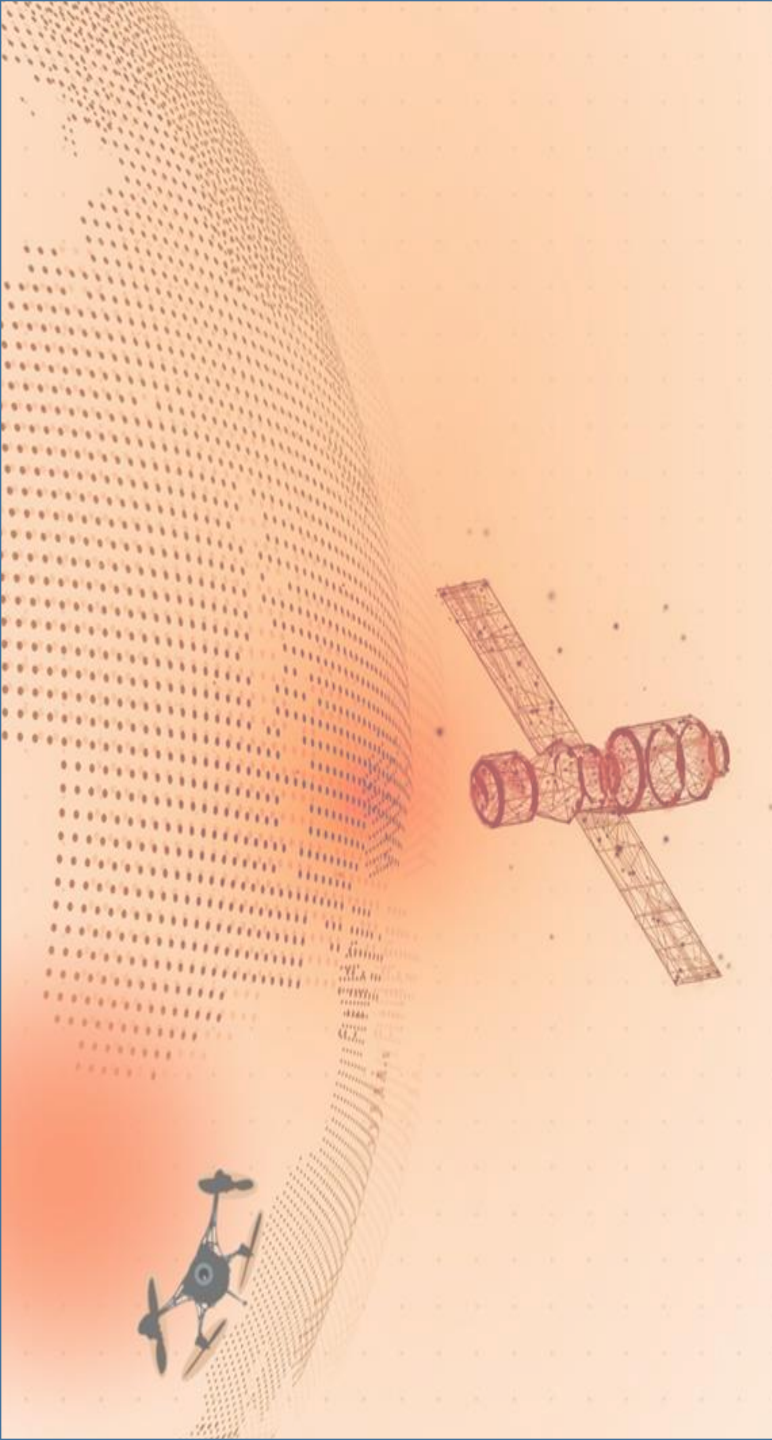


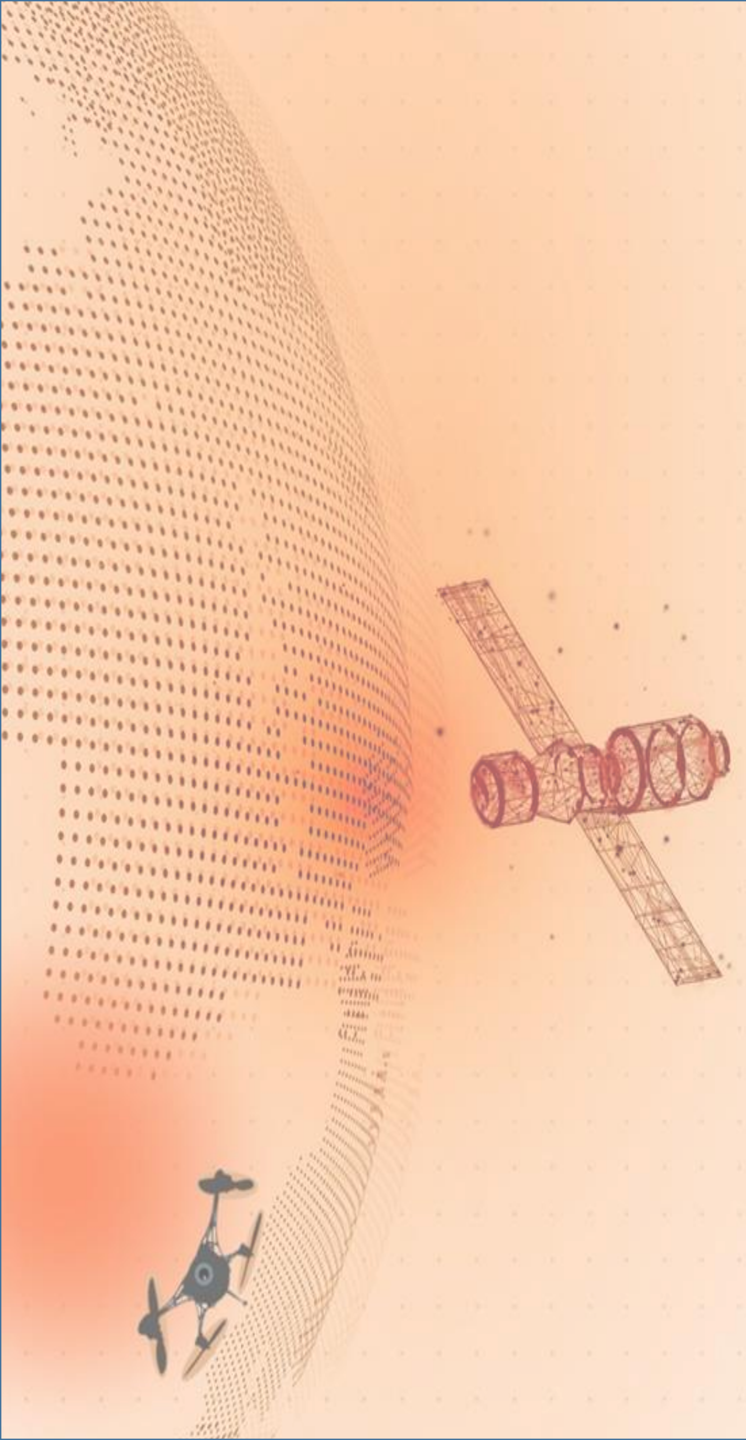
Center of Aerospace Technologies ltd

Radio-Thermal Imaging Technologies for searching for hydrocarbon deposits

Center of Aerospace Technologies ltd

All over the world, one of the newest methods for studying the geological and tectonic structure, forecasting and searching for mineral deposits is Earth remote sensing (ERS). Radio-Thermal Imaging Technology (RTT), which our company owns and is an element of remote sensing, has been used for more than 10 years to solve geological problems around the world.

Today at the Center of Aerospace Technologies ltd. extensive research experience has been accumulated in order to identify deposits of oil, natural gas, and gas condensate. RTT has established itself as a working tool for studying the structure of the geological environment, as well as a method for identifying geothermal anomalies, which are prototypes of hydrocarbon trap zones (search objects) containing formations saturated with oil or gas.



1. RADIO-THERMAL IMAGING TECHNOLOGIES (RTT)

RADIO-THERMAL IMAGING TECHNOLOGIES (RTT)

RTT is considered as a passive remote sensing method based on recording the radiated thermal energy of the Earth, which is represented by a continuous spectrum of electromagnetic waves and is expressed by a physical parameter - radio brightness temperature.

For solving geological problems: searching for underground water and hydrocarbon resources, the most informative methods are those that have the effect of “translucency” of the Earth’s crust, which is characterized by **Radio-Thermal Imaging Technologies (RTT)**.

RADIO-THERMAL IMAGING TECHNOLOGIES (RTT)

Geography of work performed using the RTT method:

RADIO-THERMAL IMAGING TECHNOLOGIES (RTT)

Brief physical foundations of Radio Thermal Imaging Technologies are presented in the article “**Basics of Thermal Imaging Technologies and their experience” (Stepchenko V.N., Bagryancev V.A., Rodnaya V.A. World of Geotechnics ISSN 2520-2987 “World of GEOTECHNIQUES” 1(61)'2019 UDC 550.836**) (**link**) , which shows the geophysical aspects of deciphering and interpreting space information with an illustration of the results of research in recent years, the connection of satellite images with the deep structure of the Earth. The technology is based on remote sensing using multi-temporal satellite images of thermal radiation from the Earth's electromagnetic spectrum.

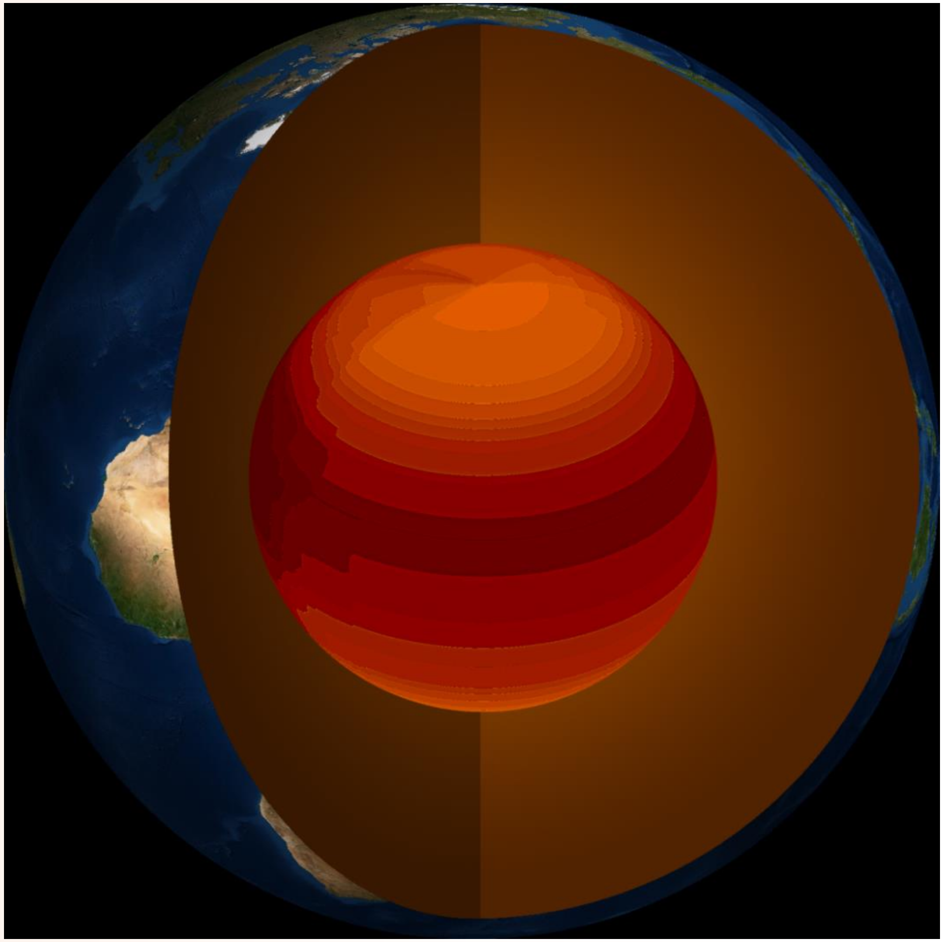
Information received from Earth satellites in the radio-thermal range of electromagnetic waves (Landsat 8 (OLI/TIRS), GCOM-W1 (AMSR-2), ASTERGDEM, Sentinel, etc.) is used as initial data.

Satellite images in the radio-thermal range are the initial information basis for geophysical introscopy in the presence of an appropriate processing tool (in our case, this is our own software), decoding and target interpretation.

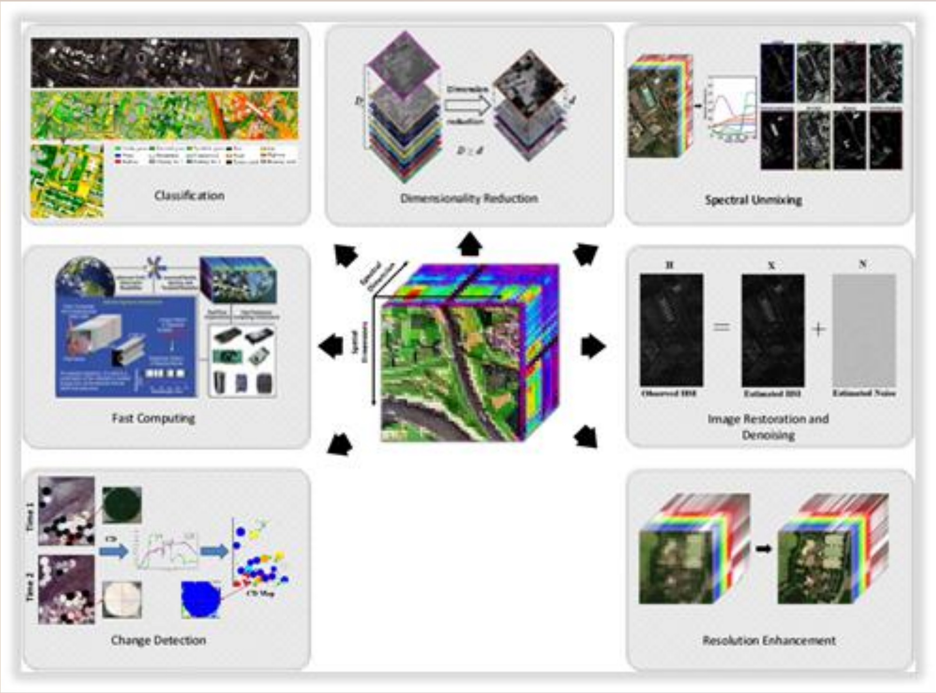
Processing of space images is carried out in the Software (through a training sample) with the construction of a 3D cube model.

RADIO-THERMAL IMAGING TECHNOLOGIES (RTT)

A significant difference between RTT lies in the algorithm for processing aerospace images: the contrast value of radio brightness temperatures [ΔT] and heat flux density are used to calculate and visualize all inhomogeneities of the Earth's crust, including faults of various ranks that control hydrocarbon deposits. In addition, the processing program allows you to enter an infinite number of points carrying initial a priori information about geology, increase the temperature sensitivity and resolution of the survey, and, as a result, obtain a more reliable and more accurate picture of the structure of the Earth in the process of interpretation.



Building a geothermal model of a 3D cube



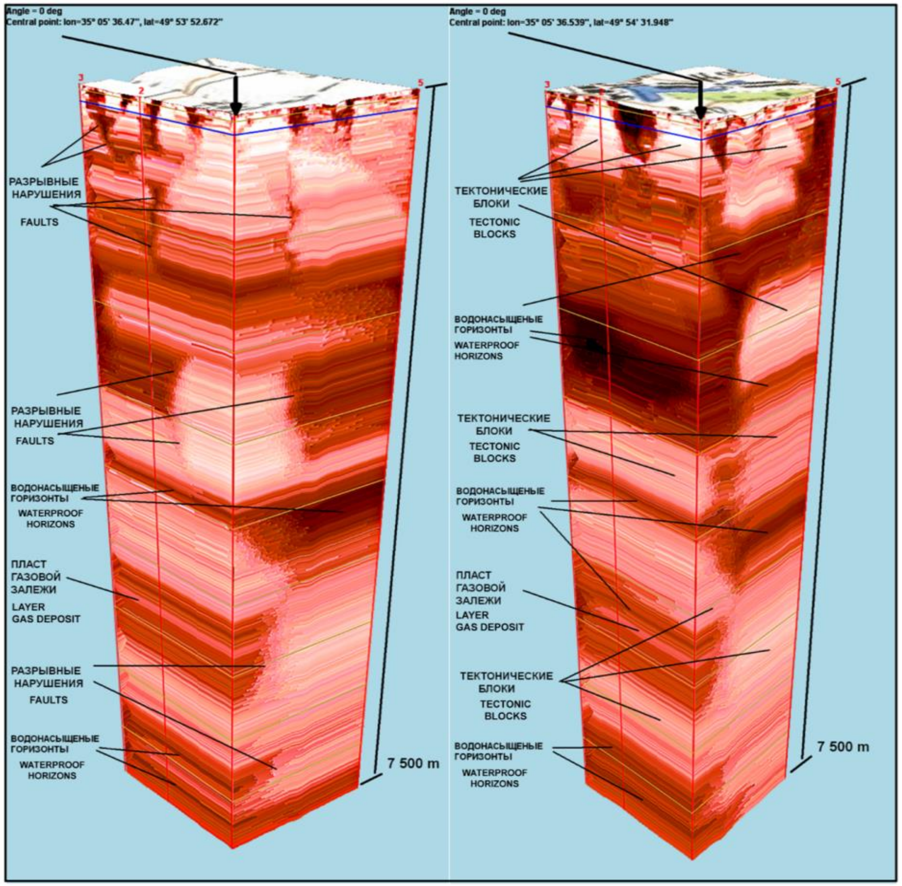
The construction of a geothermal model of a 3D cube is carried out through a combination of several microwave channels, then the information of the resulting vertical profiles of radio brightness temperature can be calculated. One of the elements of constructing a geothermal 3D cube is the use of technologies to increase temperature sensitivity at each point of the cube (pixel). For example, the generalization method.

By applying decoding elements to a digitally processed integral thermal satellite image of the surface, or rather, to its endogenous component, cleared of landscape and man-made influences, we obtain layer-by-layer geothermal scenes that make up a volumetric geothermal 3D cube.

Building a geothermal model of a 3D cube

ОБЪЕМНЫЕ ВЕРТИКАЛЬНЫЕ РАЗРЕЗЫ
построены по данным геотермического 3D куба

VOLUME VERTICAL CUTS
built according to the geothermal 3d cube



В основе аксонометрических проекций лежат квадраты [основой может быть плоская фигура любой геометрической формы], вырезающие фрагменты из тела 3D куба. Используя специализированные программные средства, полученые объемные разрезы, можно увеличивать и уменьшать, вращать и поворачивать под любым углом. Для целей наиболее наглядного представления деталей разреза.
Пример интерпретации объемных геотермических вертикальных разрезов с указанием блочных структур и разрывных нарушений, отображением водонасыщенных горизонтов и газовых залежей.

An example of constructing and interpreting volumetric vertical sections based on geothermal 3-D cube data

Optimal scales for constructing 3D models. Possibility of retrieving information from a 3D cube model

Using the RTT method and the capabilities of satellite radio-thermal imaging data, you can create 3D models of the Earth or other planets on scales from M1:50,000,000 to M1:10,000. Depends on the globalization or detailing of geological problems. In the near future, we can expect to receive materials using low-flying aircraft to build 3D models at scales M1:5,000 to M1:500.

Retrieving information at any point of a 3D cube is possible by constructing horizontal sections of any shape and size along the envelope of the terrain or by cutting (like a knife) with a given discrete distance between layers.

Receiving information at any point of a 3D cube is also possible by constructing vertical sections of any length with a horizontal pixel increment. Or by constructing 3D volumetric sections (perspective) of any shape in any direction with pixel increments horizontally and vertically. With any top background that is included in the database (map, image, relief, thematic map, etc.).

Discretion, accuracy, detail in area and depth

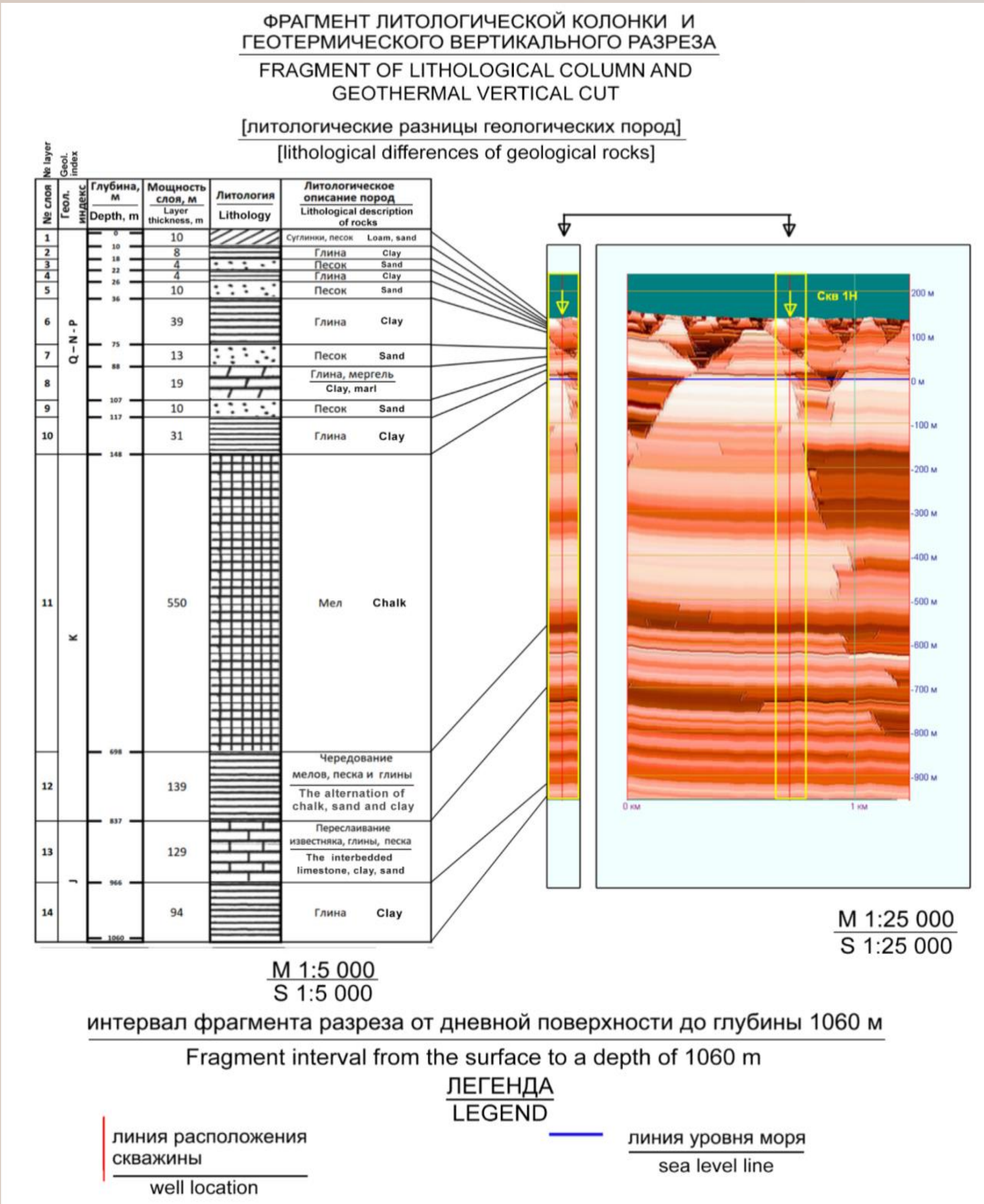
The detail of near-surface skin layers depends on the detail of thermal infrared (IR) images. For example, IR images of the Landsat-8 thematic cartographer are considered correct for work scales no larger than M 1:25,000 horizontally and no larger than M 1:10,000 vertically. IR images from the Aster thematic cartograph can be considered correct for work scales no larger than M 1:10,000 - M 1:5,000.

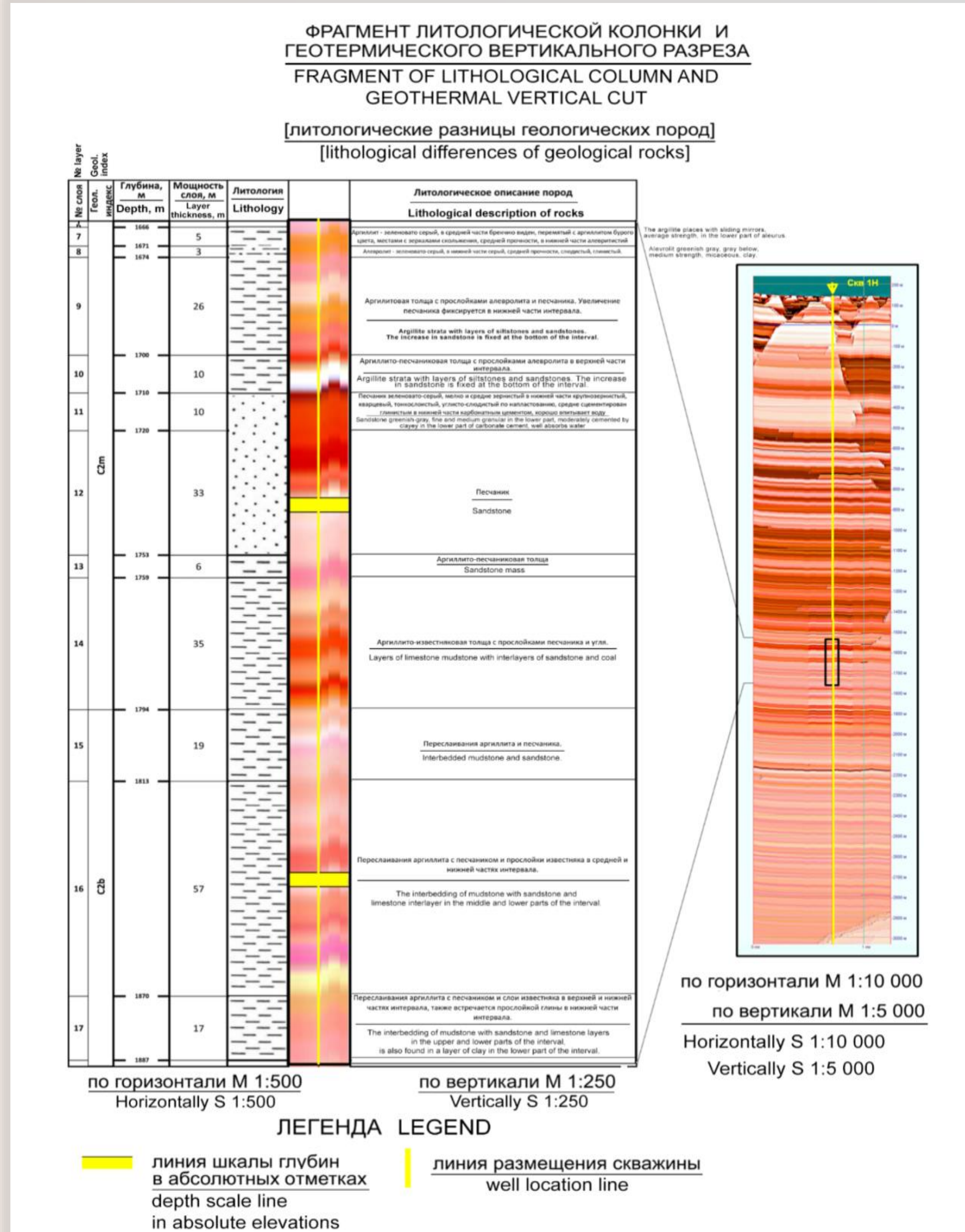
For these and larger scales, satellite radiometers can also be used: AVHRR, MODIS, AMSR, SSMI, WINDSAT, VIIRS, ATMS and others.

There are technologies for restoring image resolution: IR images can be realized on a scale of work 2-5 times more detailed (using technologies for restoring resolution and image detail). With depth, detail decreases. But it can also be restored using image restoration technologies. It is practically possible to refine images using Landsat and Aster materials down to 2.5 m and 1.25 m, respectively.

Examples of detailing the geological section on a vertical geothermal section are shown on **slide 12**, where lithological differences in rocks identified from drilling data are clearly highlighted in color and tone.

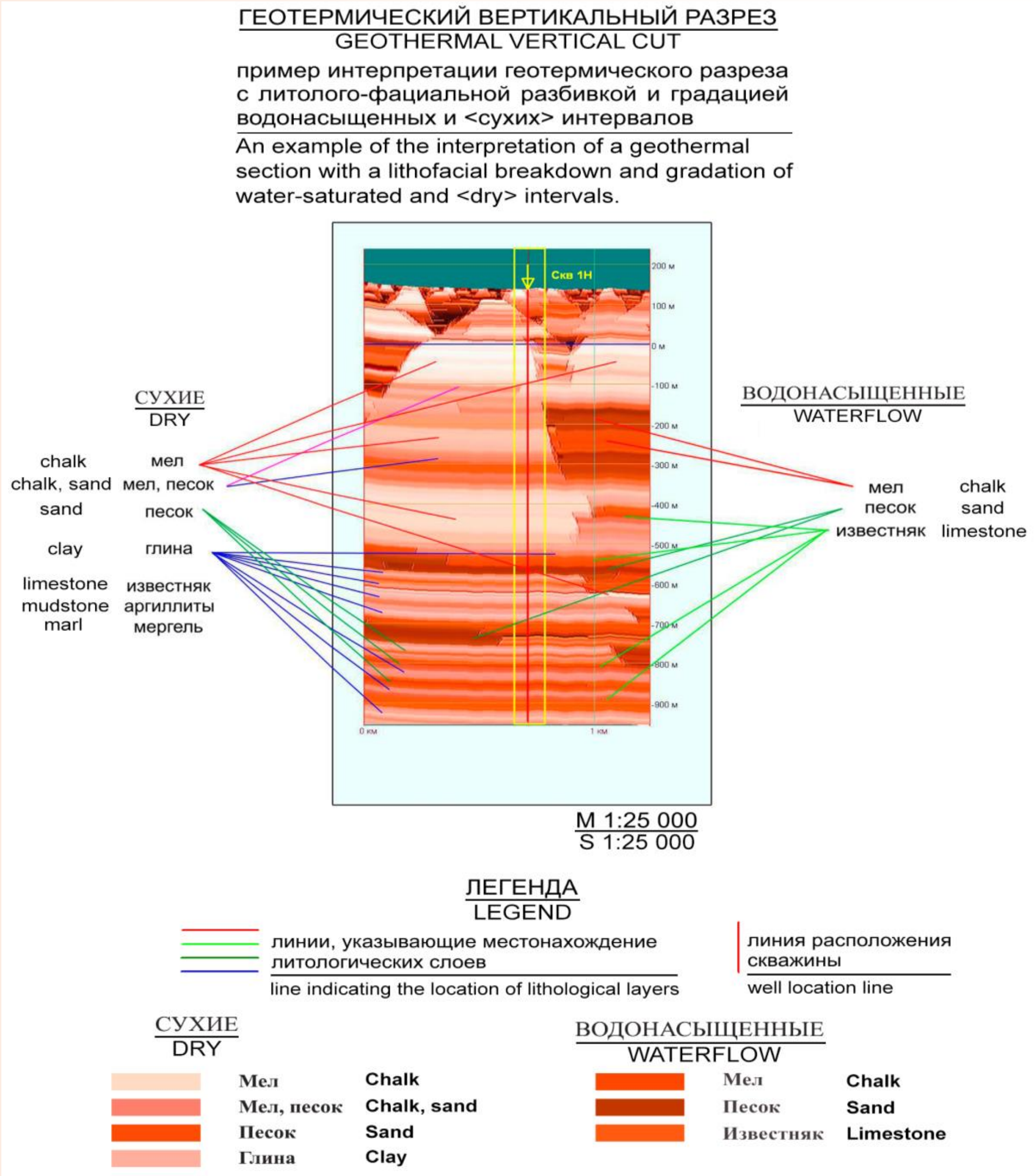
Identification of lithological intervals of a well section using RTT data

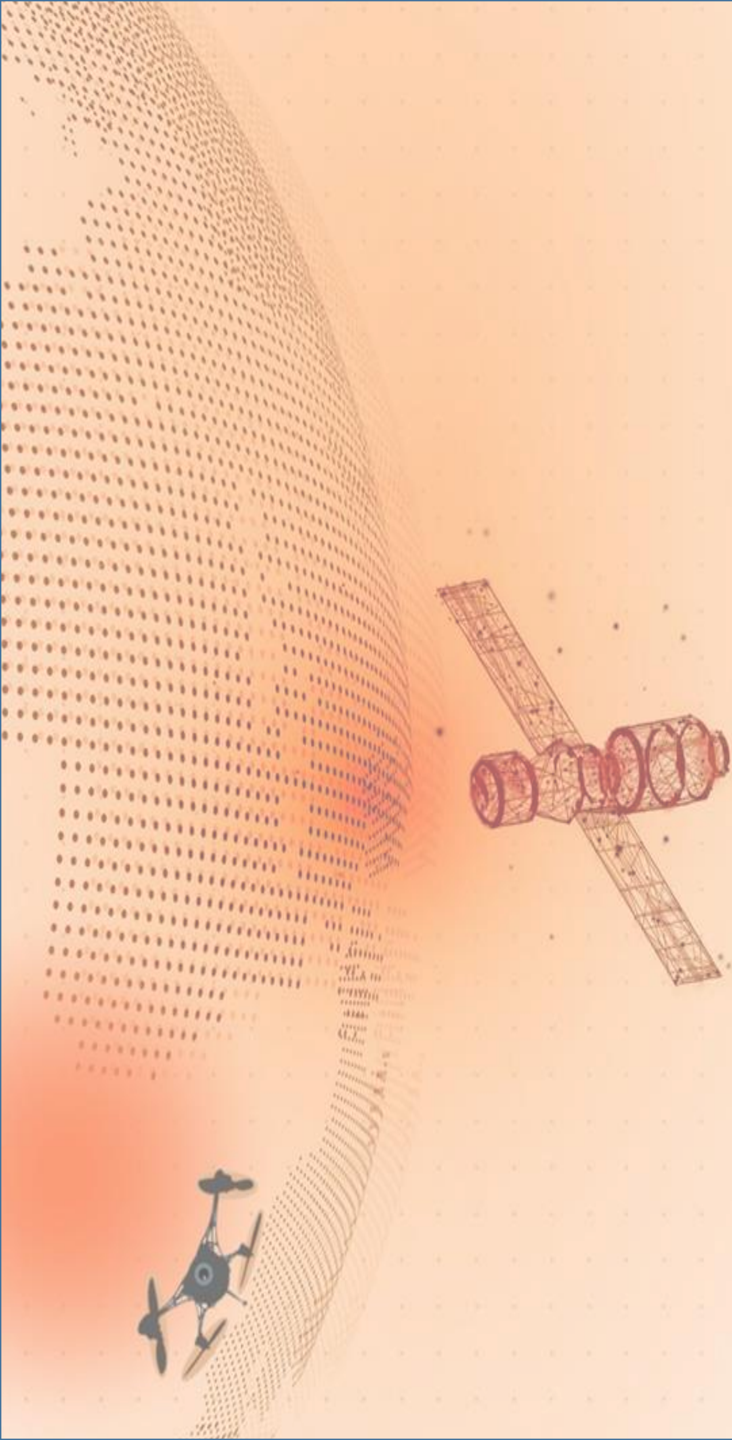




Identification of lithological intervals of a well section using RTT data

An example of identifying "dry" and water-saturated lithological intervals of the 1-Hc well section according to RTT data





2. SEARCHING AND MAPPING HYDROCARBON DEPOSITS

Model calibration

Calibration of the 3D cube model is carried out to clarify the position and depth of structural heterogeneities of the proposed hydrocarbon deposit, by comparison with a reference object, for example, an explored deposit. For these purposes, information from existing geological exploration wells or existing production wells (well passport) is used as a reference object.

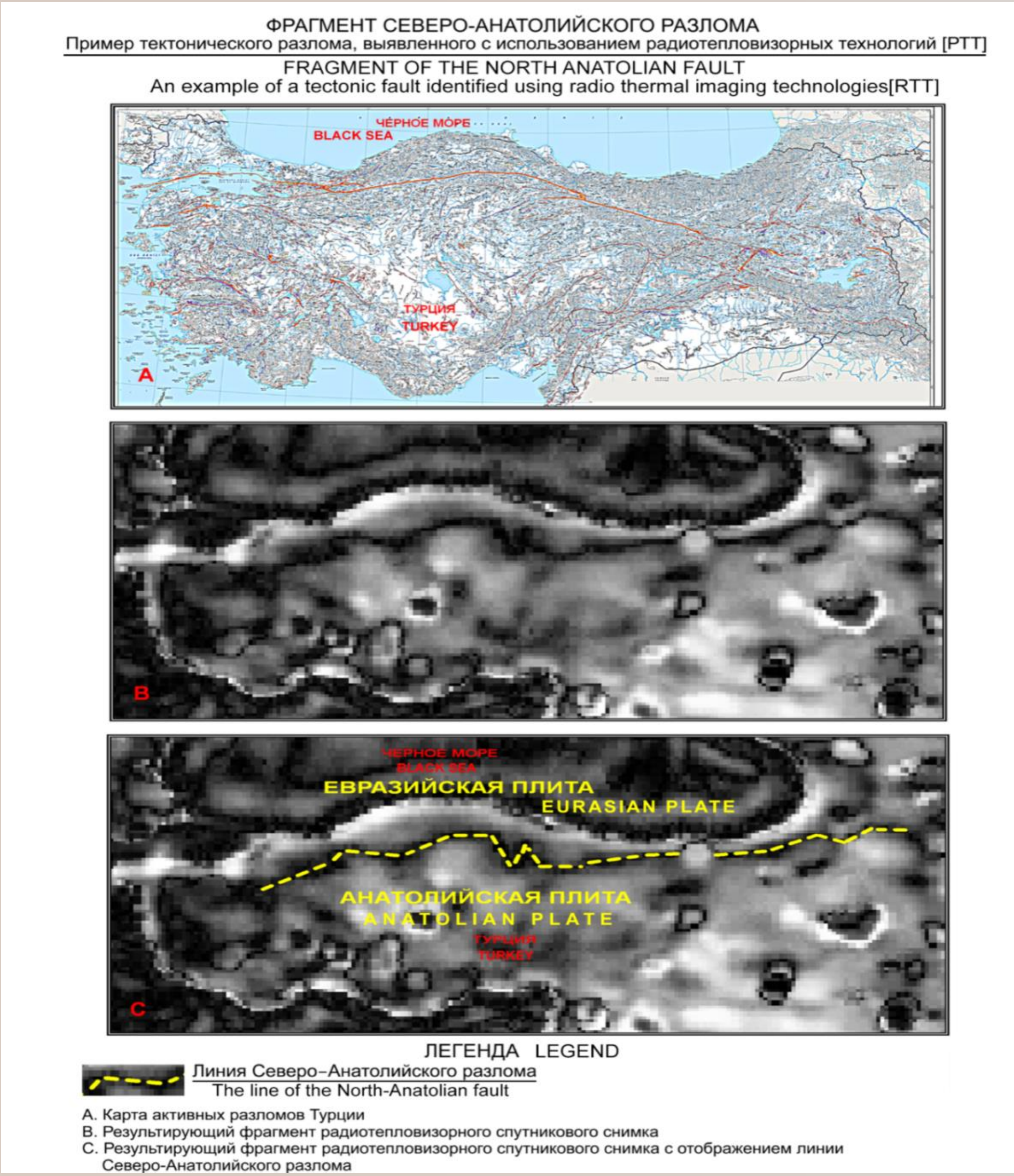
Model calibration is performed for each search object, depending on the mineral and geological and tectonic conditions of the region.

For correlation, a graph of the dependence of the nomenclature of a layer (multiple layers) on depth is used. Data obtained empirically during calibration. The useful layer is identified based on unambiguous (protected) geological materials.

It should be noted: the more reliable geological material is used for the study area (sampling), the more accurate the calibration, and as a result, the geothermal cube maximally reflects the geological structure of the study area and the spatial position of the useful deposit.

Our database contains information on more than 100 test sites - the most famous oil and gas fields, examples of successful operation of which are confirmed by production data. In the absence of data from exploratory drilling, production wells or other geological studies for a given area, the method of analogies is used.

Faults identified by the RTT method

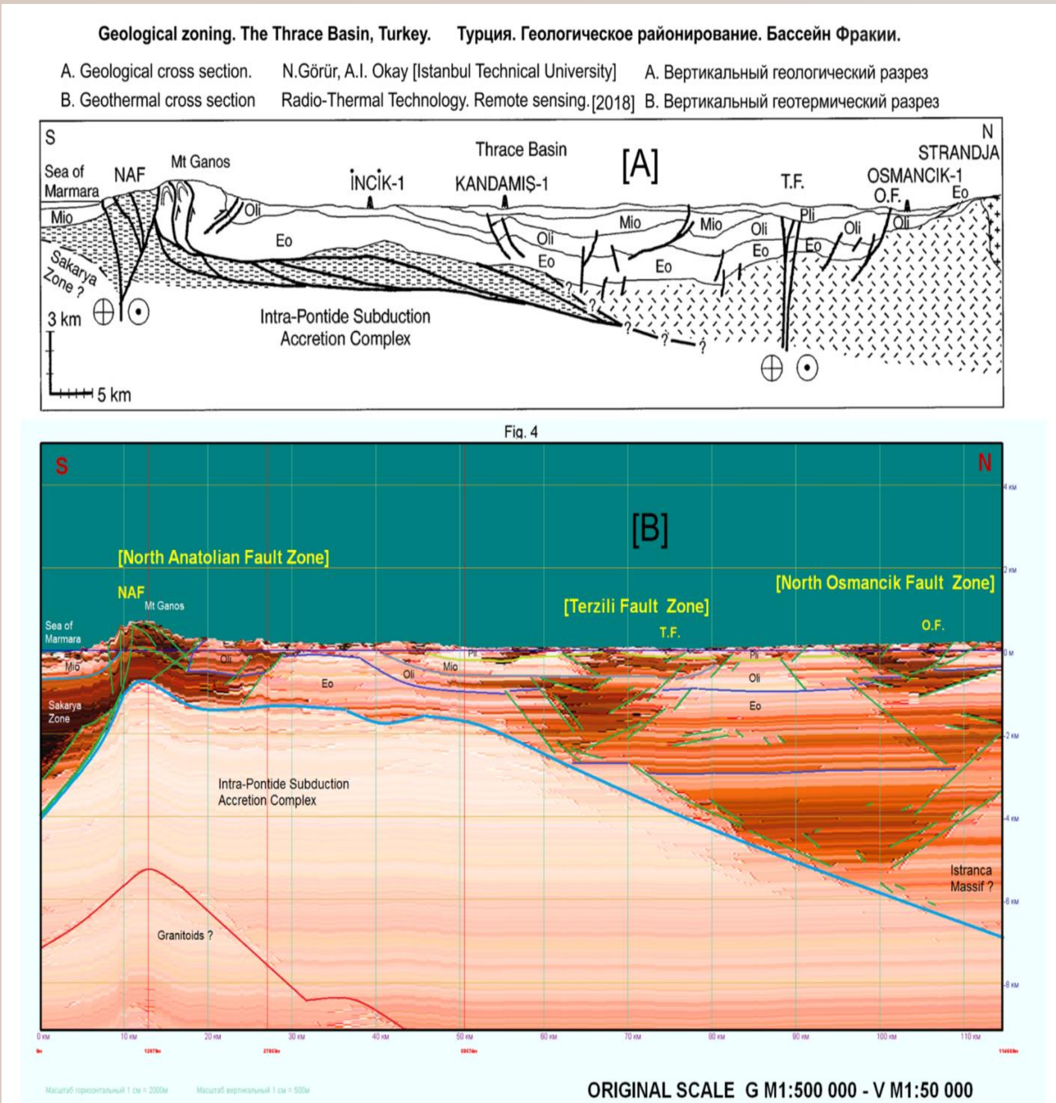


One of the main advantages of the method is the ability to map and determine the spatial position of zones of tectonic faults and faults, which create the block nature of the structure of the Earth's crust, control hydrocarbon deposits (HC), act as hydrocarbon recharge channels and influence the formation of highly productive fractured reservoirs.

Faults are a striking example of geothermal field inhomogeneities. The algorithm of the Space Image Processing Software provides for the block structure of the earth's crust.

Blocks of any order are separated from each other by discontinuities.

Faults identified by the RTT method



Comparative geological [**A**] and geothermal [**B**] sections showing structural connections between the Thrace basin and surrounding tectonic provinces

Criteria for identifying hydrocarbon traps

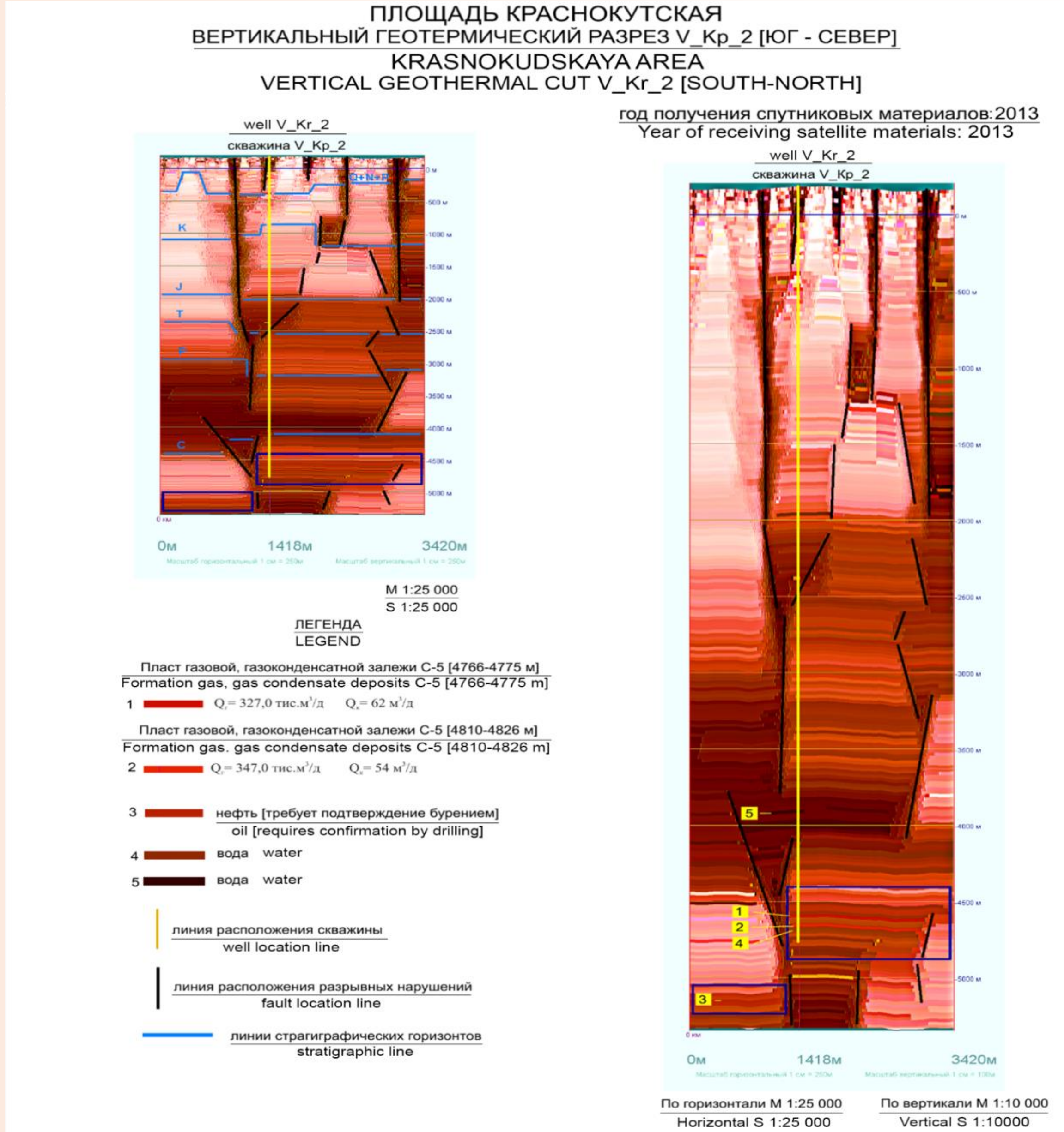
Traps containing hydrocarbons on vertical geothermal sections (**slide 19**) can be recognized as horizontal layers similar in color scale from pink to red photo tone (light-gas, dark-oil). Based on the degree of contrast (pale medium or bright), hydrocarbon formations can be characterized as (weak, medium or highly saturated). At the same time, lithological differences in rocks can be recognized using various methods of spectral analysis by fragmenting the part of the section of interest. Layers that do not contain hydrocarbons, but are filled with water, have color shades: from light brown to brown and black. Water quality can also be recognized using spectral analysis methods. Each trap in the upper and lower parts is limited by impermeable rocks in the form of a pack of layers ("caps").

Below the trap, as a rule, there are water-saturated layers. The trap is limited on the western part by an "active" fault, which performs the function of recharge (migration) from the lower layers to the upper ones, and depends on the processes occurring in the Earth's crust and mantle, or in the opposite direction, under the influence of gravitational forces (absorption or funnel effect). There is a limiting fault on the eastern side.

A trap containing hydrocarbons on horizontal geothermal sections (**slide 19, 20**) can be recognized as the upper and lower parts of a close plan location.

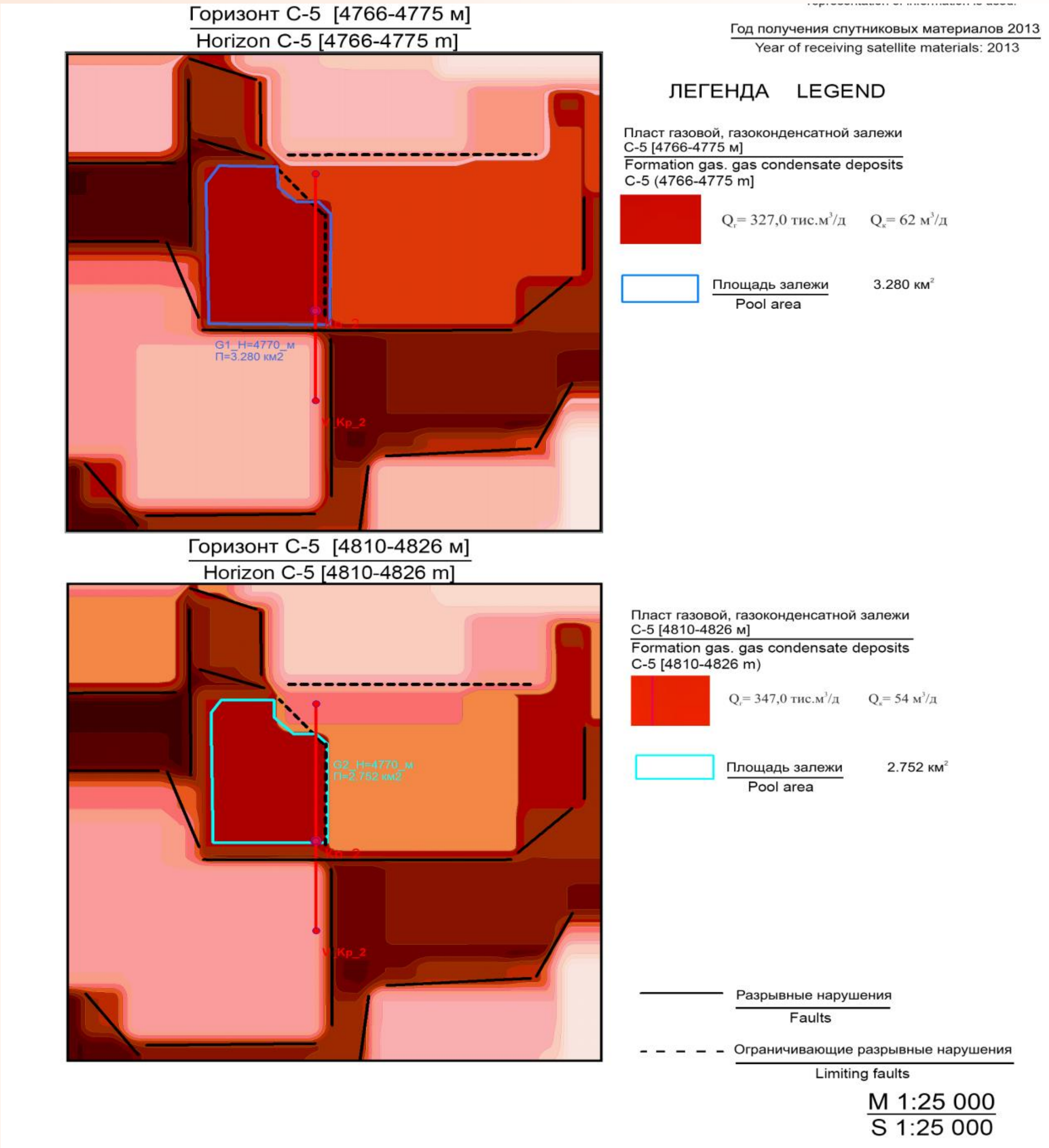
Criteria for identifying hydrocarbon traps

Vertical geothermal section V_Kr_2. Krasnokutskaya area of the Dnieper-Donetsk depression (DDV)



Criteria for identifying hydrocarbon traps

Horizontal geothermal sections (slices) at depths of 4766-4775m and 4810-4826m. Krasnokutskaya area of the Dnieper-Donetsk depression (DDV)



Criteria for identifying hydrocarbon traps

Differences between waterlogged areas and hydrocarbon-containing areas. Benchmark, PTT indicator

Classically, water-flooded areas on radio-thermal imaging images look much darker (“hotter”) than gas-oil-saturated areas and are located within orographic structures (slide 19, 20). Water, oil, and gas screen (retain) heat coming from the depths of the Earth. Therefore, under equal physical conditions, water is always “hotter” than oil and gas, because The emissivity of water is greater.

The calibrator (benchmark, indicator), against which the radio brightness temperature is measured, in radiometric receivers is a black body simulator (emissivity close to 1), cooled to -2730 C [00 K]. Therefore, the minimum values of the measured heat (with 16 bits of information, will be maximum = 65535 value units) will be white (“cold”), the maximum – black (minimum = 0 value units) – “hot”.

For reference. *Characteristics of an absolutely black body: a physical body that, at any temperature, absorbs all electromagnetic radiation incident on it in all frequency ranges and polarizations of the spectra. The radiation spectrum of a completely black body is determined only by its temperature*

Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

The studies were carried out within a given area on a scale of 1: 25,000. The depth of the study was up to a horizon of -4500 m, in absolute elevations.

To achieve this goal, specific tasks were solved, the main ones being the following :

- Study of the geological and tectonic conditions of the region and the research site based on materials from research in previous years;
- Selection and acquisition of space scenes (series of images) using different (detail and depth of research) space satellites in the study area;
- Converting a series of satellite images to increase their resolution and constructing satellite orthophotos at a scale of 1:25,000;
- Model calibration. Creation of three-dimensional cubes (volumetric radio-thermal image of the Earth's interior) of the study area of a given scale. Modification of a geothermal image of a 3-D cube according to the absolute terrain;
- Construction of vertical sections and horizontal sections, using the corresponding sections of the 3-D cube, in order to identify structural geological anomalies corresponding to hydrocarbon deposits;
- Comparison of anomalies identified at the site with anomalies identified at the test well

1. Deciphering, interpreting materials and identifying the results obtained with test structures of hydrocarbon deposits.

Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

Calibration of the 3D cube model was carried out to clarify the position and depth of structural heterogeneities of the proposed oil and gas deposit, by comparison with a reference object - an explored deposit.

For these purposes, information from existing geological well 1 was used as a reference object: date of drilling, geographic coordinates, depth of deposit(s) at different horizons or aquifers, characteristics of hydrocarbons (oil, gas), debit, date of debit measurement, stratigraphy.

To process satellite images, a proprietary software package was used, and algorithms with a training set were used.

When constructing the Project, as well as when providing coordinates of fictitious wells, the WGS-84 coordinate system (EPSG:4326) is used.

Volumetric images (geothermal cube), consisting of successive scenes of thermal contrast, contain information about all heterogeneities of the geoenvironment: tectonic faults, blocks, useful structures.

To interpret geothermal sections, available materials on geology, stratigraphy, and oil and gas potential of the study area were used.

Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

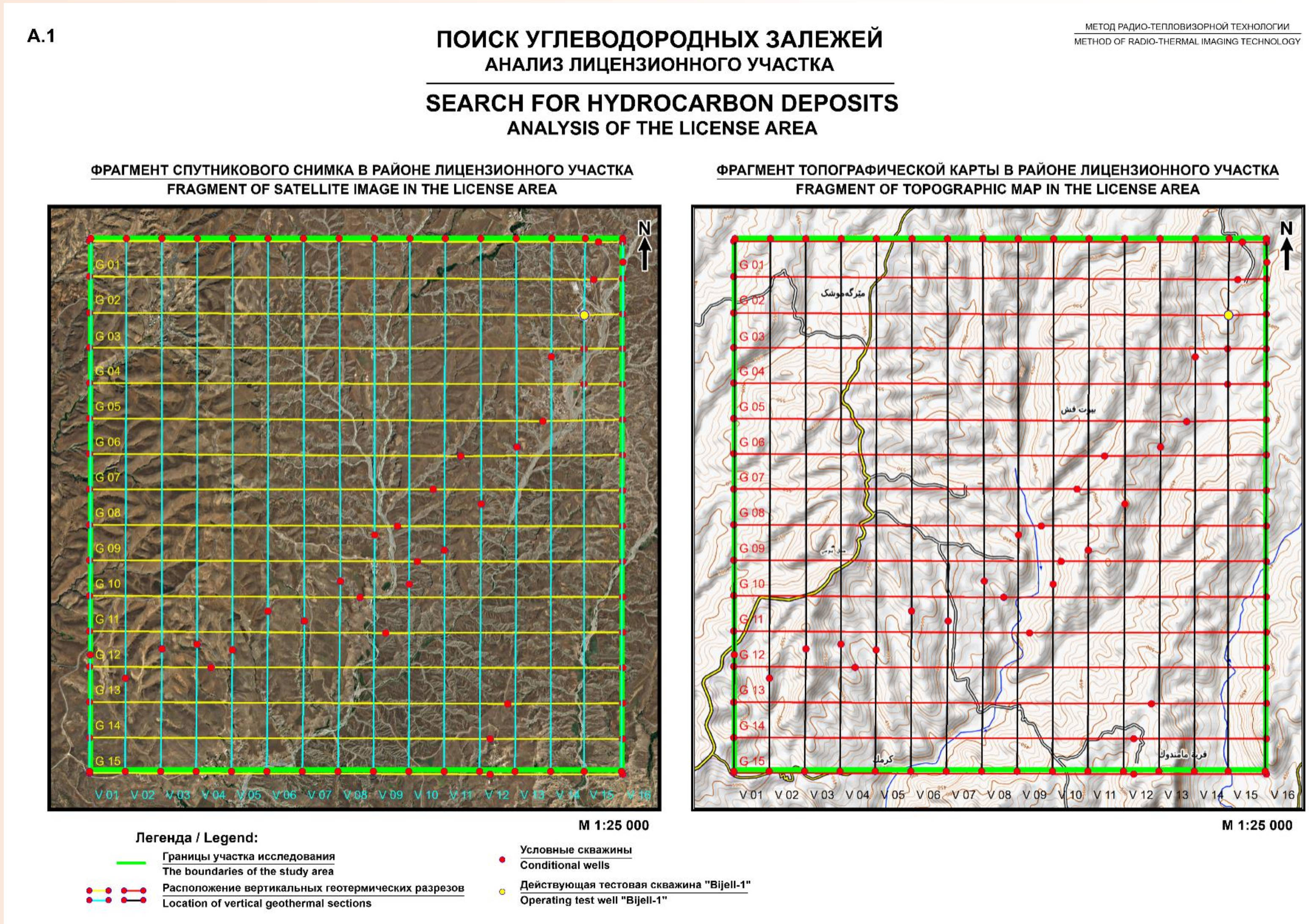
Based on the results of studies of the site on a scale of 1:25,000, based on a 3-D cube, 32 vertical geothermal sections were built to a depth of -4500 m (in absolute elevations) with a step of 500 m. Horizontal scale 1:25,000, vertical 1:10,000 Section lines with the index G - W-E directions, cut lines with the index V - S-N directions (**slide 25**). In addition, 15 horizontal sections (slices) were built across the area along the horizons where hydrocarbon deposits were discovered from -2940 m to -3560 m (in absolute elevations) and projections of horizontal sections onto a satellite image and a topographic map.

In the Zagros region in the study area, heterogeneities are associated with faults in rock blocks, deep faults and fault zones controlling hydrocarbon deposits and the surrounding sedimentary rocks. The dominant role of faults in the formation of hydrocarbon deposits is noted.

The satellite image (**slide 26**) shows the main structures of the study area: a mantle fault (yellow line) running parallel to the river bed, interpreted as a thrust (?) and two anticlinal structures (red lines, corresponds to the geological map), in the axial part of which Deep faults can also be traced.

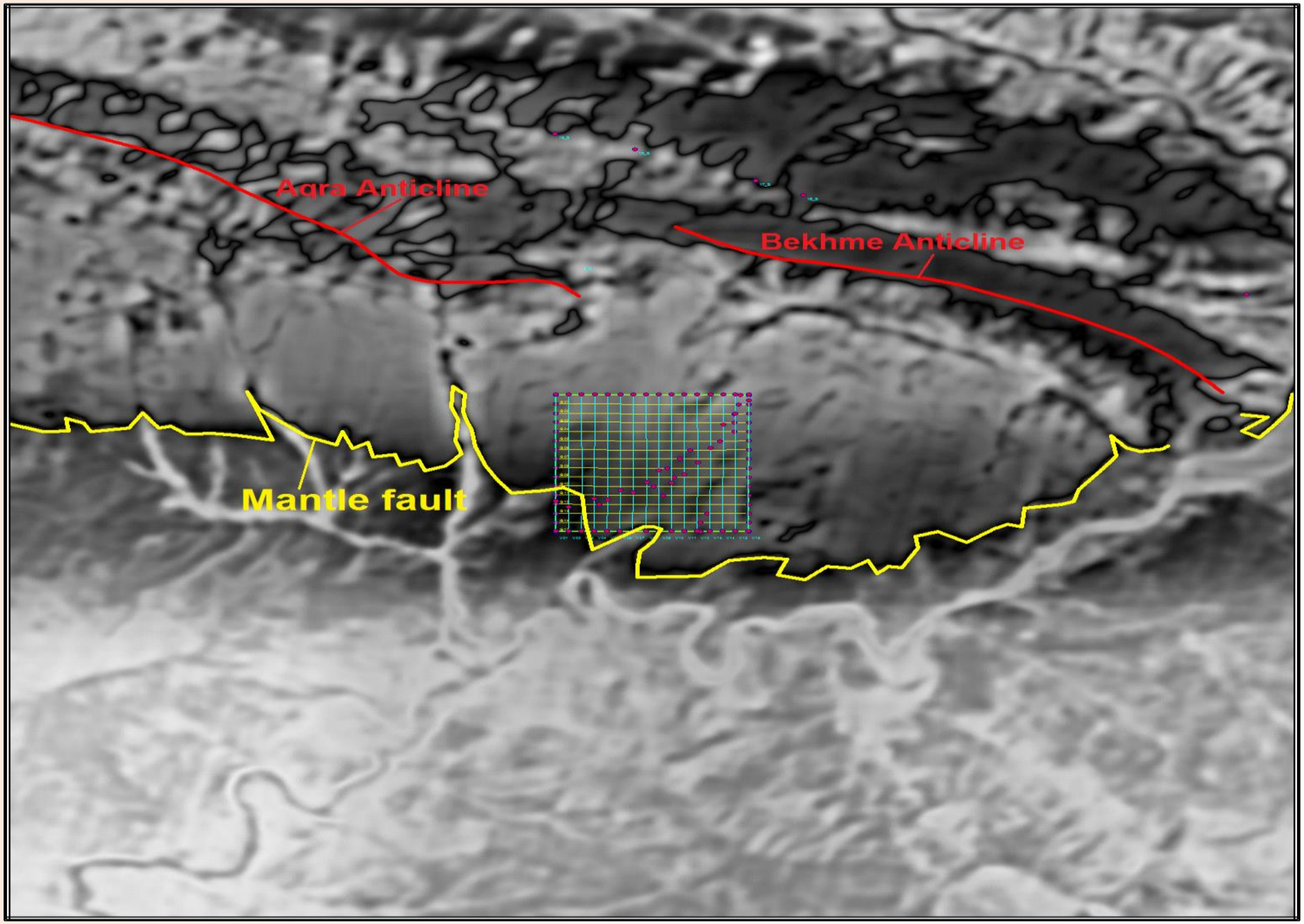
Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

Lines of geothermal sections on a satellite image and on a topographic map



Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

Mantle fault (yellow lines) and major Zagros anticlines (red lines) in a satellite image of the study area



Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

On vertical geothermal sections (**slide 28, 29**) to a horizon of -4500 m, geological massifs of host sedimentary rocks, mainly of marine origin, are shown in light tones; fault destructive zones are shown in shades of brown. Anomalies corresponding to hydrocarbon traps are recognized as horizontal layers similar in color scale from pink to red photo tone (light - gas, dark - oil). Based on the degree of contrast (pale medium or bright), hydrocarbon formations can be characterized as (weakly, moderately or highly saturated), confined to carbonate fractured reservoir rocks.

An example of interpretation of the identified heterogeneities of the geological section is illustrated by vertical geothermal sections G 03 (**slide 28**), V 15 (**slide 29**), passing through the known well 1, according to which the model was calibrated, and the geological drill column was used to interpret the geothermal sections.

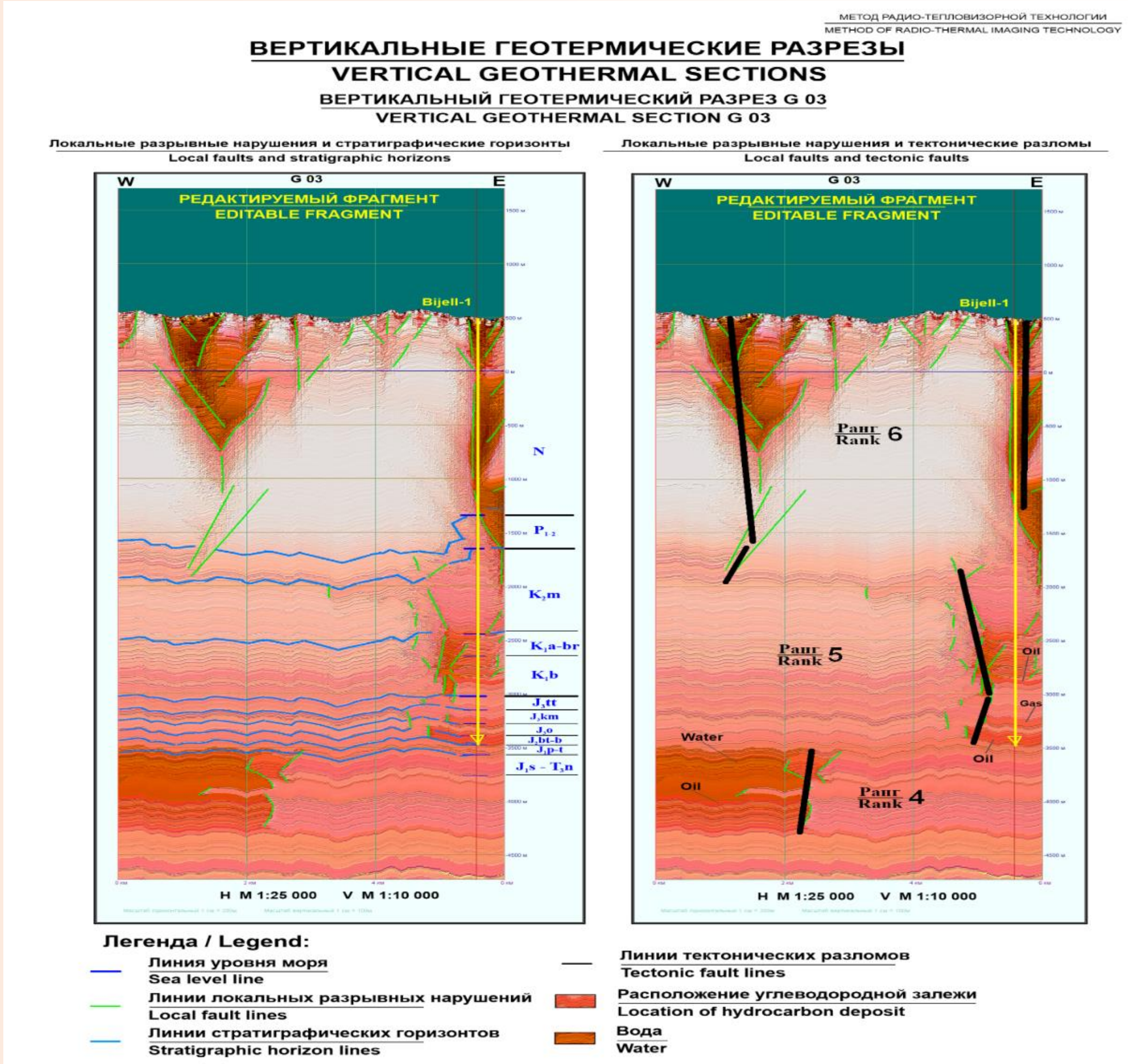
In the sedimentary rock mass to a depth of -4500 m, at absolute levels, 3 blocks of oil and gas traps of varying thickness and potential were identified:

Block **A** – Cretaceous, Block **B** – Jurassic, Block **C** – Triassic.

Slide 30 shows the recommended well to drill.

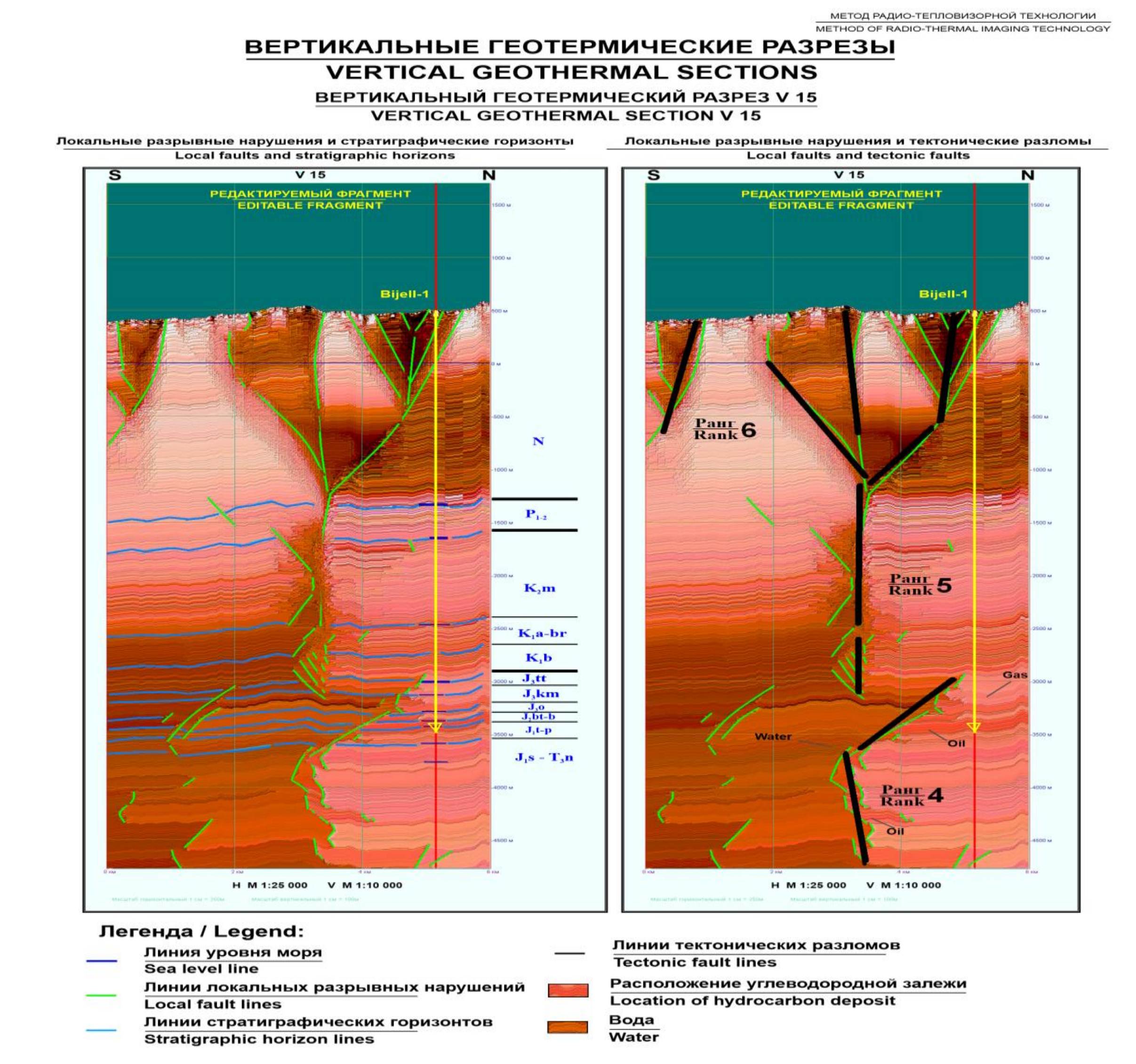
Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

Vertical geothermal section G 03 highlighting stratigraphic units (left), gedynamic blocks of ranks 4, 5, 6 (according to I.M. Gubkin) and hydrocarbon deposits (right)



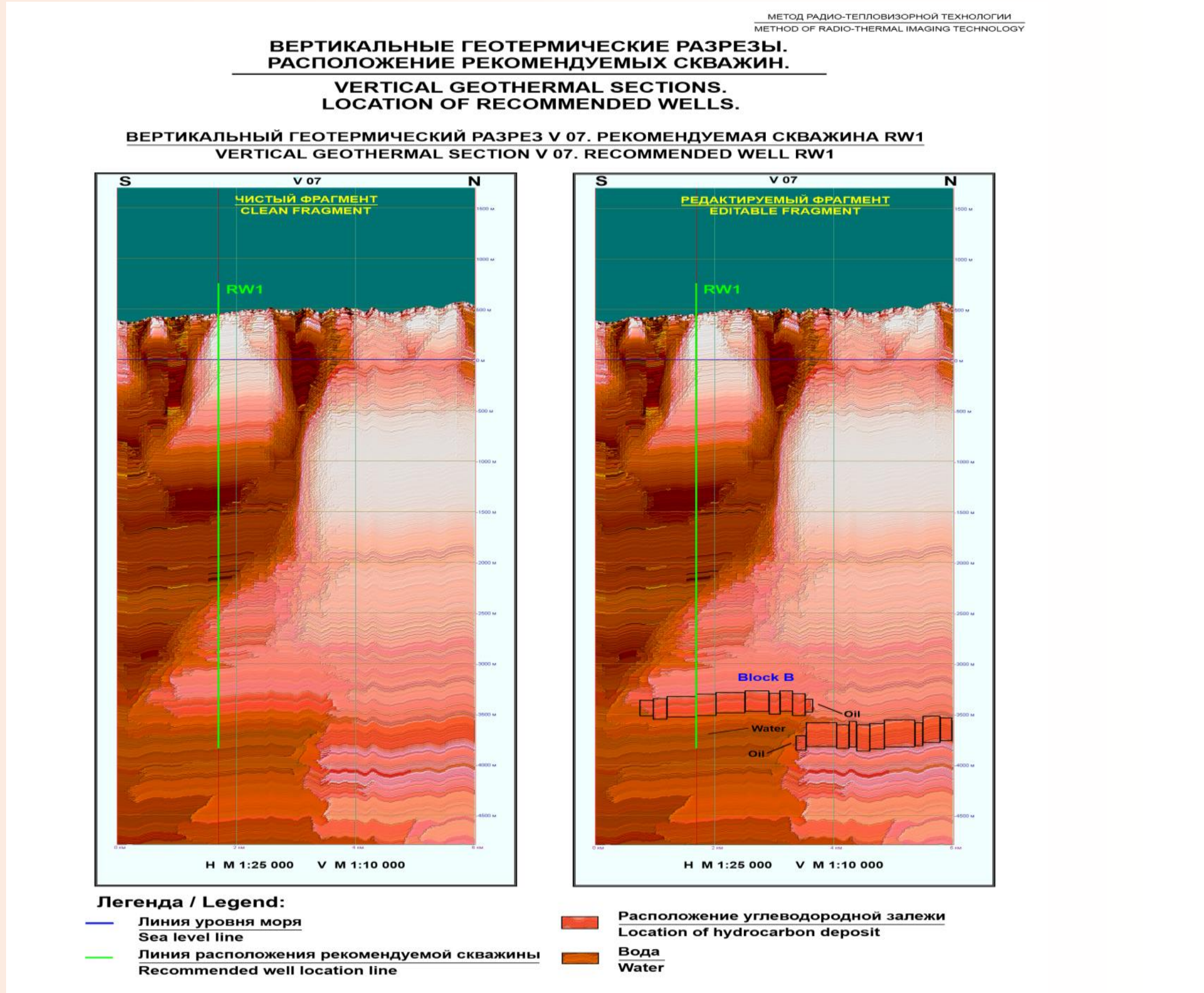
Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

Vertical geothermal section V 15 highlighting stratigraphic units (left), geodynamic blocks of ranks 4, 5, 6 and hydrocarbon deposits (right)



Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

Recommended exploration well RW 1 for drilling for hydrocarbons in the area of the structure on the vertical geothermal section V 07



Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

Block **B** is the most promising for the study area, which is confirmed by testing of well 1.

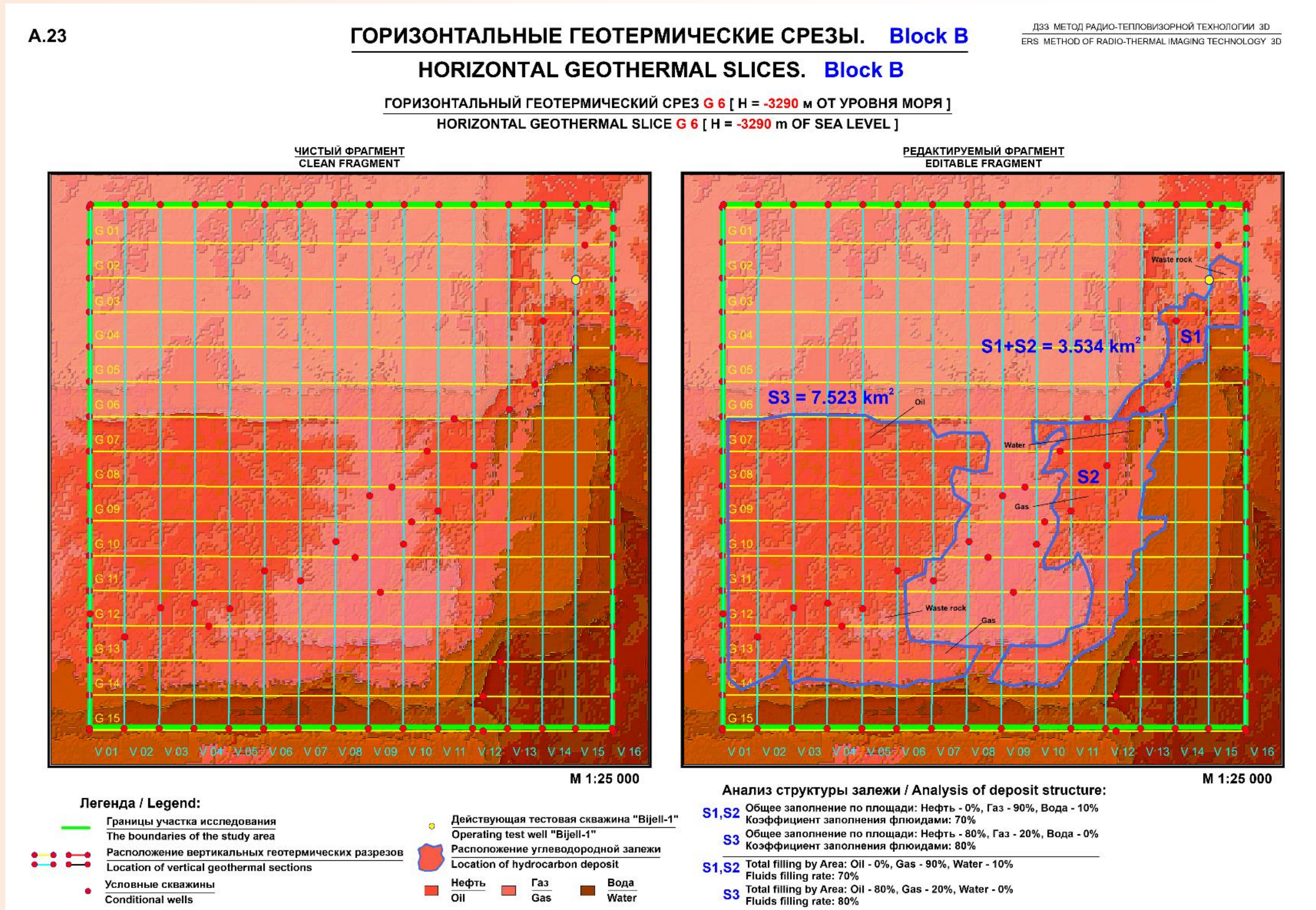
Based on the Jurassic horizons of Block **B**, horizontal sections (slices) were constructed every 30 m in the depth range -2940 ÷ -3560, presented on **slide 32**. On horizontal sections, an analysis of the structure of the deposit was performed, an assessment of the total filling with hydrocarbons and water by area, the areas for each deposit were calculated . Fluid filling is 70-95%.

Anomalies identified as oil and gas containing horizons of Jurassic age are identified in Block **B** on all vertical geothermal sections. Block **B** consists of two types of deposits: upper gas and lower oil. The general depth range of Block **B** is from the horizon -2940 m to the horizon -3570 m. Gas is present in rocks from the horizon -2940 m to the horizon -3440 m, with a thickness of up to 100 m, oil - -3260 ÷ -3570 m, with a thickness of 50 -250 m. The host rocks of the reservoir are mainly limestones, dolomites, and black shales. Below are horizons filled with water. The apparent length of Block **B** on geothermal sections is 1-5 km.

To assess the distribution of hydrocarbon reservoirs over the area, projections of hydrocarbon deposits were constructed on a topographic map of the area (**slide 33**).

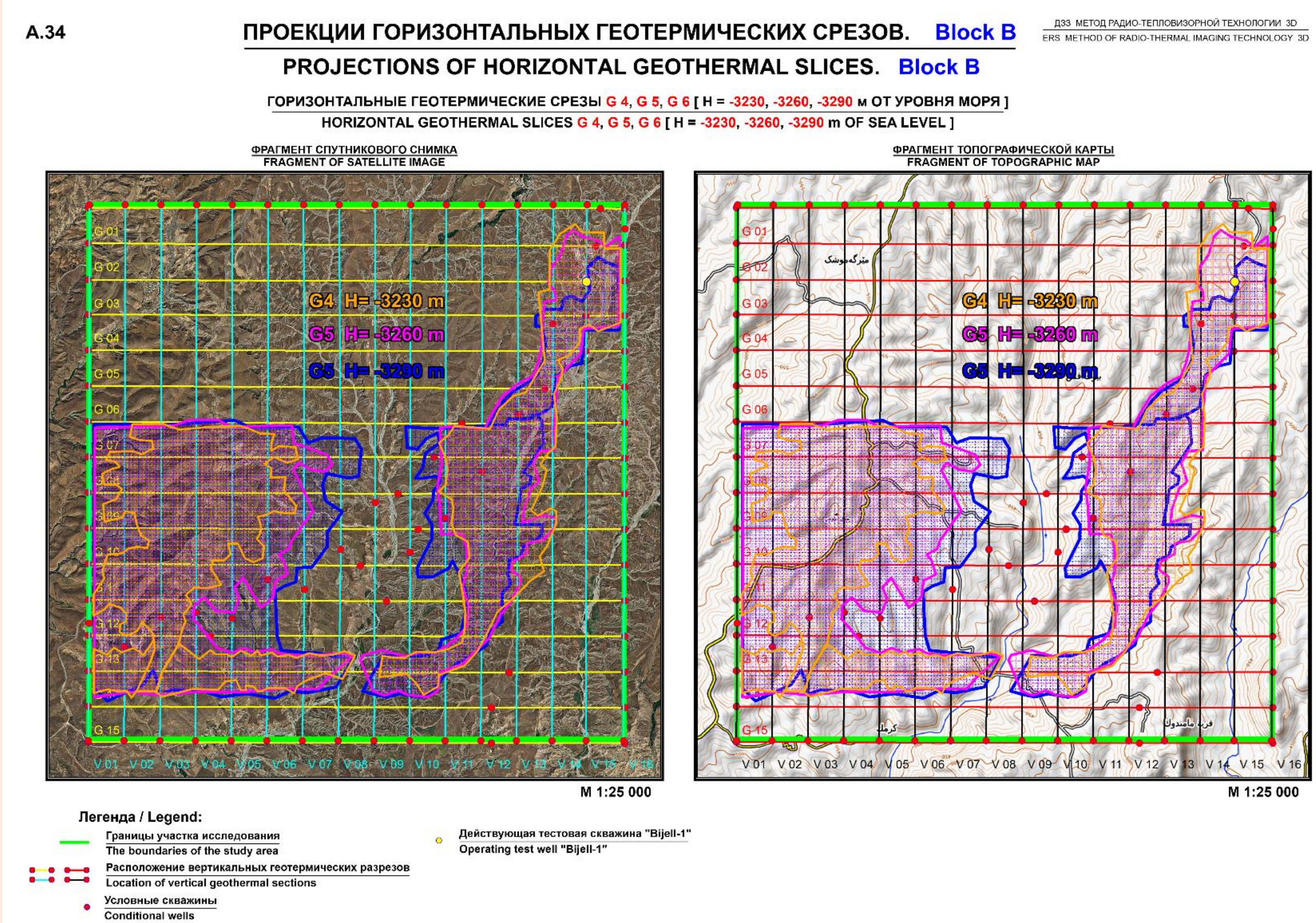
Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

Horizontal geothermal section at a depth of -3290 m with identification and analysis of oil and gas containing structures. **Block B**.



Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

Projections of horizontal geothermal sections on a satellite image and on a topographic map. **Block B**.



Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

Preliminary resource assessment

Using vertical geothermal sections built over an area on a scale of 1:25,000, we made a predictive assessment of the expected results for a given area of a hydrocarbon field.

For calculations, blocks within a localized anomaly in the Jurassic deposits of Block B were identified on all vertical sections.

The areas of delineated deposits are shown on horizontal sections and projections of the deposit onto a topographic map; calculations for blocks are given on each vertical section.

The total volume of hydrocarbon filling in the field section, taking into account the accepted coefficients, is 72,269.615 thou m3 of oil and 49,154.638 thou m3 of gas.

The total amount of oil in the field area is 62,000 thou tons.

The degree of reliability of hydrocarbon resource assessment depends on the availability of initial data on actual wells in the area of the study area

Using the Radio-Thermal Imaging Technology method to predict oil and gas content using the example of a site in the Kurdish Autonomous Region of Iraq

CONCLUSIONS

The main goals of the Research Program for the structure of the KAR for the spatial determination of hydrocarbon deposits by Earth remote sensing (ERS) using radio-thermal imaging (RTT) technology in the Kurdish Autonomous Region of Iraq have been fulfilled.

The study area has high prospects in terms of oil and gas saturation. Hydrocarbon reservoirs belong to the Triassic, Jurassic and Cretaceous geological periods.

In the sedimentary rock mass to a depth of -4500 m, at absolute levels, 3 blocks of oil and gas traps of varying thickness and potential are identified: Block **A** - Chalk, Block **B** - Jura, Block **C** - Triassic.

Block **B** (Jura) is the most promising for the study area, which is confirmed by testing of well 1.

The predicted zones for the placement of oil and gas traps have been identified and delineated, taking into account the geological structure and the corresponding formation. Fault zones that control hydrocarbon deposits are shown.

The coordinates of the optimal location of the recommended 3 exploration wells have been determined.

For the reservoirs of Block **B** (Jura), the contingent reserves of hydrocarbons were calculated for a fragment of the field.

Recommendations for searching for oil and gas

As demonstrated above, volumetric images (geothermal cubes), consisting of successive scenes of a gradient of radio brightness temperature (or thermal contrast) contain information about the deep structure of the geoenvironment (tectonic faults, blocks, structures, lithological contacts), as well as the location of hydrocarbon traps, aquifers horizons, which are the main object of search, which allows us to recommend the RTT method for spatial determination of oil and gas reservoirs.

The RTT remote sensing method is environmentally friendly. Allows you to obtain information about the structure of the Earth in hard-to-reach places for ground-based geophysical methods.

Center of Aerospace Technologies ltd

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