Mobile and direct-prospecting methods: the possibility of their application for areas of geothermal water accumulation searching and mapping

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Abstract. The results of application of the frequency-resonance technology of remote sensing data processing and geoelectric methods of forming a short-pulsed electromagnetic field (FSPEF) and vertical electric-resonance sounding (VERS) within prospecting areas in Turkey, Slovakia, Mongolia, Nevada (USA), England and Ukraine are analyzed. Anomalous zones of "thermal water" type have been found within all survey areas. The drilled geothermal wells in all surveyed areas in Turkey fell into the contours of the anomalous zones of "thermal water" type. In some areas, a detailed vertical sounding by VERS method and vertical scanning of satellite data were carried out; the depths and thicknesses of aquifers were determined, and the water temperatures in them were estimated. For a more confident search for zones of accumulation of fresh (mineralized, geothermal) water, it is necessary to process remote sensing data at a scale of 1:10 000 and larger. The results of frequency-resonance processing of satellite images can be verified and refined by FSPEF and VERS methods. The joint use of these methods allows accelerating and optimizing the geothermal sources prospecting and exploration of. Approved mobile geophysical methods are recommended for practical use during prospecting and exploration of geothermal waters within known zones of geothermal sources development.

1. Introduction
For many years the authors have purposefully carried out experimental studies within large blocks and individual local areas of interest from an exploratory point of view in order to study the feasibility and expediency of mobile and direct-prospecting methods using for geophysical studies conducting on various types of minerals, including water (drinking, mineral, geothermal). Such methods include the developed ground-based geoelectric methods [1, 2], as well as the operative technology of processing and decoding of remote sensing data (RS) [2-6]. Approval of these methods and their practical application for the solution of oil and gas exploration problems was actively carried out (and carried out) by the authors both on onshore and in the offshore in different regions of the world [2-3, 5-7]. A significant amount of research using mobile remote sensing data processing technology was carried out by the authors in 2017. In particular, this technology has been successfully tested in the areas of exploration wells drilling in the Mediterranean and Black Seas, as well as in the area of gas hydrate production in the South China Sea.
The article presents and analyzes the results of experimental work to study the possibility of using ground-based geoelectric methods of FSPEF (SCIP) and VERS, as well as the frequency-resonance technology of remote sensing data (satellite images) processing for the detection and mapping of geothermal sources and thermal water accumulations.

2. Methods
The developed and used direct-prospecting technology includes the method of frequency-resonance processing and interpretation (decoding) of remote sensing data (RS) (satellite images) [2-6], as well as mobile ground-based geoelectric methods of the forming a short-pulsed electromagnetic field (FSPEF (SCIP)) and vertical electric-resonance sounding (VERS) [1-2]. This mobile technology is developed on the principles of a "substance" paradigm of geophysical research [2], the essence of which is the search for a specific substance – the gas, gas condensate, gold, uranium, water, etc. The technology also includes a separate technique for the maximum values of reservoir pressure in reservoirs estimating [5]. This fundamentally important technique is widely used during the search and exploration of oil and gas accumulations.

Mobile method of frequency resonance processing of remote sensing data is used at the first (early) stage of prospecting and exploration of deposits of various minerals. At the second stage of geological prospecting, the ground-based geoelectric methods of FSPEF (SCIP) and VERS can be applied (and are actively used) [1-2]. Surveying by FSPEF (SCIP) method makes it possible to find and map anomalies of the "deposits" type (DTA). Sounding by the VERS method within the boundaries of the mapped DTA anomalies, the intervals and depths of occurrence of anomalous polarized layers (APPs) of the "gas deposit" or "oil deposit", "aquifer" type, etc. are determined.

Technology in general, as well as its individual components (methods) has been tested at numerous search areas in various regions of the world for the combustible and ore minerals searching [1-10].

Currently, the direct prospecting methods are actively used for the commercial hydrocarbons accumulations searching, including in areas of non-traditional reservoirs: crystalline rocks, dense sandstones, deposits of the Bazhenov suite, shales, and coal-bearing basins. The technology has been used repeatedly to assess the prospects of oil and gas potential of the search blocks and areas within offshore, as well as in the depth horizons of the cross-section.

The results of applying the method of frequency resonance processing of remote sensing data for searching of ore objects with different mineralization are given in [4]. In works [8-10] some results of using mobile technologies for prospecting and exploration of aquifers and thermal waters are presented.

Geophysical work for the purpose of detection and localizing areas of the thermal waters accumulation using direct prospecting methods is carried out in two stages.

At the first stage, frequency-resonance processing (deciphering) of satellite images of search sites is carried out with the purpose of detection and mapping of zones with thermal water (anomalous zones of the "thermal water" type). At this stage of the search: a) maps of anomalous zones (predicted sites of aquifer availability) are constructed; b) for each isolated anomalous zone a preliminary evaluation of the water temperature characteristics is carried out; c) possible search intervals for the depths of occurrence of aquifers; d) the coordinates of the most promising locations for exploratory wells are determined.

At the second stage of the survey, field work is carried out using geoelectric methods of FSPEF (SCIP) and VERS. In this case: a) the contours of the selected anomalous zones of the "thermal water" type are detailed and refined; b) vertical sounding is carried out within the allocated contours of anomalies in order to determine the depth intervals of the anomalous polarized layers (APLs) of the "thermal water" type and to estimate the water temperature in the individual APLs; c) the construction of vertical cross-sections of the APLs of the "thermal water" type is carried out; d) site are chosen for the exploratory wells location.

To conduct search operations, the performers should be provided by the following data: a) geographic coordinates of the search site; b) the location (coordinates) of one or more hydrothermal
wells, located near the work site; c) information on the geologic cross-section of hydrothermal wells (depths of thermal water, type of reservoirs).

After preliminary analysis of the data, the scale of the maps necessary for the work is determined. In accordance with these scales, the area is divided into search sites. The amount and cost of search works depend on the number of sites.

3. Areas of work and research objectives

The first approbation of ground-based geoelectric methods of FSPEF (SCIP) and VEPP for searches and mapping of thermal water accumulations was carried out in the region of wide development of geothermal sources in Turkey. At the final stage of these studies, a frequency-resonance method of remote sensing data processing was used to localize the contours of a separate anomalous zone.

Experimental studies using only the technology of frequency-resonance processing of satellite images were carried out on a large block in Slovakia, on two search sites in Mongolia, the geothermal water search area in Nevada (USA), three areas of geothermal sources location in Turkey and two search sites in Ukraine. A detailed demonstration study was conducted at the local site of the deep geothermal exploration well Eastgate location in Weardale County, Great Britain. The main objectives of the research can be formulated as follows:

1. Additional testing of mobile direct-prospecting geophysical technologies on search sites and areas in various regions of the world, promising for geothermal resources.
2. Practical demonstration of the potential of direct-prospecting technology in prospecting and exploration of geothermal water accumulation. The expediency of using such methods and technologies is noted in many publications, including [11].
3. Detection and mapping within the surveyed local areas of anomalous zones of the "thermal water zone" type, the allocation within the detected anomalies of areas with maximum values of water temperature. Estimation of depths and thickness of reservoirs with thermal waters, as well as water temperature in individual reservoirs.

3.1 Ground-based geoelectric research in Turkey

Experimental studies on the area of geothermal sources development were carried out in 2012. Due to the fact that the measurements during the FSPEF (SCIP) survey were carried out, mainly along the roads, the following scheme for presenting the measurement results was adopted. The chart shows the trajectory of the car moving, and the measurement points within the anomalous zones which are highlighted in red. In addition, schematic route maps of geothermal water temperatures, based on the results of the measurement data processing, are also shown on the trajectory maps. The results of measurements within one (fourth) fragment of the investigated geothermal development zone are shown in figure 1. It follows from this that due to the route-based nature of the measurements, individual local anomalous zones are not completely traced and not contoured.

Note that in figure 1 only about a fifth of the surveyed territory is shown. The results of measurements at other sites are presented on an additional three schematic maps, the dimensions of which are 47.5 \times 31.0 \text{ km}, 141.0 \times 31.0 \text{ km} and 22.4 \times 36.2 \text{ km}, respectively. The results of the FSPEF (SCIP) survey in all the surveyed areas are shown on the map of relative temperature anomalies calculated from the results of satellite image processing (figure 2).

It is advisable to note that during the measurements in areas of anomalous zones, geothermal wells and operating hospitals were visually observed. In principle, this circumstance can be considered an additional confirmation of the efficiency and efficiency of the mobile geoelectric method of FSPEF (SCIP) in terms of detection and mapping of zones of geothermal water and source distribution.

During field measurements, VERS sounding in the 500-3000 m interval was performed at one point, the position of which is shown in figure 1. The sounding point is located in the zone of maximum values of the water temperature. The sounding results are shown in figure 3. By sounding in the interval of 1235-3000 m, 8 horizons of geothermal water of different thickness and temperature are allocated: 1) the depth of the reservoir is 1235 m, the thickness of the layer is 28 m, the water
temperature is 160°; 2) 1367 m, 13 m, 200°; 3) 1599 m, 11 m, 220°; 4) 1722 m, 18 m, 240°; 5) 2045 m, 56 m, 320°; 6) 2195 m, 80 m, 320°; 7) 2455 m, 205 m, 320°; 8) 2805 m, 111 m, 340° (figure 3). Note that with increasing depth of bedding, the water temperature rises.

Figure 1. Map of zone of geothermal water location along the road (using the ground-based geoelectric survey). Area 4. 1 – scale of water temperature (in °C); ground-based survey points: 2 – temperature > 20 °C; 3 – temperature < 20 °C

Figure 2. Map of anomalous zones of "thermal water" type superimposed on a map of relative temperature anomalies, calculated from the results of satellite images processing.

In the upper part of the cross-section, in the depth interval of 500-1200 m, five water-bearing horizons with a low water temperature were additionally identified by sounding: 1) the depth of the horizon is 512 m, the thickness of the layer is 20 m; 2) 680 m, 13 m; 3) 755 m, 10 m; 4) 970 m, 14 m; 5) 1141 m, 12 m.

We also pay attention to the fact that in figure 3, the left part of it shows two sounding diagrams. Here the diagram (curve) of the blue color fixes the position of the aquifers, including geothermal water, in the cross-section. The second diagram of light-black color characterizes the type of rocks in the cross-section. It is also worth noting that, at almost all intervals of the depths of the location of the aquifers, these two diagrams coincide - one indicates the presence of water, the other indicates a reservoir.
After the completion of the field work, the processing and interpretation of the RS data of the fragment of anomalies, shown in the lower left corner in figure 1, has been conducted additionally in the office conditions. The main task of processing was the detailed mapping of the detected anomalous zones by area. The results of the processing are shown in figure 4. During the processing of remote sensing data, two systems of tectonic fractures, northeastern and northwestern, were discovered. A characteristic feature is that the fault zone of the northwestern strike is traced only in the southwestern part of the area, and in the northeastern direction only in the northeastern part of the site.

Almost in the central part of the site, in the zone of intersection of the central faults, a section of maximum temperatures of geothermal water has been identified. Within its limits is a single point of sounding (figure 4).

In general, the joint analysis of ground-based measurements by the FSPEF (SCIP) method and the results of processing and interpretation of remote sensing data suggests that vertical migration of...
geothermal water at the maximum water temperature (in the fault crossing zone) is quite possible in the mapped anomalous zone. Further, geothermal water migrates along the faults and fills the reservoir.

3.2 Experimental site in Slovakia

So it turned out that prior to field work within a known zone of geothermal sources development, RS data processing was performed at one of the sites in Slovakia, based on the results of which a schematic map of the maximum temperature of geothermal waters was constructed (figure 5). Remote sensing data processing at the site was carried out without analysis and consideration of existing geological and geophysical materials. During the processing of remote sensing data in the northwestern part of the survey area, two faults zones, northeastern and northwestern, were identified. At the intersection of these zones, the maximum values of the temperature of the thermal water are established by the results of processing (figure 5).

Figure 5. The schematic map of geothermal water temperatures in area of thermal sources investigations in the central part of Danube basin (Slovakia). (According the results of the satellite data decipher). 1 – scale of maximal values of thermal water temperatures; 2 – boreholes; 3 – zones of tectonic disturbances.

We note that the zone of faults of the north-eastern strike is known from the available geological and geophysical data. However, there is no information on the faults of the northwestern strike.

In this connection, and taking into account the results of later experimental studies within the known geothermal water distribution zone, it is expedient to analyze in detail the available geological and geophysical materials in the zone of maximum temperatures of geothermal water detected and mapped by the results of processing and interpretation of remote sensing data of a separate site in Slovakia (figure 5). The expediency of such an analysis is determined by the following points.

1. In the surveyed area (figure 5), the maximum values of the temperature of the thermal water are determined by the results of the remote sensing data processing in the fault crossing zone.

2. A similar situation is observed in the area of thermal water distribution, shown in figure 4. Here, high temperatures are also confirmed by ground-based measurements by the methods of the FSPEF (SCIP) and VERS.

3. In the high-temperature zone in figure 5 the water can be found in the basement rocks, at depth. Naturally, these horizons are not disclosed here.

Practical experience shows that when processing remote sensing data of a larger scale, the geothermal water development zones can be more confidently and authentically mapped. In this regard, it is advisable to carry out the processing of remote sensing data of a larger scale in this area.
This site can also be inspected by ground-based geoelectric methods of FSPEF (SCIP) and VERS. At the same time, the VERS sounding will allow us to estimate the depths and thickness of geothermal water reservoirs.

3.3 Reconnaissance studies in Mongolia

The exploratory works in Mongolia were carried out in 2014 on two relatively large blocks—“Ulan-Bator” and “Kharkhorin”. The processing of remote sensing data within the limits of search areas was carried out in reconnaissance mode. The processing scale of satellite images was 1: 200000 (figures 6 and 7).

At the initial stages of image processing, the allocation and tracking (tracing) of linear zones of tectonic fractures were carried out, in the region where, in most cases, aquifer horizons are localized. Through the faults, water can also migrate from the lower part of the cross-section to the upper one.

During processing at resonant frequencies of water of various types (fresh, mineralized, geothermal), local zones of possible accumulation of geothermal waters were isolated and mapped. In this case, the temperature of the water was estimated in each detected anomalous zone.

At this stage, in addition to the central points of the detected and mapped anomalous zones of the "geothermal horizons" type, an approximate estimate of the depth intervals for the geothermal horizons searching was obtained using a special method of remote sensing data vertical scanning.

The results of remote sensing data processing and vertical scanning data within the search areas "Ulan-Bator" and "Kharkhorin" are shown in figures 6 and 7. Within the search area "Ulan-Bator" seven local zones were discovered for the search for horizons with geothermal water, and on the "Kharkhorin" area – two zones. The depths of occurrence of aquifers have been estimated. All the mapped anomalous zones of the "geothermal horizons" type are promising for the discovery of geothermal water deposits within their boundaries and are recommended for detailed study and drilling.

Figure 6. Map-scheme of contours of zones of potential accumulation of geothermal waters in the Ulaanbaatar search site in Mongolia (based on the results of frequency-resonance analysis of remote sensing data). 1–scale ruler; 2– sections of a potential (possible) cluster of geothermal waters (anomalous zones No. 1-7); 3– tectonic fractures; 4– contours of the search area.
When choosing the location of wells for geothermal water, additional studies within the detected anomalous zones can be performed by traditional geophysical methods, or geoelectric methods of FSPEF (SCIP) and VERS. Detailing can also be done by remote sensing data processing at a scale of 1: 10,000 and larger.

3.4 Results of remote sensing data processing in Nevada
In conducting the demonstration studies in Nevada, the materials of the publication [12] were used. At the initial stage of the studies, taking into account the materials of [12], a relatively large fragment of the area was processed at a scale of 1: 80,000 (figure 8). To search for aquifers (horizons) this is a fairly small scale of processing - small search objects on this scale can be missed.

A number of tectonic fractures, an extended anomalous zone of the "water" type and two relatively small anomalous zones of the "geothermal water" type were found in the surveyed area (figure 8).

At the next stage of the work, the local area with anomalous zones of the "hydrothermal water" type was processed on a larger scale - 1: 20,000. The results are shown in figure 9. When decoding the satellite image, the depths of the location of the collectors as well as the maximum values of the water temperature were also estimated. In addition, the central points of the detected anomalous zones are determined - their coordinates are shown in figure 9. These points can be considered the most optimal for drilling exploratory wells for water.

Estimating the results of experimental work on the site in Nevada as a whole, we can state that within its limits there are promising geothermal objects (anomalous zones) that deserve detailed study and drilling. It is also advisable to pay attention to the small depths of aquifers occurrence. Such results were obtained for the first time during the search for thermal waters.
3.5 The search for geothermal water in Turkey

In 2015, searches for thermal water accumulations in Turkey were carried out on three search sites using the frequency-resonance method of satellite images processing and decoding.

An image of the search site near the city of Erzurum was processed on a scale of 1: 60,000 (figure 10). Two anomalous zones of the "thermal water" type were found and localized on the survey area. In the central parts of the anomalous zones, the water temperature in the upper aquifer was estimated: at the point V1 - 115° C, V2 - 80° C.

At points V1 and V2, a vertical scanning of the cross-section was also carried out to estimate the intervals of depths of the aquifers and the water temperature in them. The following results are obtained: point V1: 1) 245-302 m (depth interval), T = 115° (water temperature); 2) 477-507 m, T = 165°; 3) 555-573 m, T = 174°; 4) 605-622 m, T = 176°; 5) 743-753 m, T = 179°. Point V2: 1) 229-263 m (depth interval), T = 80° (water temperature); 2) 229-263 m, T = 80°; 3) 538-553 m, T = 93°; 4) 575-588 m, T = 95°; 5) 719-723 m, T = 96°.

At the second search site in Turkey, studies were conducted in the geothermal well location area (figure 11). The map of anomalous zones of the "thermal water" type is constructed in water.
temperature isolines. From figure 11 it follows that a geothermal well has been drilled here at the site with the maximum temperature values.

It can also be assumed that the observed anomalous zones of the "thermal water" type are located here along the tectonic fractures of the latitudinal (eastern) and north-eastern strike (figure 11). At the intersection of these fractures, vertical migration of thermal waters can occur – the rise of hotter water and the filling of the horizons (collectors) in the upper part of the cross-section.

**Figure 10.** Area of hydrothermal waters deposits searching in Turkey near the Erzurum town. Map of anomalous zones of “hydrothermal water” type. 1 – scale of hydrothermal water temperature in the upper horizon (degrees Celsius); 2 – points of exploratory drilling; coordinates: V1 – N 40.0129°, E 41.1958°, T=115°C; V2 – N 39,9848°, E 41,3143°, T=80°C; 3 – contours of the search area.

**Figure 11.** A site of hydrothermal waters searches in Turkey. Map of anomalous zones of the "hydrothermal water" type. 1 – temperature scale of hydrothermal water (Celsius degrees); 2 – hydrothermal well.

Vertical scanning of the cross-section within the detected anomalous zone in the second area was not carried out.

The results of frequency-resonance processing of remote sensing data within the third search area in Turkey are shown in figure 12 on the satellite image of the site. A geothermal well is also located on this area (figure 12).

In the surveyed area, three extended zones of distribution of aquifers of the north-north-eastern strike - western, central and eastern - were detected and mapped. Anomalous zones of the "thermal water" type are fixed only in separate sections of the allocated aquifers.

By a size (area) western and central anomalous zones deserve attention. Within the western anomalous zone, near the point with the maximum values of water temperature is a hydrothermal well.
3.6 Search for accumulations of thermal waters in the Black Sea region

The developed mobile methods of searching for accumulations of hydrocarbons, ore deposits of various mineralization and water are constantly being modernized and improved. In April 2014, using the improved method of frequency-resonant processing of remote sensing data, the prospects of oil and gas potential of individual blocks and areas in the Black Sea region of Ukraine (Kherson, Mykolaiv and Odessa regions) were promptly evaluated. The emphasis was in this case on local areas, within which the ground-based geoelectric studies have been conducted previously.

Figure 12. A site of hydrothermal waters searches in Turkey. Map of anomalous zones of the "hydrothermal water" type. 1–anomalous zones of the "hydrothermal water" type (isolines in Celsius degrees); 2– zones of aquifers; 3– points with the maximum values of water temperature; 4 – hydrothermal well.

Figure 13. Map of the anomalous zones of "gas deposit" type within the prospecting area in the Mykolaiv region (Ukraine) (according to the frequency-resonance decoding of remote sensing data). 1 – scale of values of the complex parameter of reservoir pressure, MPa; 2 – geothermal anomalies; 3 – tectonic fracture zones.
During the processing of images within the detected anomalous zones, the maximum values of the fluids pressure in the reservoirs were estimated [5], and also searches for the sites of thermal water accumulation were carried out.

In Kherson region, a satellite image of a large search block was processed at a scale of 1: 400000. The approximate position of the block is determined by latitude and longitude coordinates: 46°00' - 46°45', 32°05' - 34°05'. Nine anomalies of the "Gas" type and two anomalies of the "Gas+Condensate" type are mapped within the surveyed block. Estimates of the maximum values of reservoir pressure in the contours of anomalies vary in the range 7.0-28.0 MPa. Additionally, two anomalous zones of the "geothermal water" type with temperatures of 60°C and 89°C were also discovered. Graphically, the results of the work are presented in [7]. In the same article, the materials of the work by ground-based geoelectric methods of the FSPEF (SCIP) and VEPP within the anomalous zone "Tarasovskaya" are described.

A satellite image of a relatively small search area in the vicinity of Ochakov (Nikolaev region) was processed on a scale of 1: 150,000 (figure 13). In the surveyed area, two anomalous zones of the "Gas" type with maximum reservoir pressures of 36 MPa were found, as well as three anomalies of the "geothermal water" type with temperatures of 81°C, 94°C and 114°C, respectively.

In the Odessa region, studies were carried out on eight local search sites, satellite images of six of them were processed on a scale of 1: 150,000. On the search site in the vicinity of the Arziz settlement two anomalies of the "Gas" type and four anomalies of the "Oil+Gas" type were detected (figure 14). The reservoir pressure within their limits varies in the interval of 33.0-38.0 MPa. One anomalous zone of the "geothermal water" type with a temperature of 104°C has also been fixed.

3.7 Research in the geothermal well "Eastgate" (England)
In the course of the work, research materials in England, published in [11, 13-14], and the coordinates of two deep drilled wells were analyzed and used.

In the area of the “Eastgate” geothermal well, a site was taken for further processing, the satellite image of which was placed on an A3 size sheet at a scale of 1: 5000. This is a fairly large, detailed scale of satellite images processing. The results of the frequency-resonance processing of this image are shown in figures 15 and 16.

At the initial stage of processing, zones of tectonic fractures) were detected and traced within the surveyed area. Traditionally, water (including geothermal) migrates through faults and forms accumulations, both in fault zones directly and in close proximity to them. In this regard, the traced...
zones of faults make it possible in the future to more specifically identify (detect) (geothermal) water accumulations.

Figure 15. Map of the anomalous zones of the "geothermal water" type in the area of "Eastgate" deep hydrothermal well in the UK (according to the frequency-resonance processing of satellite images). 1 – scale of geothermal water temperature, °C; 2 – Eastgate well; 3 – points of the vertical scanning; coordinates: – GH-1 – N 54.73861°, W 2.09639°; GH-2 – N 54.73279°, W 2.10541°; 4 – zones of tectonic fractures.

Figure 16. Map of the anomalous zones of the "geothermal water" type in the area of "Eastgate" deep hydrothermal well in the UK on the satellite image of area (according to the frequency-resonance processing of satellite images). 1 – isolines of geothermal water temperature, °C; 2 – Eastgate well; 3 – points of the vertical scanning; coordinates: – GH-1 – N 54.73861°, W 2.09639°; GH-2 – N 54.73279°, W 2.10541°; 4 – zones of tectonic fractures.
As a result of subsequent processing, seven anomalous zones of the "geothermal water" type were detected and mapped in the surveyed area (figures 15 and 16). The contours of the individual zones are not completely traced.

In figures 15 and 16 mapped anomalies are built in water temperature isolines. In the contours of individual anomalies, local zones with maximum estimates of water temperature are also identified. The maximum values of the water temperature in these local zones are indicated in the figures. Zones with maximum water temperatures are located, mainly, at the intersections of faults.

From figures 15 and 16 it follows that the “Eastgate” well is located on the edge of one of the detected anomalous zones. In this case, the section with a higher water temperature is located in the opposite, southeastern part of the anomaly, just in the zone of intersection of the identified faults.

An anomalous zone with a maximum water temperature (88°C) is located in the south-western corner of the survey site. Completely in a southerly direction, this anomaly was not traced. It is possible that in the zone of faults crossing the water temperature can reach 100°C.

**Figure 17.** Results vertical scanning near "Eastgate" hydrothermal wells in England (Point # GH-1). Coordinate: N 54.73861°, W 2.09639°. 1 – water layers of different temperatures; 2 – promising water horizon with t=46 °C; 3 – depth to the roof / layer thickness - water temperature.

**Figure 18.** Results vertical scanning in the area of maximal water temperature in England (Point # GH-2). Coordinate: N 54.73279°, W 2.10541°. 1 – water layers of different temperatures; 2 – promising water horizons with t=88 °C; 3 – depth to the roof / layer thickness - water temperature.
Not far from the drilled well (point GH-1) and in the zone with the maximum water temperature (point GH-2) (figures 15-16) a detailed vertical scanning of satellite data was carried out. As a result of the scanning, the depths and thicknesses of individual aquifers (intervals) and the temperature of the water in them have been determined (estimated). According to the scanning data, schematic vertical cross-sections are constructed at two points (figures 17-18).

Note that this kind of detailed research was done for the first time.

It was noted above that the maximum values of the water temperature were recorded within the anomalous zone, located in the southwestern corner of the surveyed area (figures 15-16). However, this anomalous zone is not completely traced to south.

In this regard, the satellite image of the location of this anomalous zone is processed additionally in a scale of 1: 3,000 in order to completely outline it. The results of the processing are shown in figures 19 and 20.

From figures 19 and 20 it follows that within this anomalous zone the maximum values of water temperature (t = 104.5°C) are recorded in the southeastern part of the anomaly, in the region of tectonic fracture of the northeastern strike. The water-bearing reservoir in this part of the anomalous zone is located in the depth interval of 984-988 m.

**Figure 19.** Map of the anomalous zones of the "geothermal water" type in the area of "Eastgate" deep hydrothermal well in the UK (area of southwestern anomaly). 1 – scale of geothermal water temperature, °C; 2 – points of the vertical scanning; coordinates: GH-2 – N 54.73279°, W 2.10541°, t=88°C, H= 939 - 947 м; GH-3 – N 54.73189°, W 2.10434°, t=104.5°C, H = 984 - 988 м; 3 – zones of tectonic fractures.

**Figure 20.** Map of the anomalous zones of the "geothermal water" type in the area of "Eastgate" deep hydrothermal well in the UK on the satellite image of area (area of southwestern anomaly). 1 – isolines of geothermal water temperature, °C; 2 – points of the vertical scanning; coordinates: – GH-2 – N 54.73279°, W 2.10541°, t=88°C, H= 939 - 947 м; GH-3 – N 54.73189°, W 2.10434°, t=104.5°C, H = 984 - 988 м; 3 – zones of tectonic fractures.
4. Conclusions

The results of the experimental studies carried out within the known and well-studied geothermal distribution zone in Turkey, the exploration sites in Slovakia, Mongolia, Nevada (USA), Turkey and Ukraine, the local site of the deep geothermal well “Eastgate” (UK), and also the practical experience of using mobile geophysical technologies for water search [8-9] allow us to state the following.

1. At all surveyed sites there are promising objects for the detection of geothermal waters (anomalous zones), which deserve further detailed study by geophysical methods and drilling. We also draw attention to the fact that the drilled geothermal wells in two surveyed areas in Turkey fell into the contours of the anomalous zones of the "thermal water" type, found within them.

2. The conducted studies show that in order to more confidently search for the zones of the fresh (mineralized, geothermal) water accumulation, it is necessary to process remote sensing data at a scale of 1:10 000 and larger. On a large scale, relatively small anomalous zones of the "geothermal water" type can be additionally detected in the surveyed areas. The zones, selected as a result of RS data processing on a scale of 1: 200,000 - 80,000, are only the zones, most promising for searches. In the work areas, there may also be a fracture type collector. It is understandable that it is quite difficult to get a well into the fracture. If the water is in loose sediments, then the task is somewhat simplified.

3. Mobile direct-prospecting technology of frequency-resonance processing of remote sensing data can be used to select the optimal locations for geothermal (including deep) wells. This technology allows detect and map the zones of the aquifers and geothermal waters location. At each point of the detected anomalies, the maximum values of the temperature of geothermal water can also be estimated. Detailed work for the purpose of selecting sites for prospecting water wells location should be carried out by processing remote sensing data (satellite images) in a scale of 1: 10,000 and larger.

4. The results of the application of frequency-resonance processing of remote sensing data can be verified and refined by ground-based direct-prospecting geoelectric methods of FSPEF (SCIP) and VERS. These mobile methods are also advisable to use for geothermal exploration. Surveying using the FSPEF (SCIP) method is used for the operative detection and mapping of geothermal sources and thermal water distribution zones. The maximum temperatures of thermal waters along the profiles can be estimated within the limits of the mapped anomalies. The VERS sounding allows estimate the depth of the location and thickness of the geothermal water reservoirs. The water temperature in the individual reservoirs is also estimated during the sounding.

5. The joint use of the technology of frequency-resonance processing of remote sensing data and ground-based geoelectric methods of FSPEF (SCIP) and VERS allows speeding up and optimizing the process of the geothermal sources prospecting and exploration.

6. Approved mobile geophysical methods are recommended for practical use in prospecting and exploration of geothermal waters within known zones of wide development of geothermal sources.

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