed areas within the Shakal and Halabja blocks in Kurdistan. In the Shakal exploration area, the authors received oil responses from 3 intervals: 1) 2771–2794 m, 2) 2795.3–2815.45 m, and 3) 2834.40–2854 m in limestone sections. In Halabja exploration area, oil responses were obtained from 12 intervals: 1) 297–311.5 m, 2) 328–330 m, 3) 1190–1260 m, 4) 2018–2020 m, 5) 2059–2061 m, 6) 2132–2133 m, 7) 2192–2201 m, 8) 2249–2276 m, 9) 2307–2310 m, 10) 2317–2321 m, 11) 2326–2329 m and 12) 3310–3340 m. These results suggest that the proposed alternative exploration model can provide a more direct means of assessing the hydrocarbon potential of large exploratory areas, even before other geophysical investigations provide detailed information on possible targets.

1. Introduction

The Kurdistan Region of Iraq opened to foreign investors through licence awards in 2002 and 2004. However, the main influx started in 2006 with the award of the first Production Sharing Contract (PSC) in the region [1]. The approval of the Kurdistan Oil and Gas Law in 2007 coincided with a further fifteen licence awards. A larger number and more diverse range of companies operate in Kurdistan than in federal Iraq. Initial entrants consisted mainly of European and North American small caps along with private investment firms. Significant discoveries by these companies including DNO (Bastora & Tawke), Gulf Keystone (Shaikan), Heritage Oil (Miran West), HKN Energy (Swara Tika) and Western-Zagros (Kurdamir) have proven Kurdistan to be a prolific exploration region. In

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October 2011, ExxonMobil became the first major IOC to be awarded contracts in Kurdistan. It signed six PSCs to become the largest acreage holder in the region. Chevron and Total have since also entered the region with two/three M & A deals and one licence award each. Significant new oil and gas discoveries have recently been made in Kurdistan in northern Iraq, which has emerged as one of the Middle East's most active exploration provinces (Figure 1). Continued activity in these areas is expected to lead to reserves growth, even as oil production increases. Kurdistan continues to be an active exploration play involving the largest independent oil companies in the region, including Hess, Hunt, Marathon, Murphy, Oil Search, Repsol, Talisman, OMV and MOL (through its subsidiary Kalegran). There are also two Asian NOCs, Sinopec (through Addax) and KNOC operating in Kurdistan, while Dana Gas and Crescent Petroleum operate the two gas fields, Kormor & Chemchemal.

The Shakal exploration block area is 632 km^2 with target study horizons of Paleocene and Miocene carbonate deposits. Shakal-2 (ST-1) was spudded on 23 June 2014 and reached the total depth (TD) of 2950 mMD on 31 December 2014. Shakal-3 well was spudded on 6 August 2014 and reached TD 3355 mMD on 23 December 2014.

The Halabja exploration block area is 1519 km^2 with target study horizons of Cretaceous and Paleocene carbonate and terrigenous deposits. It is believed that Kurdistan has significant yet-to-find reserves, but these two exploration block areas' geologies are more complex than they seem. After the geological and geophysical survey and drilling in the Shakal exploration block area, it needs to understand facies variation and structural evolution. Regardless of complex geology, both areas are located in a proven oil and gas zone.

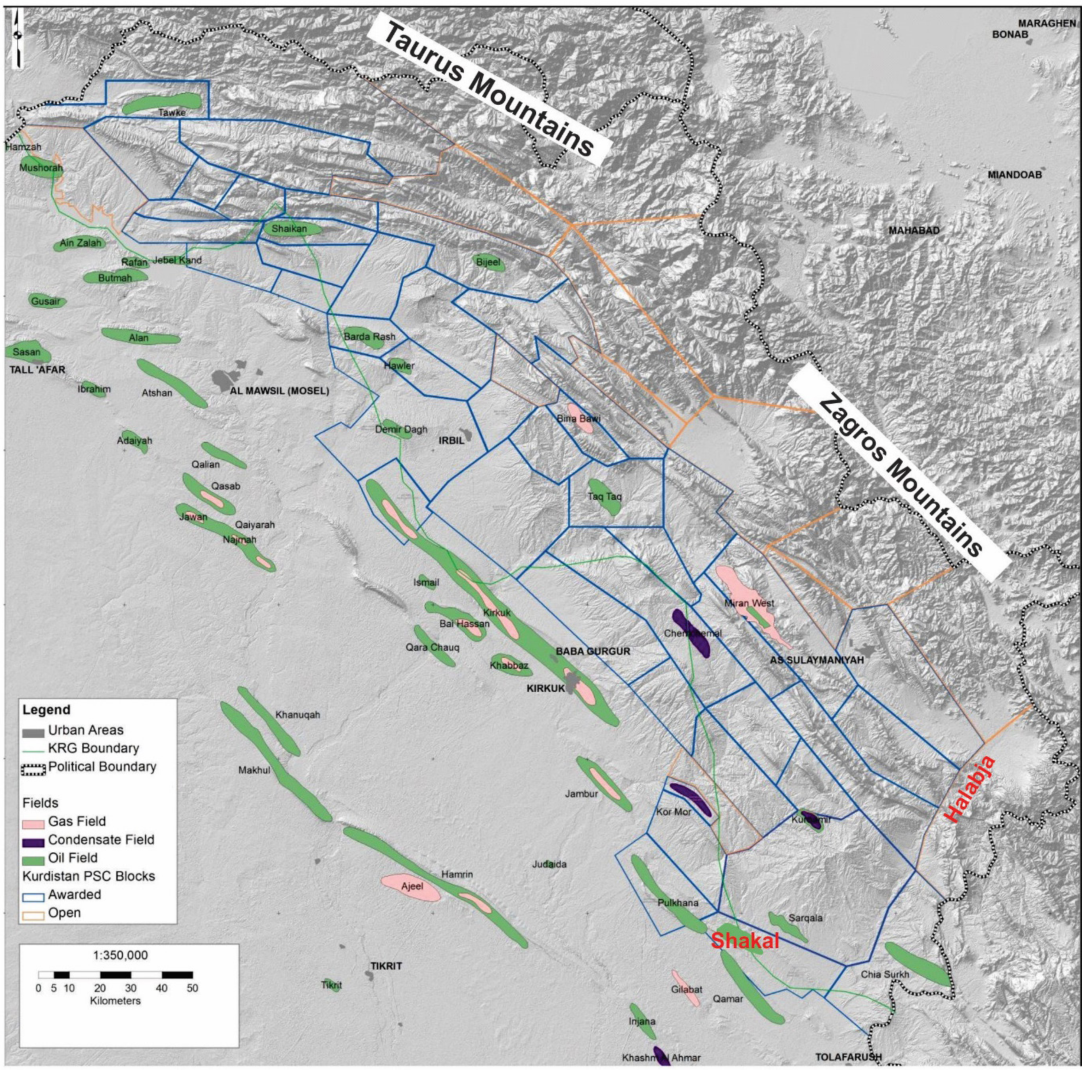

Figure 1. Shakal and Halabja area. Surrounding discoveries. Shakal & Halabja blocks are in the vicinity of significant oil and gas discoveries.

2. An Overview of the Regional Geological Background

From a regional geology point of view, the Zagros folded region occupies the extreme eastern region along the border with Iran within Iraqi Kurdistan and has a width not exceeding 50 km. Sedimentary-volcanogenic formations of the Mesozoic and Paleogene take part in the geological structure of the Zagros folded area. Mesozoic deposits are mainly represented by globigerina marls and radiolarites. Paleogene deposits—flysch and clastic rocks with a total thickness of over 5000 meters. The entire territory is characterized by a complex thrust structure. The angles of inclination of the fold along the overthrust vary from 20° to 50°.

According to tectonic the Iraqi Kurdistan lies on the border between two main geo-structural units—The Arabian part of the African platform and the Asian branches of Alpine. In general, three major tectonic zones [2] are developed in Northern Iraq (N-S):

- Thrust Zone
- Imbricated Zone
- High Folded Thrust Zone (Figure 2)
- Low Folded Thrust Zone (Figure 3)

Figure 2. High-folded thrust zone.

The occurrences of sediments and traps that generated and preserved hydrocarbons are linked to the history of the Arabian plate margin evolution [3]. The thick sedimentary cover of the Zagros orogenic belt records all the stages of evolution of the basin, evolving from a rift and passive continental shelf to a foreland basin associated with several stages of deformation related to obduction and collisions.

Figure 3. Low-folded thrust zone.

The Kurdistan Foreland basin has a complex geology and tectonostratigraphic framework which is not the subject of this paper. In the general geology map of Kurdistan (Figure 4) exploration blocks of Shakal and Halabja are located in the SE area of Iraqi Kurdistan.

According to seismic data, the geological feature of the surface expression is an NW-SE trending thrust fault that extends approximately 35 km in the strike direction and up to 8 km in the dip direction. Rocks of Tertiary age (Upper Fars and Lower Fars formations) are exposed in outcrop and are underlined by a Lower Tertiary to Cretaceous anticline that acted as a buttress and caused the younger rocks to be displaced by thrusts due to compressional tectonics (Figure 5). The structure extends from the town of Kalar to the SE and appears to continue the NW Pulkhana discovery completed in 2006. The producing fields of Jampur and Kirkuk are on trend and were originally thought to be structurally analogous to the Pulkhana and Shakal complex of structural closure. A review of drilling indicated that it should be possible to drill all of the primary objectives (Jeribe, Dhiban, Euphrates, Jaddala, and Shiranish formations) and potentially reach the secondary targets (Balambo and Qamchuga formations) as well. The closest analogue for the southern part of the Shakal block is Qara Dagh field's, productive Mio-Oligocene and Cretaceous deposits. There are no analogues for the northern part, all the nearest blocks are at the same stage (Figure 6).

Halabja area is characterized by complex dissected relief. More than 50% of the area is occupied by medium-altitude mountains with absolute elevations of 1200–1600 m, and in the extreme east and north on the border with Iran up to 2000 m, only a small part of the territory has hilly and elevated relief. The northern part of the block is composed of rocks of the Mesozoic age. The Cenozoic section is completely absent. Cretaceous deposits of the Balambo, Kometan, Shiranish, Tanjero, and Qulqula formations outcrop occur at the surface. The southern part of the block is composed of rocks of the Meso-Cenozoic age.

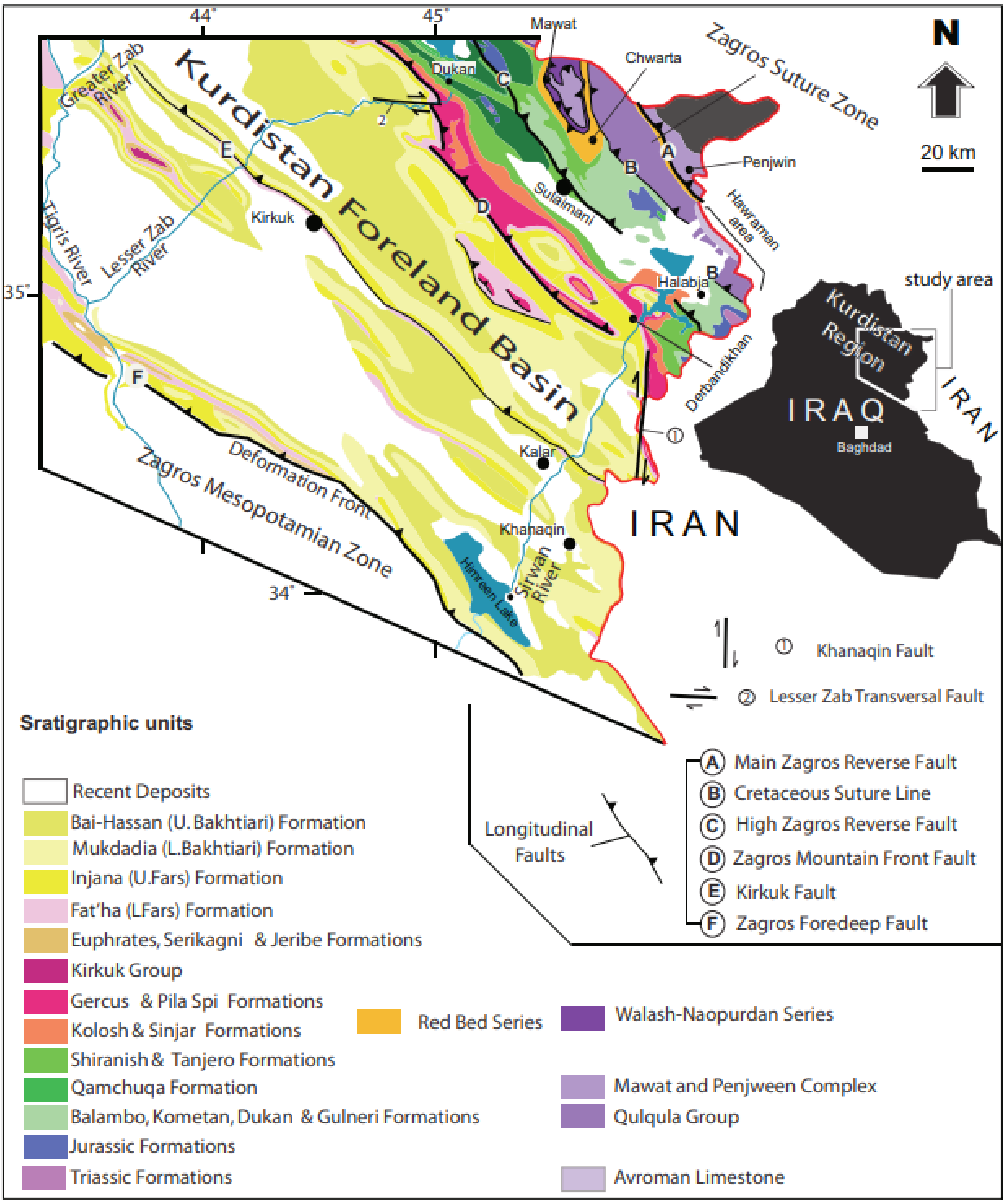

Figure 4. Geological map of the study area in the Kurdistan segment of the Zagros fold-thrust belt (modified from Sissakian [4]).

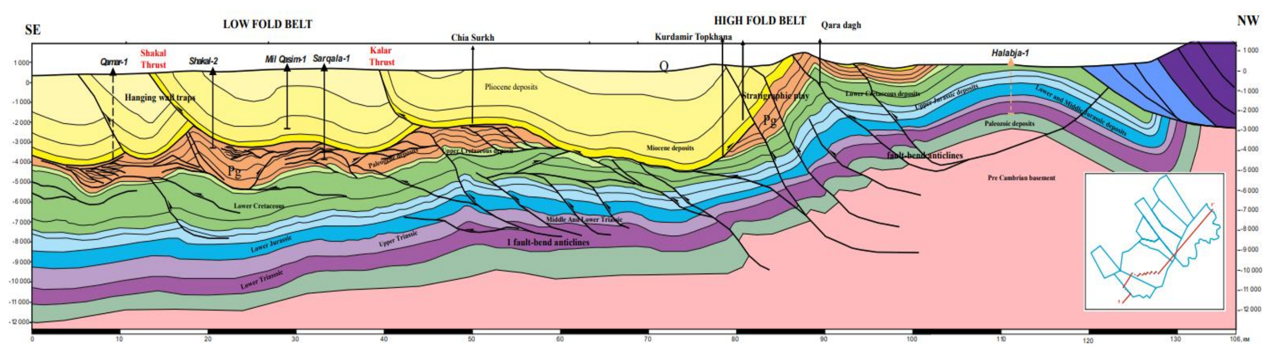

Figure 5. Geological features of the Shakal and Halabja blocks [5].

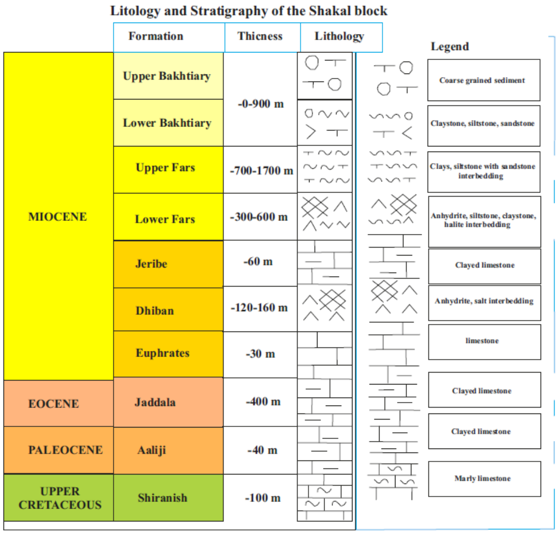

Figure 6. Lithology and Stratigraphy of Shakal block.

Deposits of the Paleocene, Eocene, and Miocene ages of the Kolosh, Sinjar, Gercus, Pila-Spi, and Fars formations occur at the surface. The Halabja block can be divided into two subblocks Upper Sirwan sub-block and Lower Sirwan sub-blocks. The Upper Shiwan Blocks occur within the Imbricated zone and consist of two Main subzones (a. Allochthonous part: consisting of Triassic and Jurassic Units with igneous intrusions; b. Autochthonous parts: consisting of the Triassic to Cretaceous rocks). Lower Shirwan sub-blocks consist of the Highly Folded Thrust zone of the foreland basin, and Low -Folded thrust zone whole Tertiary rocks are exposed on the surface (Figure 7).

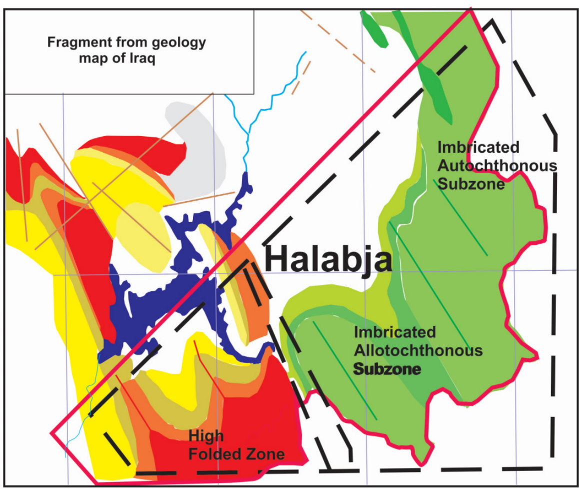

Figure 7. Halabja area. Tectonic zone. (Low Fold Belt: 36 total identified structures; 27 structures with HC shows; 3 failed structures; 6 undrilled blocks; Geologic Success Rate = 90%; High Fold Belt: 25 total identified structures; 11 structures with shows; 4 failed structures; 2 structures currently being tested; 9 undrilled blocks; Geologic Success Rate = 73.3%; Thrust belt: Remains untested).

Based on regional data (Figure 8) and neighbouring blocks (Qara-Dagh, SanGaw) the following potential reservoirs are expected in the Halabja area; 1) Cretaceous reservoirs: Qamchuqa, Kometan (Figure 9A) Shiranish; 2) Jurassic reservoirs: Barsarin (Figure 9B) Mus, Butman.

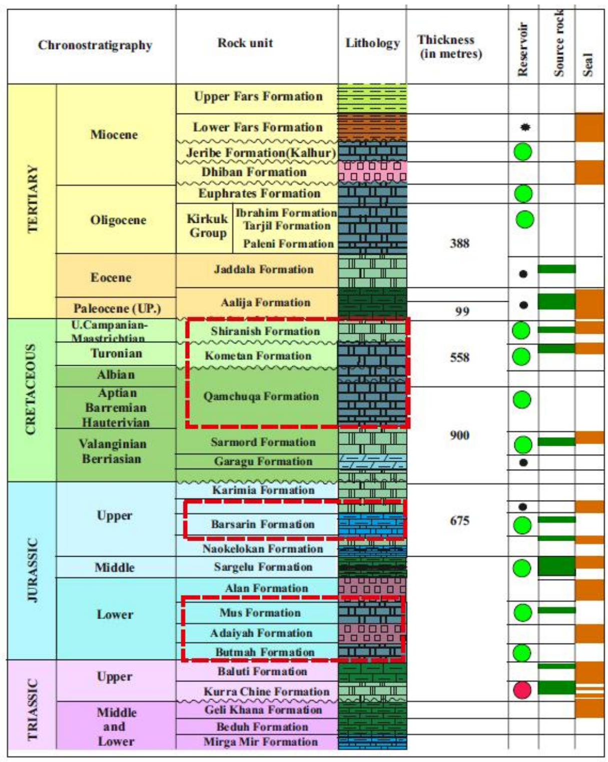

Figure 8. Stratigraphy of Halabja area. Oil reservoirs: Fars-N1, Jeribe-N1, Euphrates-Pg3, Kirkuk Group-Pg3, Jaddala-Pg2, Shiranish-K2, Gas reservoirs: Shiranish-K2, Chia Gara-J3, Kurra Chine-T3.

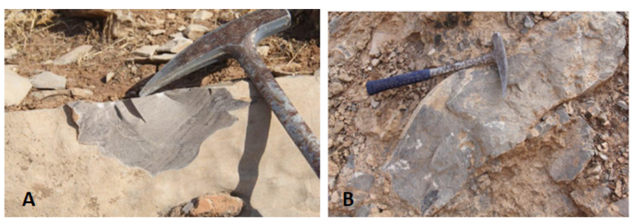

Figure 9. (A) Limestones of the Kometan formation; (B) Stromatolite limestones/dolomites of the Barsarin formation.

Halabja Block is a frontier acreage with no wells yet. Target horizons of the study: Carbonate and terrigenous sediments of the Cretaceous and Paleocene ages. The closest analogue for the southern part of Halabja is a Qara Dagh, productive deposits of the Mio-Oligocene and Cretaceous. There are no analogues for the northern part, all the nearest blocks are in the same stage. According to geophysical data, the deep junction of structures in the south of the Halabja and Qara Dagh blocks is still unclear, but it is possible that they form a single zone. In terms of surface geology, it is assumed that Jurassic, Triassic, and possibly Upper Paleozoic deposits are promising.

3. Research Method

In geophysics, special attention is paid to electromagnetic (or so-called geoelectric) methods of oil and gas exploration. To date, there are advanced instruments for geophysical research, which can practically be considered direct indicators of hydrocarbons. These devices theoretically prognosis the presence of oil and gas accumulations, which even the best seismic methods still cannot do consistently and reliably. This is a direct reconnaissance method based on frequency-resonant processing and interpretation of remote sensing data. Direct-search mobile technology is carried out using frequency-resonance processing of satellite data and interpretation of space and photo images. The method also includes vertical electro-resonant sounding (scanning) of any studied section with the integral assessment of the prospects for the oil and gas (or ore) potential of search areas [6]. Shortly we named it Mobile technology. Mobile technology successfully detects any subsurface substance (hydrocarbons, water, or other) with a 100% guarantee. The developed method is an effective express technology for the prompt solution of environmental, engineering-geological, and geological-geophysical problems. A phenomenological description of the technological features of mobile technology, in general, is as follows: "It is based on the latest achievements in astrophysics, mathematics, knowledge of electromagnetic radiation, computer technology, and software."

From basic physics, it is known that the wave can be travelling or standing. A standing wave is an oscillatory (wave) process in distributed oscillatory systems with a characteristic spatially stable arrangement of alternating maxima (antinodes) and minima (nodes) of the amplitude. Such an oscillatory process occurs when several coherent waves interfere. An antinode is the section of a standing wave in which the oscillations have the greatest amplitude. When do standing waves occur? When primary and reflected sound waves meet in space, they overlap and interact. The result is a standing wave! It got its name because the distribution of nodes and antinodes in it is constant in time. Nikola Tesla was the first to discover standing electric waves in the deep horizons of the Earth, and Dr. Yakimchuk developed the appropriate equipment, which, based on Tesla's theory, works as a direct reconnaissance method. So, the theoretical basis of the mobile technology method is based on "standing" electric waves, discovered by Nikola Tesla in 1899. The bottom line is when we shout and hear a return echo, we know that the sound has reached a wall or other obstacle, reflected, and returned. Just like sound, an electrical wave is reflected, this phenomenon is known as a "standing wave", that is, a wave with fixed nodes and antinodes. Tesla wrote: Instead of sending sound vibrations to a distant wall, I sent electrical vibrations deep into the Earth, and instead of a wall, the Earth answered me. Instead of an echo, I received a standing electrical wave reflected from the distant depths. The model of the structure of a fragment of the earth's crust can be represented as a set of flat capacitors. N. Tesla believed that the Earth is a spherical capacitor formed by different layers (from the core to the surface of the Earth) with different parameters—thickness, permittivity, density, and contact potential difference. The model of the structure of a fragment of the earth's crust can be represented as a set of flat capacitors. The dielectric constant of the formations is designated as $\varepsilon 1$, $\varepsilon 2$, $\varepsilon 3$ (respectively). Between the layers, a contact potential difference ΔU is formed and exists, the sign of which depends on the sign of the differences in the dielectric permittivity of the two contact layers. Thus, N. Tesla for the first time experimentally substantiated the possibility of sounding and studying the entire Earth using standing electric waves (Figure 10).

The theoretical substantiation of this technology is based on the fact that the atoms in all molecules have a certain spatial position and their electromagnetic field with a characteristic spatial-frequency intensity distribution. The spatial-frequency structure of electromagnetic fields of any substance is determined by the chemical composition and spatial structure of the molecules. A large amount of a homogeneous substance will create a collective electromagnetic field characteristic of this substance, the radiation power of which is proportional to the concentration of the substance in a given direction. We can assume that a linear polarization wave with a given frequency response, which carries information about the structure of matter, is not absorbed by the medium (environment) and its intensity does not decrease with distance. Then a homogeneous substance at a random depth of the Earth will create a field similar to how this substance would be on the surface. It turned out that the characteristic of electromagnetic waves of a large amount of hydrogen, oil, gas, water, and other substances is fixed in a certain way on a satellite image.

When carrying out instrumental measurements using the developed computerized complexes, the spectra of satellite, aerial, and other photographs of objects of study are sequentially compared with the spectra of rock samples, the desired minerals, and chemical elements. In modified versions of the methods of fre-

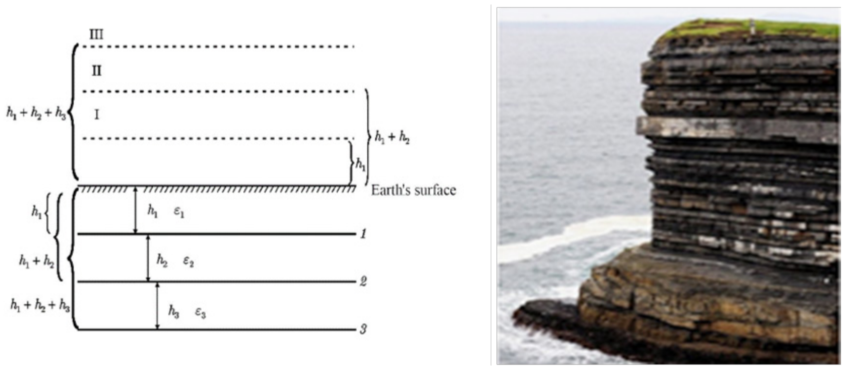

Figure 10. Model of the standing electric waves formation in the deep horizons of the Earth. Model (fragment) of the Earth's crust: h1-h3: thickness of sedimentary rock strata; ε1-ε3: their dielectric constant; 1-3: the boundaries of the layers; I-III: antinode of standing waves the length of the main waves has the following values: λ1 = 2h1; λ2 = 2 (h1 + h2); λ3 = 2 (h1 + h2 + h3). The length of other waves is 4 = 2h2, 5 = 2h3, 6 = 2 (h2 + h3), but they may not have antinodes on the earth's surface and their effect on the voltage on this plate will be minimal.

quency-resonance processing of satellite images and photographs, as well as vertical sounding (scanning) of the cross-section, existing databases (sets, collections) of sedimentary, metamorphic, and igneous rocks (https://karpinskyinstitute.ru/ru/info/sprav/petro/petro-mobil.pdf), minerals and chemical elements are used. Features and capabilities of the used method, as well as the measurement technique, are described in more detail [6-9]. Unlike classical geophysical methods, the mobile method used makes it possible to investigate the composition of the studied section. In each specific case, we obtain information on what the studied section consists of; what rock complexes are in it - sedimentary, metamorphic, or igneous? And we determine in the first approximation (and clarify at the stage of detailing) the intervals of the section that are promising for the detection of combustible and ore minerals, immediately, in the process of measurements (signal registration) by the developed instrumentation (i.e., without additional stages of modelling and geological interpretation of the results of instrumental measurements).

4. Results of Instrumental Measurements

The drilled wells within the Shakal exploration area were discovered by seismic studies shown in Figure 11. Shakal-3 well targeted the Jaddala-Aaliji reservoir interval which was encountered at a depth of 3280 mMD. The well was perforated behind the 7" liner against the reservoir intervals of Jaddala Fm. No hydrocarbon flow was found in the Jaddala-Aaliji interval. Shakal-2 well was initially planned to test by perforating behind the 7" liner against the reservoir intervals of Upper Jaddala and Euphrates formations. However, the interval of Dhiban formation was kept as an optional case to be reviewed and decided according to the results of the first two drill steam tests (DSTs). It was later tested as well and found oil shows in the Upper Jaddala and Euphrates formations. Formation water was received from the Dhiban interval. In Shakal-1 well three DSTs tested in the Jaddala-Aaliji formations, which resulted also in oil shows. In the Dhiban interval was received formation water.

Signals from oil, condensate and sedimentary rocks of very weak intensity were recorded from the surface of the local area indicated in Figure 12. In this regard, further work was not carried out to fix the intervals of responses from hydrocarbons. However, within the entire block, intense signals were recorded from diamonds and graphite, as well as from the kimberlite volcano. The root of the kimberlite volcano was determined to be at a depth of 723 km. The upper edge of the kimberlite volcano was fixed at a depth of 120 m. Signals at diamond frequencies were recorded from 152 m.

4.1 Local Fragment within the Shakal Area

In the area of the drilled wells (rectangular contour in Figure 12), responses from oil, condensate, bacteria, phosphorus, dead water, diamonds and graphite, limestones and kimberlites were recorded from the surface. The lower limit of limestones as a potential hydrocarbon reservoir is fixed at a depth of 4676 m. At 2770 m, we determined the boundaries of the lower and upper parts of the productive section, which consists mainly of limestones. When scanning the section from a depth of 2770 m and further, we obtained responses of oil from limestones from 3 intervals: 1) 2771–2794 m, 2) 2795.3–2815.45 m, and 3) 2834.40–2854 m. Below 2854 m was missing oil responses. It should also be noted that there are no signals from oil at the surface of 2771 m from the upper part of the section. From this, it follows that the productive hydrocarbon

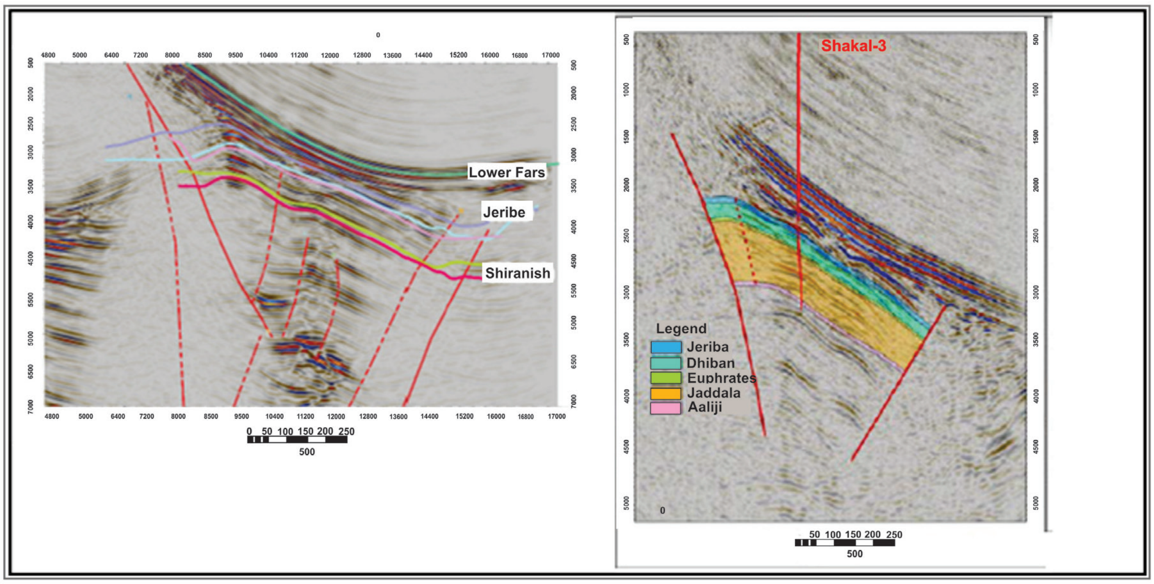

Figure 11. Seismic profiles through the Shakal structure.

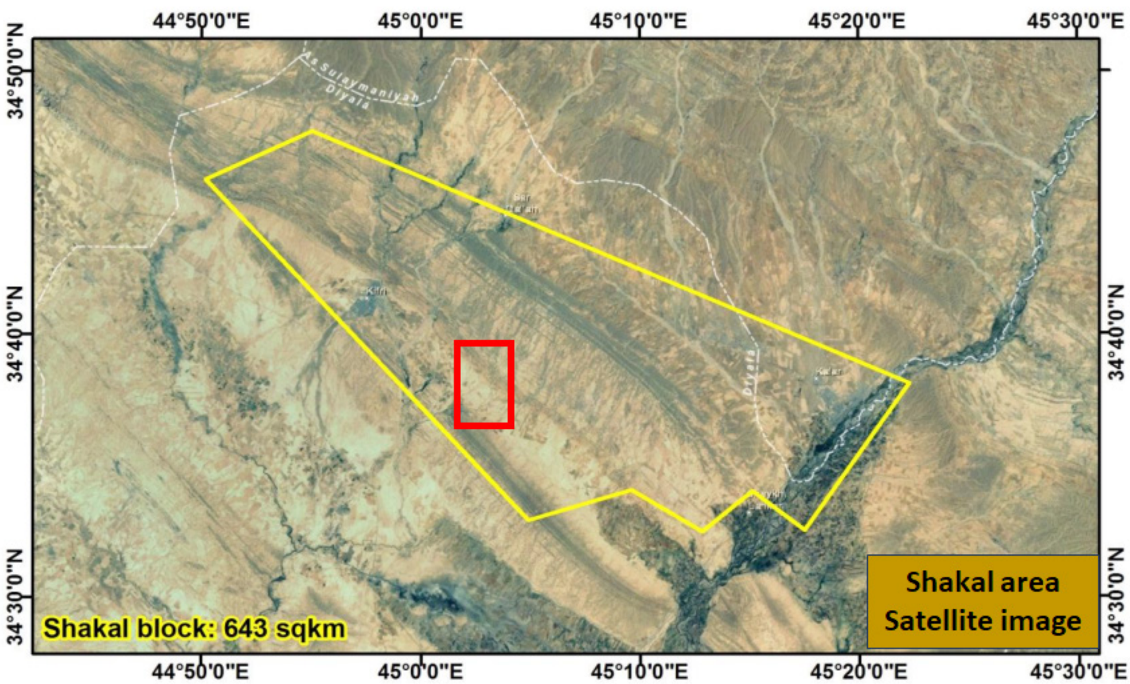

Figure 12. Satellite image of the Shakal area.

intervals are between 2771 and 2854 meters.

4.2 Halabja Exploration Area

No exploration drilling took place in the Halabja area. Based on analysis of regional data the expected reservoirs are carbonate. Local development of the seal is Lower Fars formation. On the adjacent block, oilfields are identified. High uncertainties in the Halabja area are structures at target formations; facies distribution and petrophysical properties of expected reservoirs; seal at the areas where Lower Fars is absent and effective hydrocarbon maturation. All blocks around the Halabja area are in the exploration stage. In complex topography, large areas are under minefields.

Frequency resonance processing of a satellite image of the Halabja block (Figure 13) from the surface of recorded

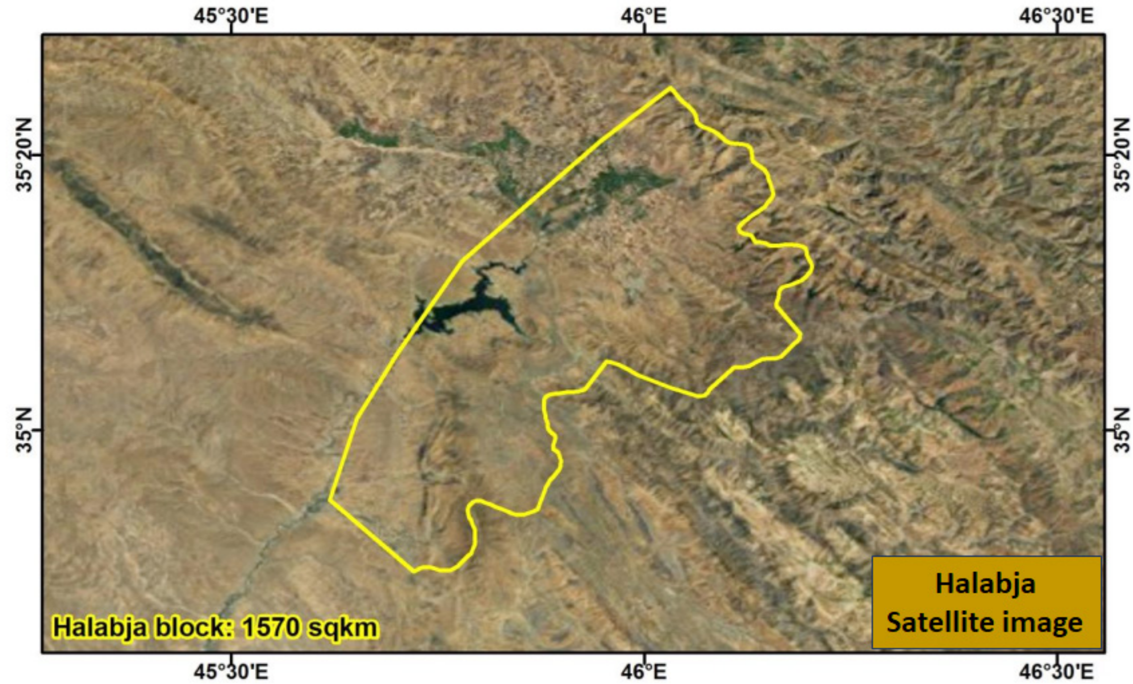

Figure 13. Satellite image of the Halabja area.

responses (signals) at the frequencies of oil, condensate, gas, phosphorus, bacteria, sodium chloride and dolomites. We adhere to the abiogenic-mantle origin of hydrocarbons. In the studied blocks of Kurdistan, the synthesis of hydrocarbons occurs at the 57-kilometre border. The applied mobile technology made it possible to register responses at the frequencies of oil, condensate, and gas in the Halabja area. In this area, the responses of a salt volcano were recorded. Scanning of the section made it possible to determine the upper boundary of the salt at a depth of 480 m. Oil responses were also received from 12 intervals:

1) 297–311.5 m, 2) 328–330 m, 3) 1190–1260 m, 4) 2018–2020 m, 5) 2059–2061 m, 6) 2132–2133 m, 7) 2192–2201 m, 8) 2249–2276 m, 9) 2307–2310 m, 10) 2317–2321 m, 11) 2326–2329 m and 12) 3310–3340 m. We traced the section up to 4 km (Figure 13). Below 3340 m there were no HC responses.

5. Discussions

Pilot studies on the territory of Kurdistan were carried out with the aim of additional testing, as well as improving the methodological methods of mobile technology. In fact, this was a continuation of earlier work, the results of which are presented in Yakimchuk et al., 2019 [4] and Yakimchuk et al., 2020 [5-7]. The obtained values of the cross-sectional parameters at the survey sites in Kurdistan are integral estimates, not point ones. To obtain point estimates, it is necessary to conduct a study with a dense grid over the entire area. A minimum survey grid should be carried out every 5 meters. Electromagnetic, resonant frequency signals must travel vertically and horizontally as is common in conventional seismic surveys. The distinguishing feature is that mobile technology deals with satellite imagery and photographic images. In the study in the integrated mode, the object under study carries approximate predictive values, and in individual objects, it is performed by a limited number of measurement procedures.

The selected intervals of responses at the frequencies of oil and gas are areas for searching for oil and gas deposits. I would also like to note the fact that a kimberlite volcano with a root at a depth of 723 km and an upper edge at a depth of 120 m was discovered within the Shakal block. When scanning the section, responses at diamond frequencies began to be recorded from 152 m. a very interesting object for the search for diamond ore. The position of a diamond-bearing kimberlite volcano within the block can be determined by detailed processing of a satellite image of the block. This means that the scanning procedure must be performed with a scanning step of at least 1 meter with a dense horizontal grid. This allows us to get more detailed information about the distribution of the diamond.

The materials presented above also testify to the expediency of using direct exploration methods at the stages of site selection for laying exploration wells. It is also expedient to carry out an additional survey of the identified structures using mobile geological exploration methods at the stages of planning on drilling exploration wells within them. It can be assumed that an increase in drilling success by at least two times will contribute to a significant increase in the efficiency of the exploration process. This is also evidenced by the results of the approbation of mobile technology in areas of exploratory wells in various regions of the world. Studies of this nature were carried out on drilling rigs in the Black Sea (Maria-1, Melnik-1, within block 1-14 Khan-Kubrat, Tuna-1 area), in the North Sea (57°10.644'N, 01°07.066'E), South African shelf (Brulpadda-1AX), Angola shelf (6º19'4.8" S, 10º53'33" E), Pakistan shelf ("Kekra-1"), shelf Alaska (Mukluk, the most expensive in history), Peru shelf (Marina-1), Uruguay shelf (Raya-1), Lebanon shelf (Block 4), Azerbaijan shelf (SAX01), Omelkovschinskoye oil field (Republic of Belarus), at the Shebelinskaya-888 well, at the Zapadno-Krestishchenskoye field (emergency well) (Yakimchuk and Korchagin [5-7]). Experiments carried out in Kurdistan have been added to the database, which testifies in favour of the deep (endogenous) genesis of hydrocarbons in the process of hydrogen degassing of the Earth.

6. Conclusions

The results of the conducted experimental investigations of an intelligence nature within two blocks in Kurdistan allow us to state the following:

A) Fixation of SW responses during frequency-resonance processing of satellite images of blocks indicates the expediency of carrying out a detailed search in their search work.

B) According to the results of the study of the section within the local section of the Shakal block, the interval of section 2760–2860 m is the most promising for the search for oil deposits.

C) Within the Halabja block, the most promising for oil exploration are intervals from 295 to 3340 m.

Research materials conducted at sites in Kurdistan demonstrate the operability and effectiveness of mobile technology in the search for hydrocarbon accumulations on land. Low-cost technology in general, can be used in various regions for a preliminary assessment of the oil and gas potential of little-studied and unexplored prospecting blocks and local areas. Promptly conducted additional studies by direct methods in local areas of drilling exploration wells will contribute to increasing the success of drilling (increasing the number of wells with industrial hydrocarbon inflows). Well, placement in the areas of vertical channels of fluid migration can lead to an increase in the inflow of hydrocarbons.

Author Contributions

Mykola Yakymchuk is an author of the mobile technology methods. Arzu Javadova took an active participation in exploration drilling and G&G analysis of Shakal and Halabja area. Ignat Korchagin participated in different approbation of mobile technology in areas of exploratory wells in various regions.

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Conflict of Interest

There is no conflict of interest.

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