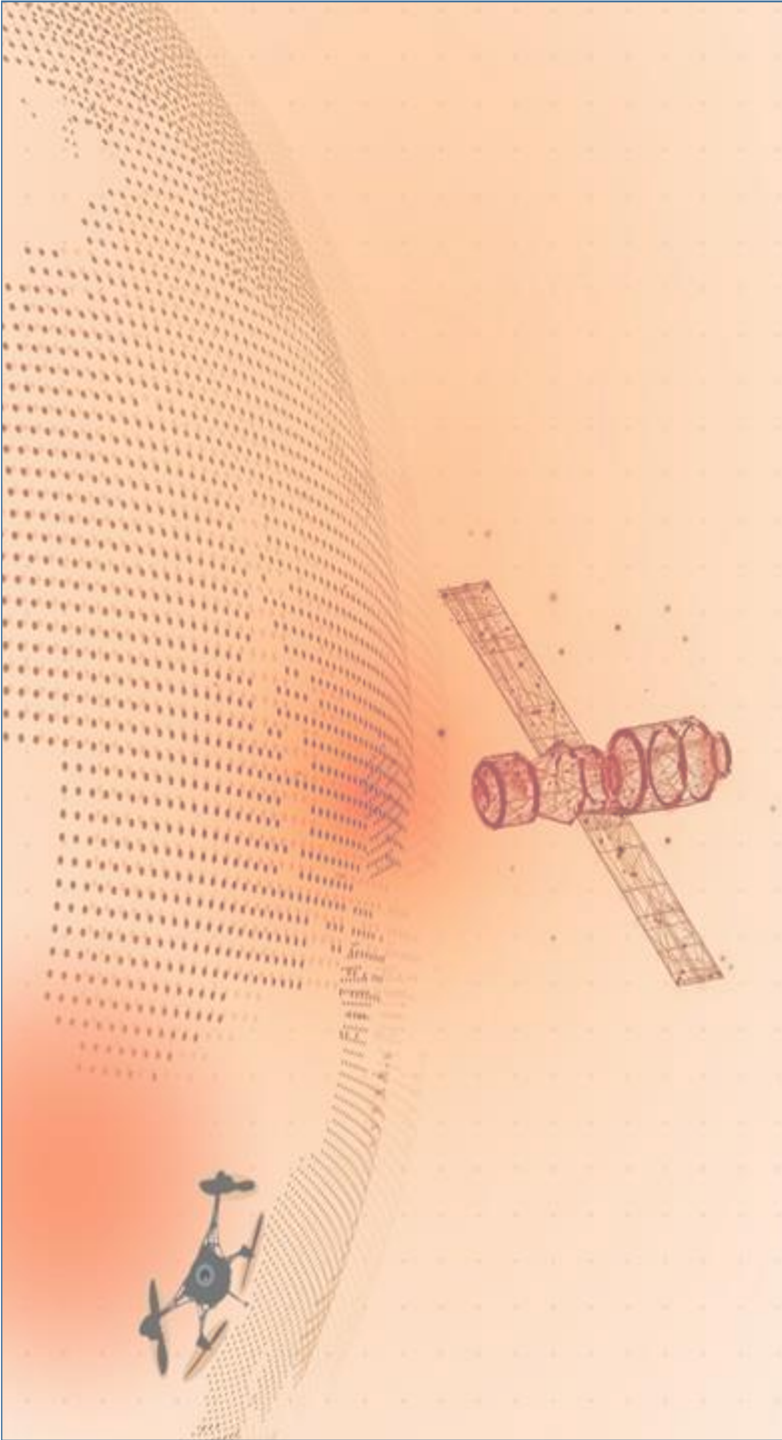


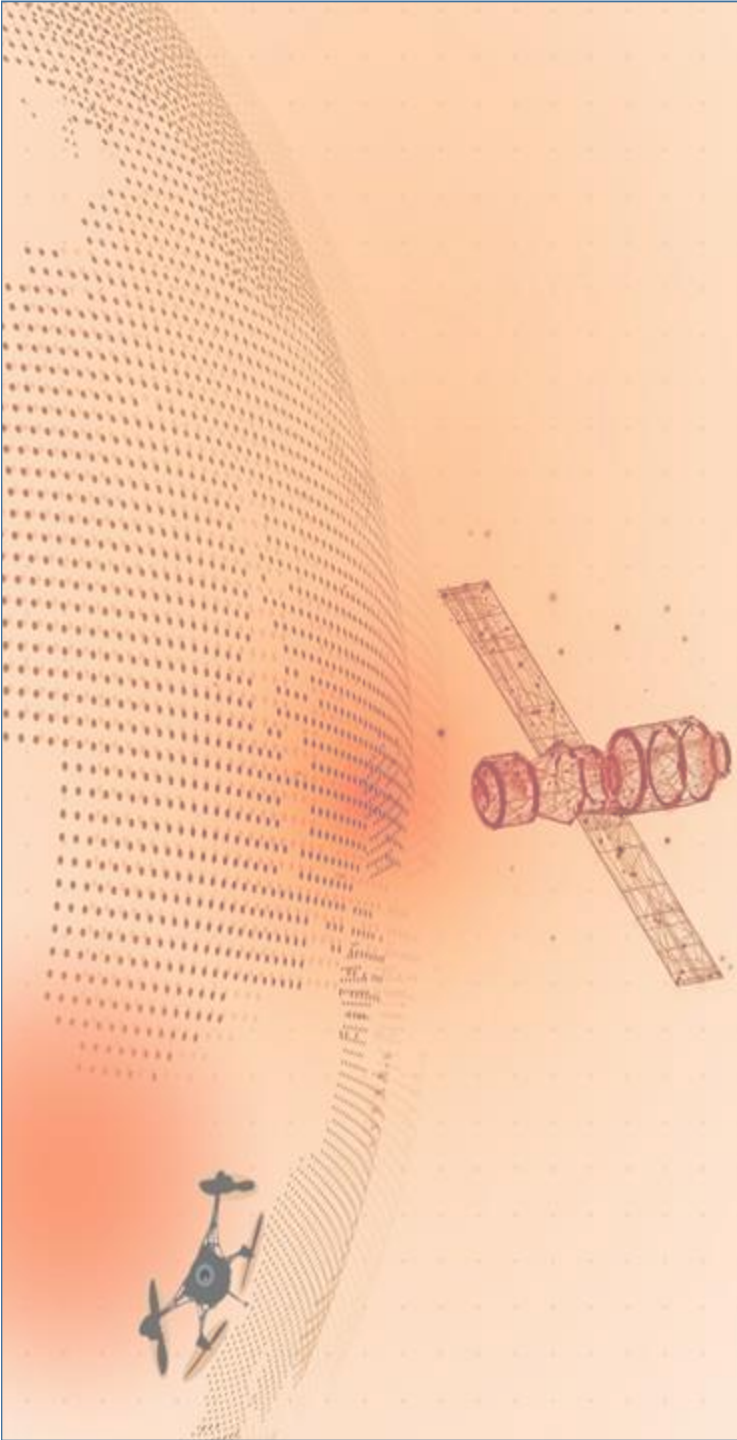
Center of Aerospace Technologies ltd

Radio-Thermal Imaging Technologies for searching for groundwater

Center of Aerospace Technologies ltd

All over the world, one of the newest, constantly developing 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 to identify and map groundwater. 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 flooded zones and aquifers in the geological massif.



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.

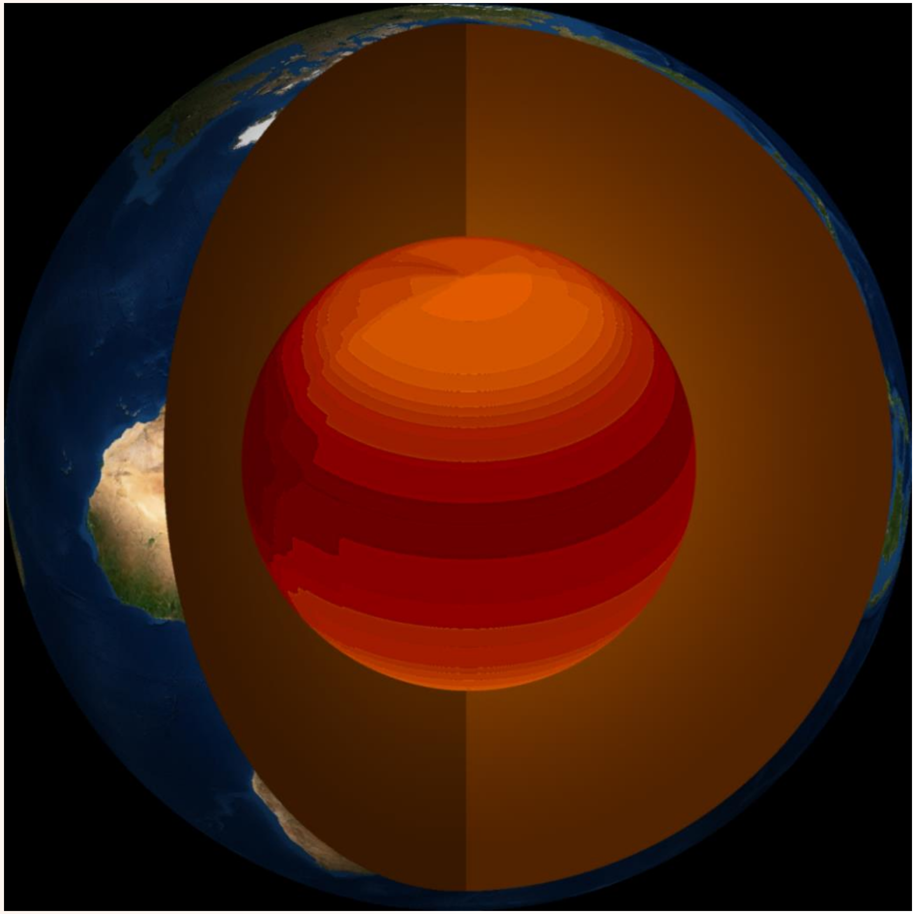
The initial data is information received from Earth satellites in the radio-thermal range of electromagnetic waves (Landsat 8 (OLI/TIRS), GCOM-W1 (AMSR-2), ASTERGDEM, Sentinel, etc.).

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.

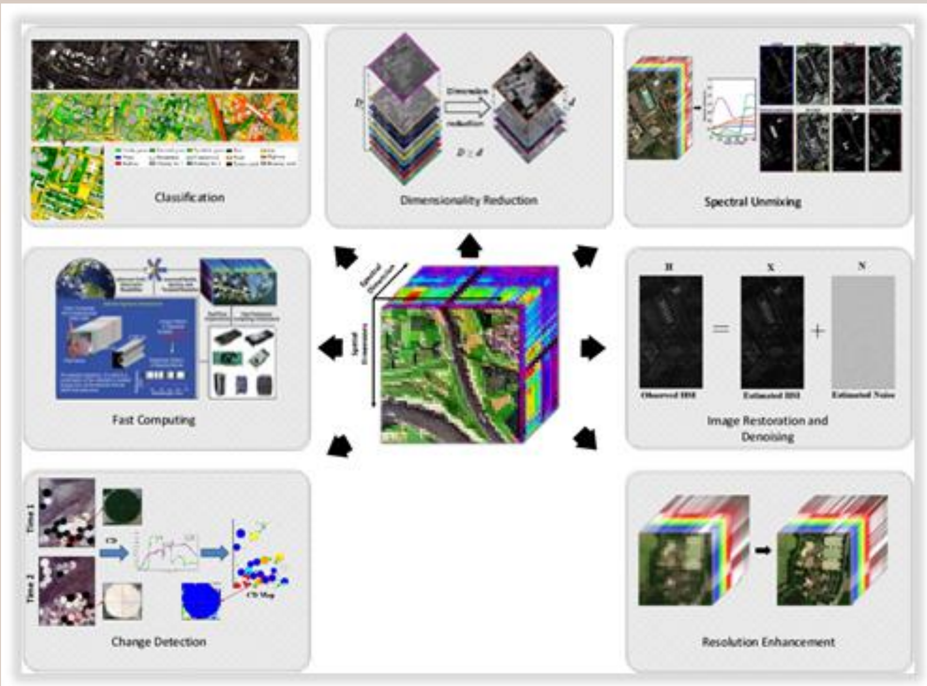
Processing of space images is carried out in the Software (through a training sample) with the construction of a 3D cube model.

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 heterogeneities of the Earth’s crust, including aquifers in sedimentary rocks, water-logged fault and fissure zones in rocks. 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.



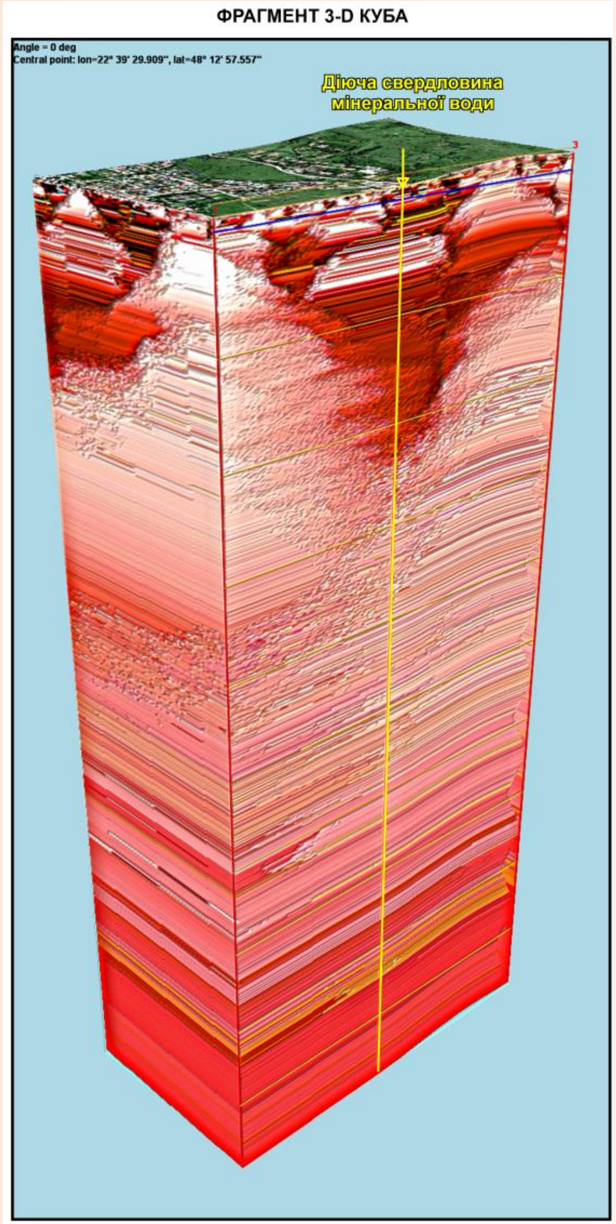
Building a geothermal model of a 3D cube



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

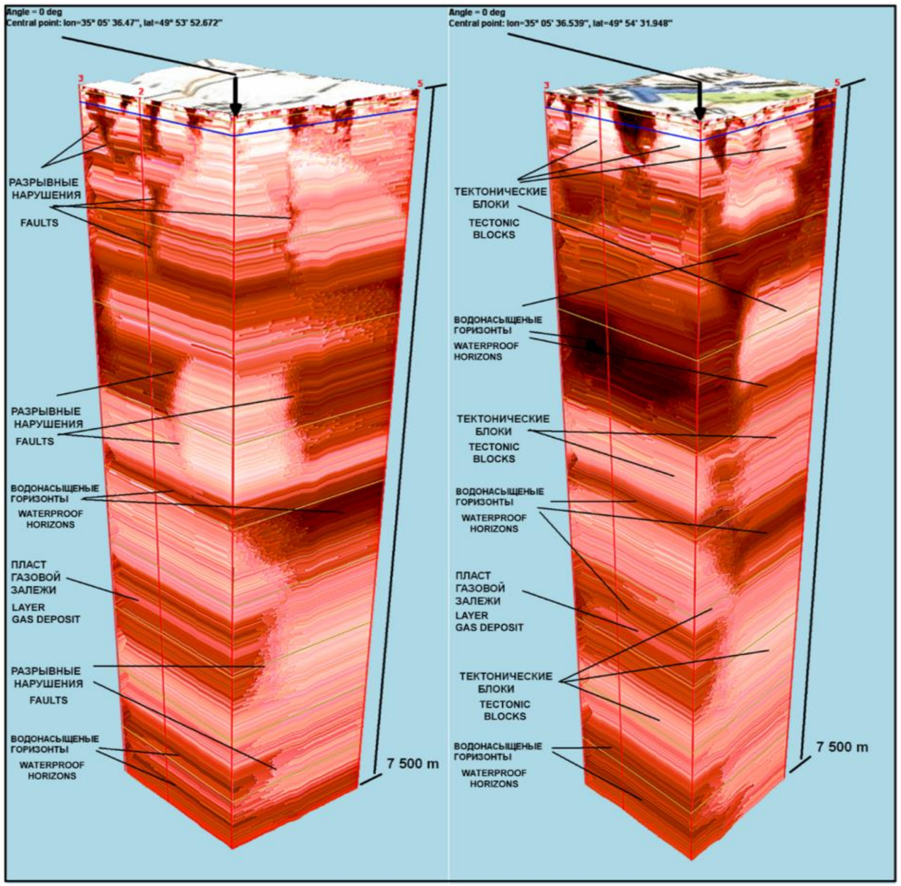


An example of constructing volumetric vertical sections based on geothermal 3-D cube data

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

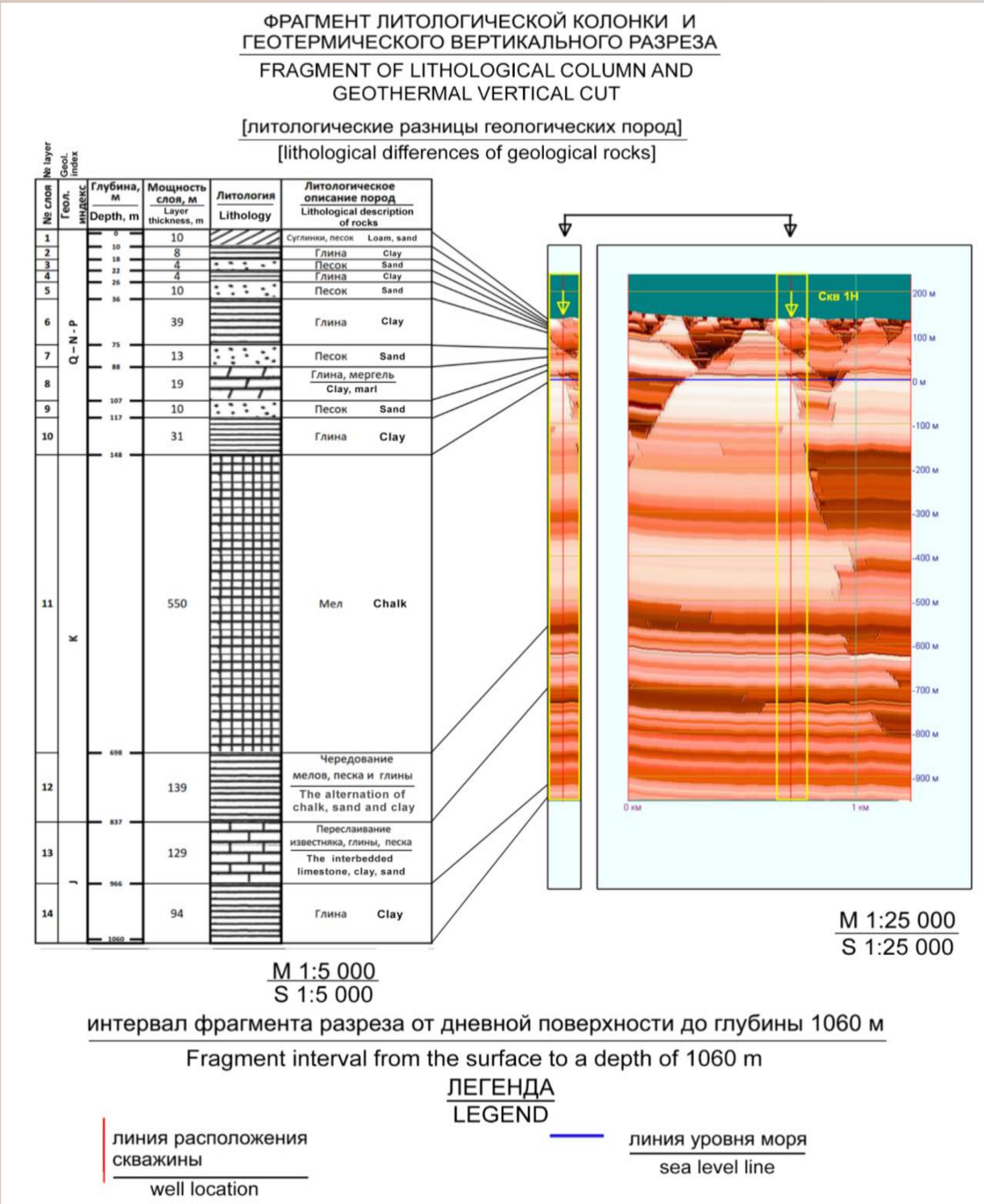
The detail of near-surface skin layers depends on the detail of thermal infrared (IR) images. For example, IR images of the Landsat-8 thematic cartographer are considered correct for work scales no larger than M 1:25,000 horizontally and no larger than M 1:10,000 vertically. IR images from the Aster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

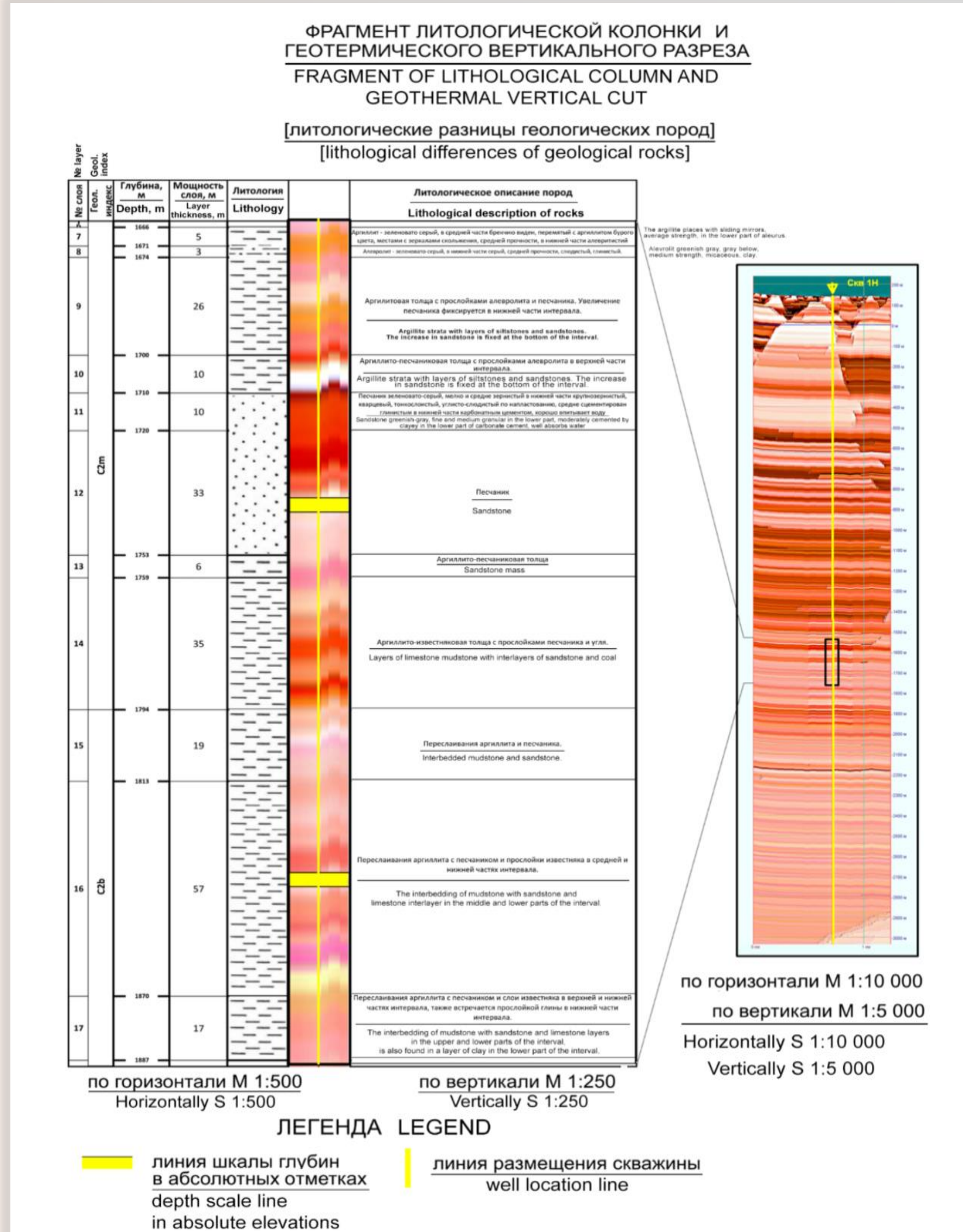
For these and larger scales, satellite radiometers can also be used: AVHRR, MODIS, AMSR, SSMI, WINDSAT, VIIRS, ATMS and others.

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 13**, where lithological differences in rocks identified from drilling data are clearly highlighted in color and tone.

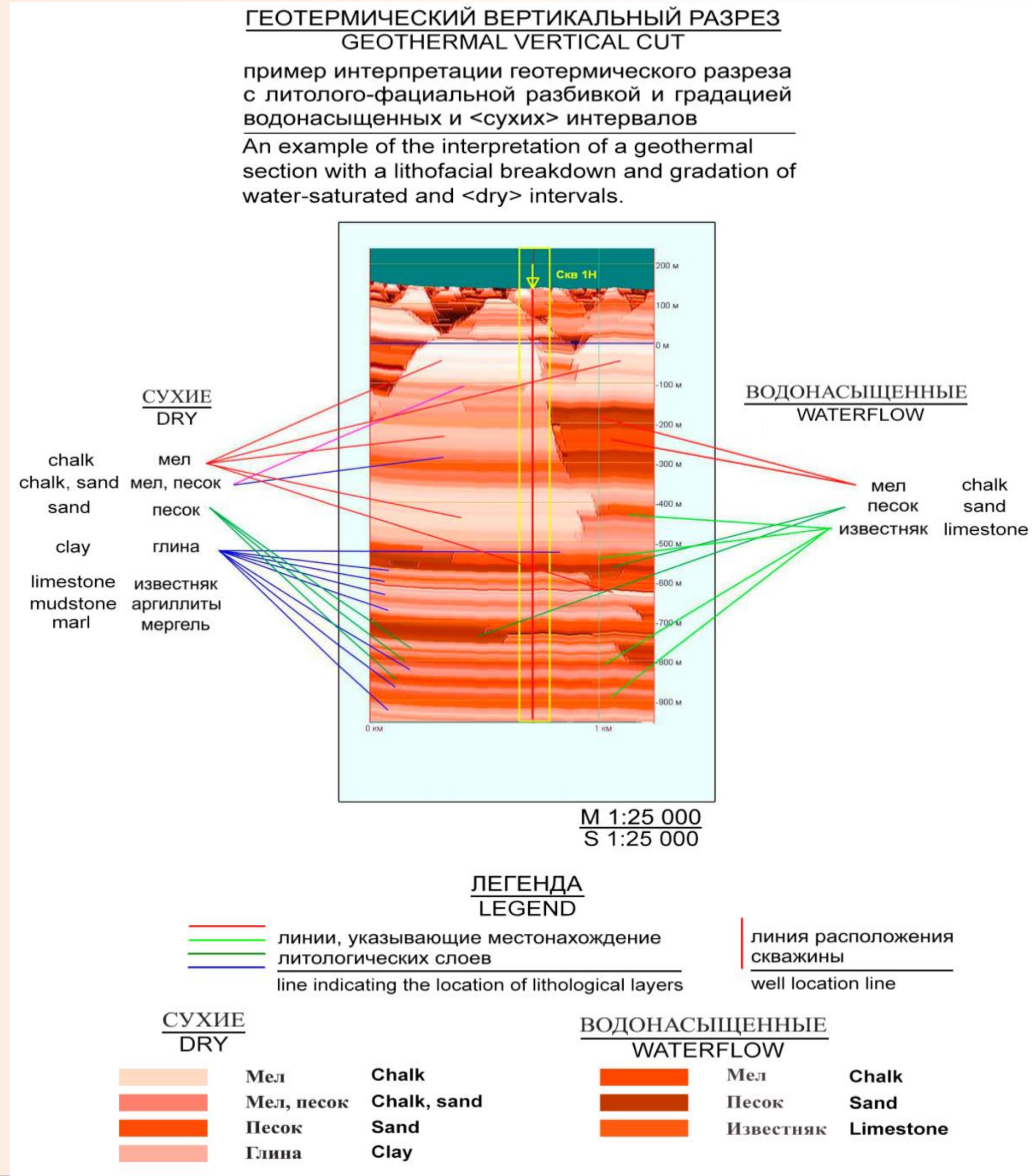
Identification of lithological intervals of a well section using RTT data

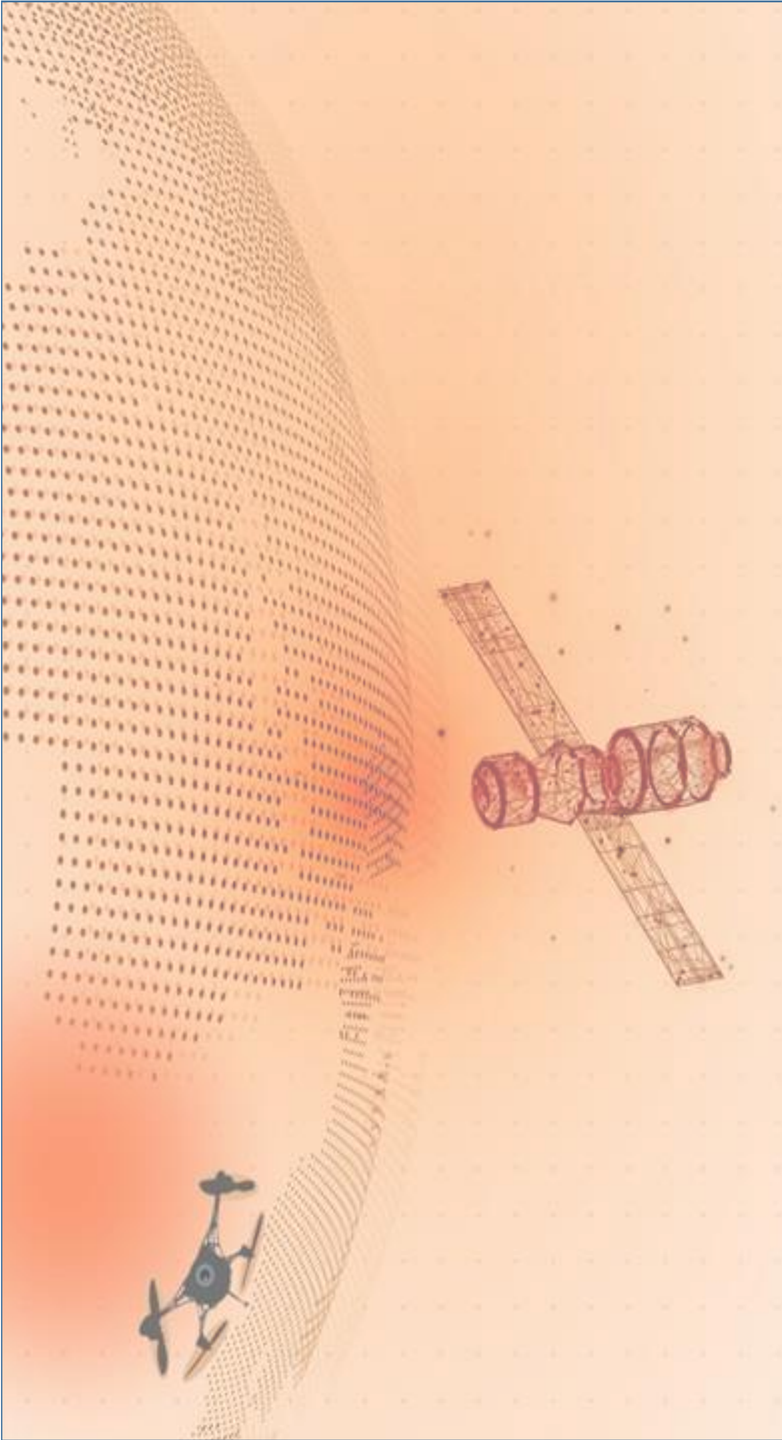




Identification of lithological intervals of a well section using RTT data

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





2. SEARCHING FOR GROUNDWATER

Model calibration

Calibration of the 3D cube model is carried out to clarify the position and depth of structural heterogeneities of the proposed aquifer, by comparison with a reference object, for example, a previously explored aquifer.

For these purposes, information from existing hydrogeological or water wells (well passport) is used as a reference object. Hydrogeological maps and sections can also serve as a reference object.

Model calibration is performed for each search object, depending on the type and type of groundwater, hydrogeological and geological-tectonic conditions of the region.

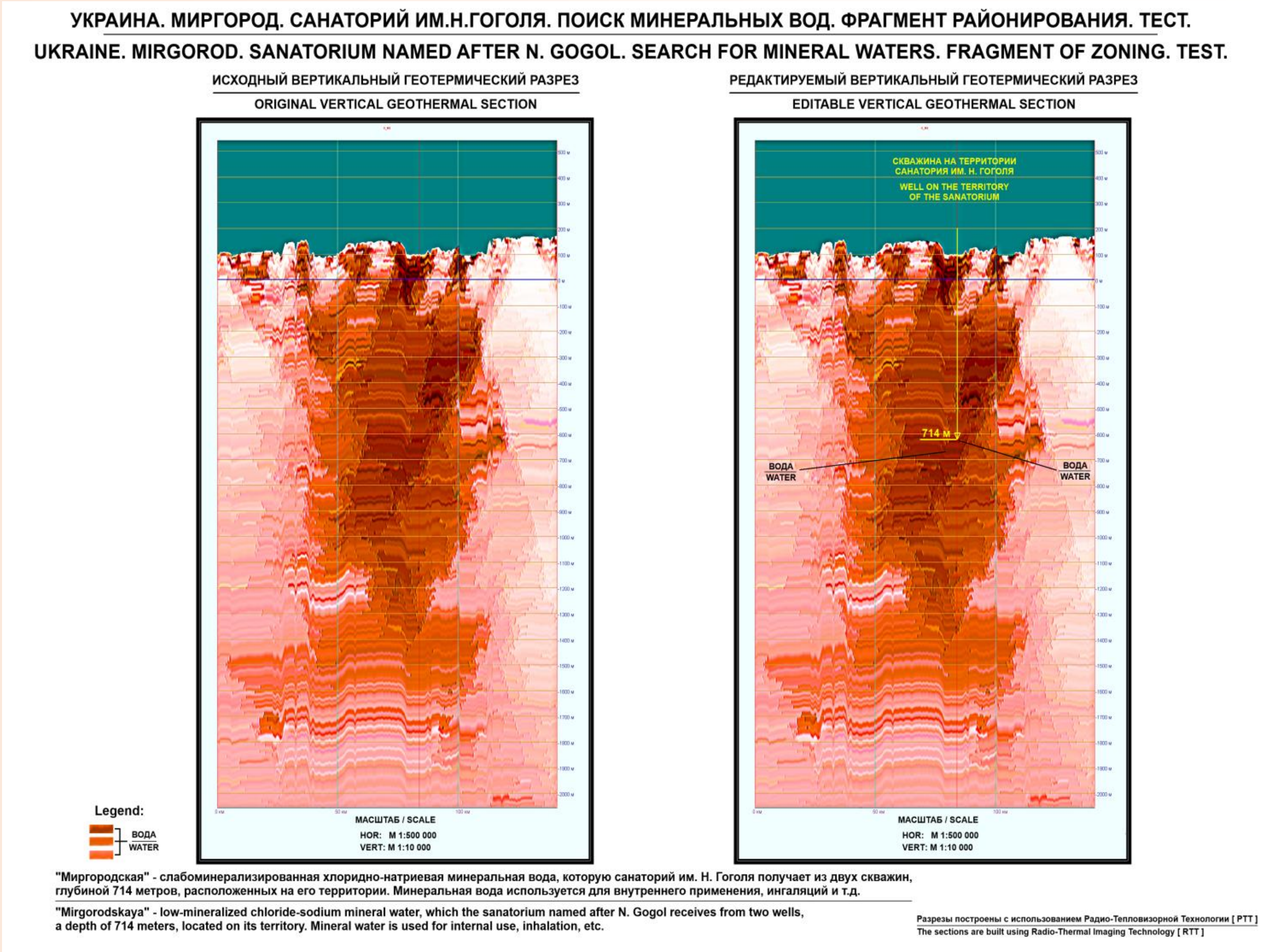
For correlation, a graph of the dependence of the nomenclature of a layer (multiple layers) on depth is used. Data obtained empirically during calibration. A useful layer (aquifer or horizon) is identified based on unambiguous hydrogeological materials.

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 water resources.

Our database contains information about more than 300 test sites - the most famous groundwater deposits of various genesis and mineralization. In the absence of testing data from exploratory drilling, water wells or other hydrogeological studies for a given area, the method of analogies is used. Examples of test sites in the Mirgorod region (Ukraine), Budapest (Hungary) and the Dnepropetrovsk region (Ukraine) are shown on **slides 17, 18, 19**.

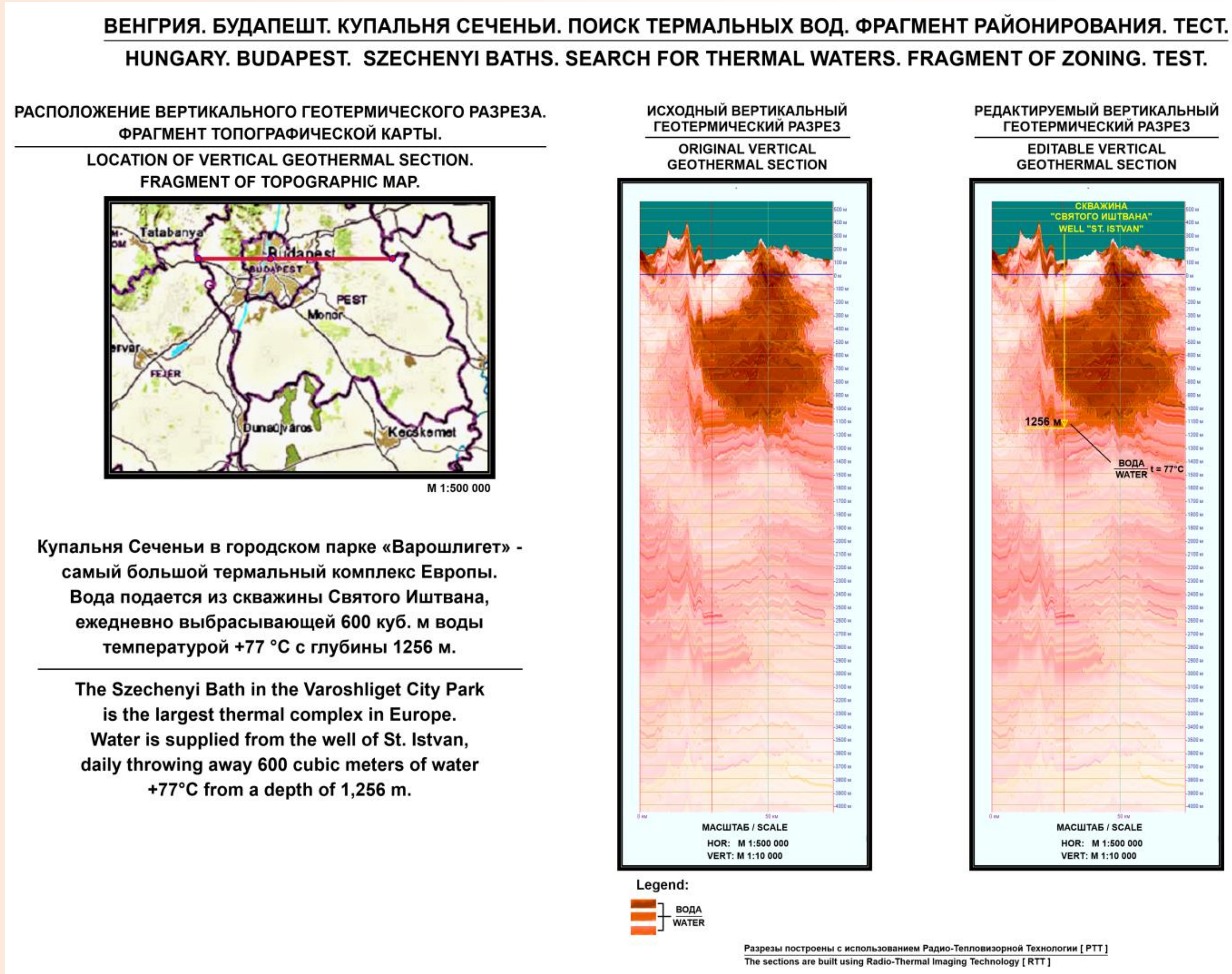
Test site in the Mirgorod area, Ukraine

Vertical geothermal section through the Mirgorodskaya mineral water well with a depth of 714 m.



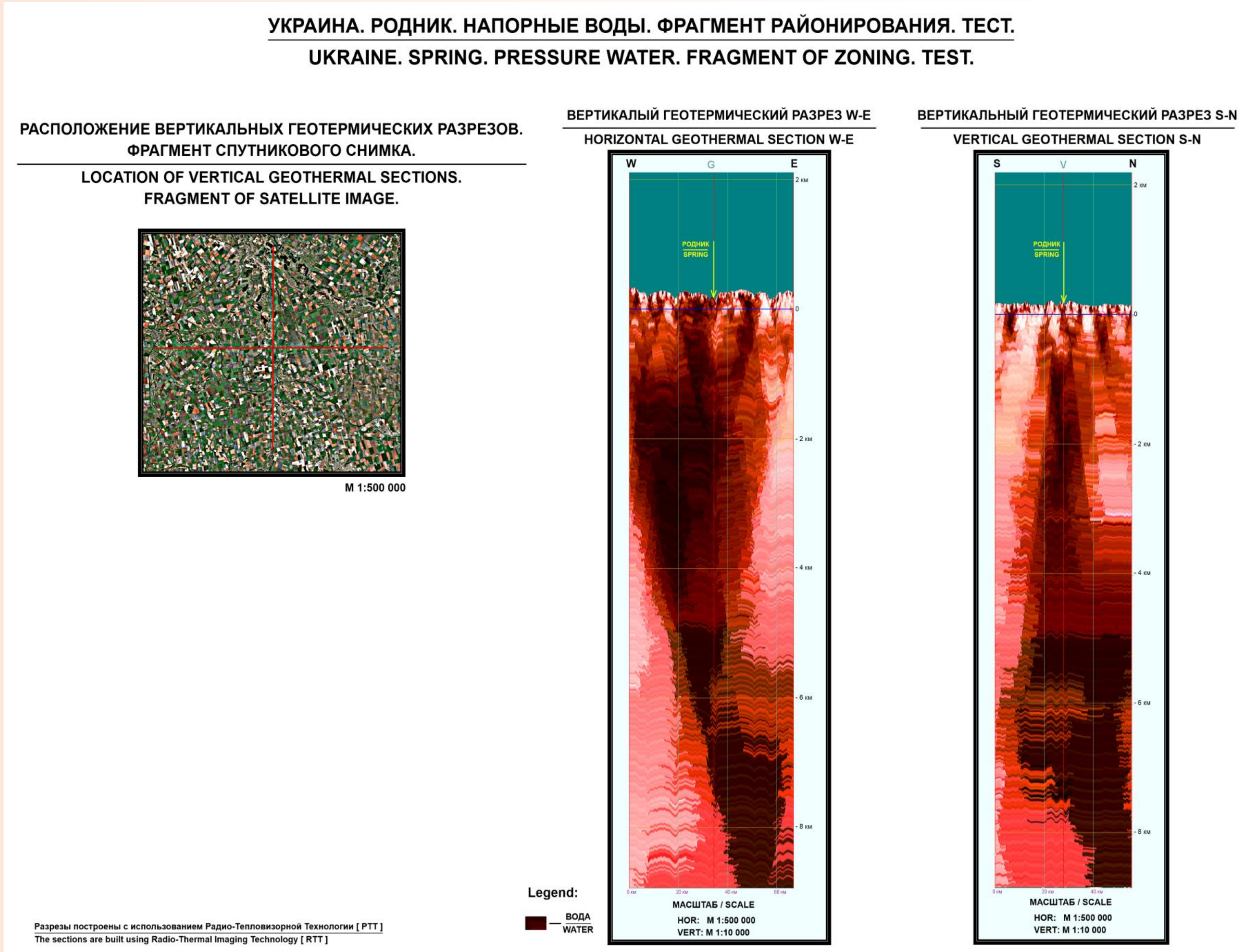
Test site in the Szechenyi Bath area, Budapest, Hungary

Vertical geothermal section through the well of thermal waters “St. Ishtman” with a depth of 1256 m

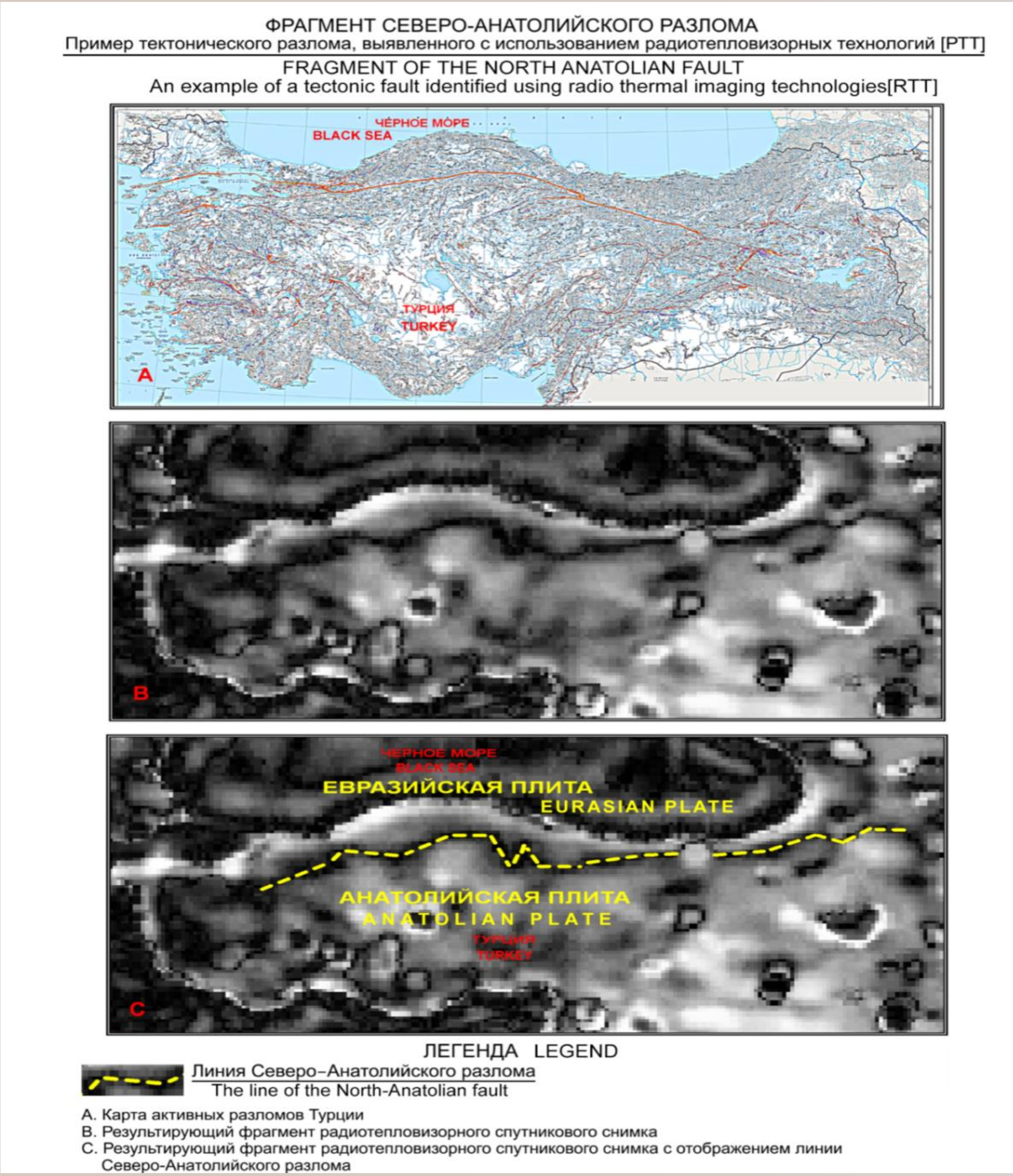


Test site in Dnepropetrovsk region, Ukraine

Vertical geothermal section through a permanent spring in the Dnepropetrovsk region, Ukraine. Flooded fault zone. Pressure waters. The release of groundwater to the surface of the relief.



Faults identified by the RTT method



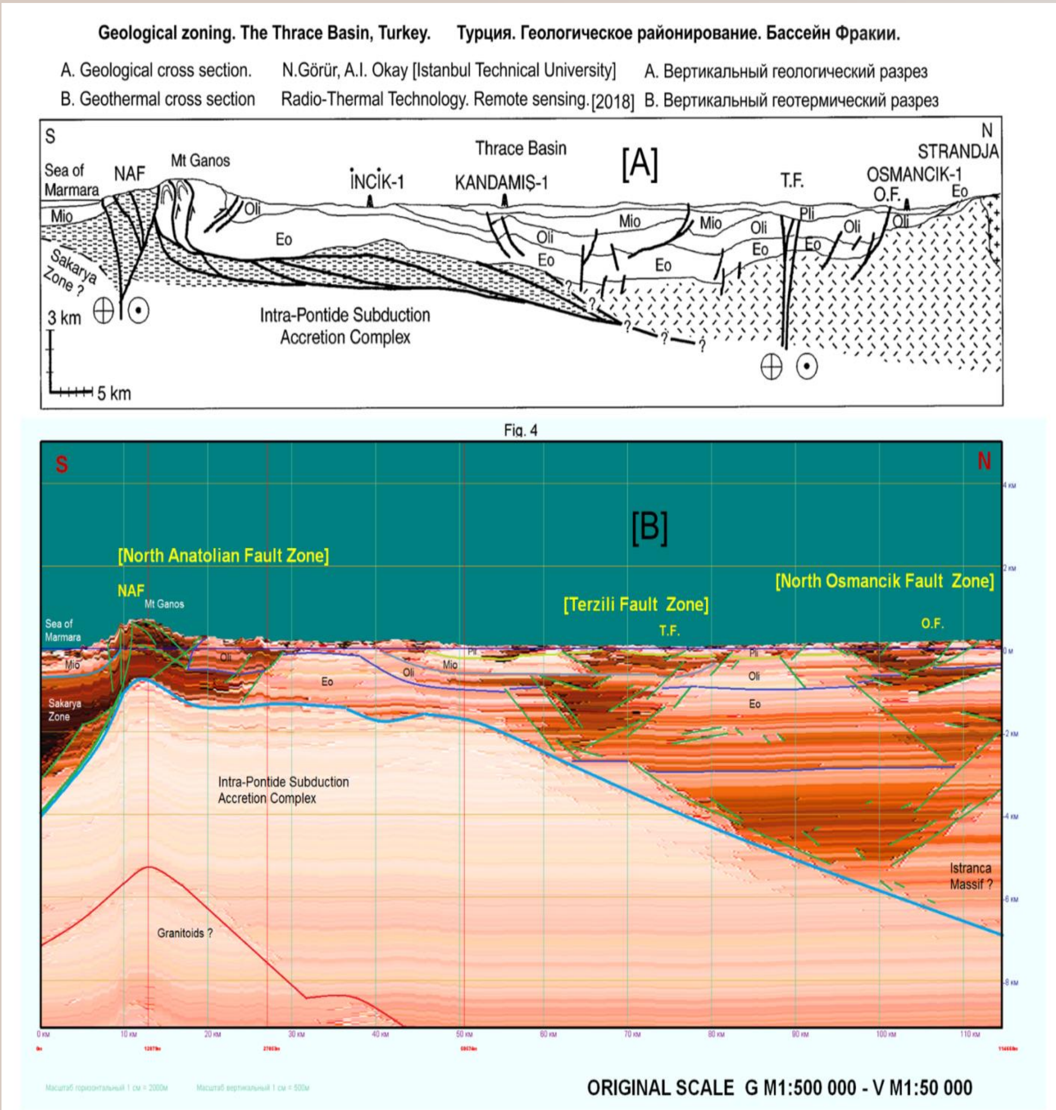
One of the main advantages of the method is the ability to map and determine the spatial location of zones of tectonic faults and faults, which create the block nature of the structure of the Earth's crust and influence the formation of water-filled crack zones in rocks.

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



Groundwater from zones of major tectonic disturbances is mainly characteristic of folded mountainous areas, less often of ancient crystalline shields and dislocated rocks of platform foundations. They are usually observed in the form of linearly elongated, relatively narrow flows moving in rock zones of crushing, brecciation, or increased fracturing of rocks near tectonic disturbances. In such zones, both pressure and non-pressure waters are formed.

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

Identification of aquifers and groundwater reservoirs

Water-filled layers in vertical geothermal sections have color shades: from light brown to brown and black. Water quality can also be recognized using spectral analysis methods.

Slide 23 shows groundwater from fresh to mineral and thermal in the fault zone at different depths of the geological section.

Groundwater reservoirs on horizontal geothermal sections can be recognized as the upper and lower parts of a close plan location.

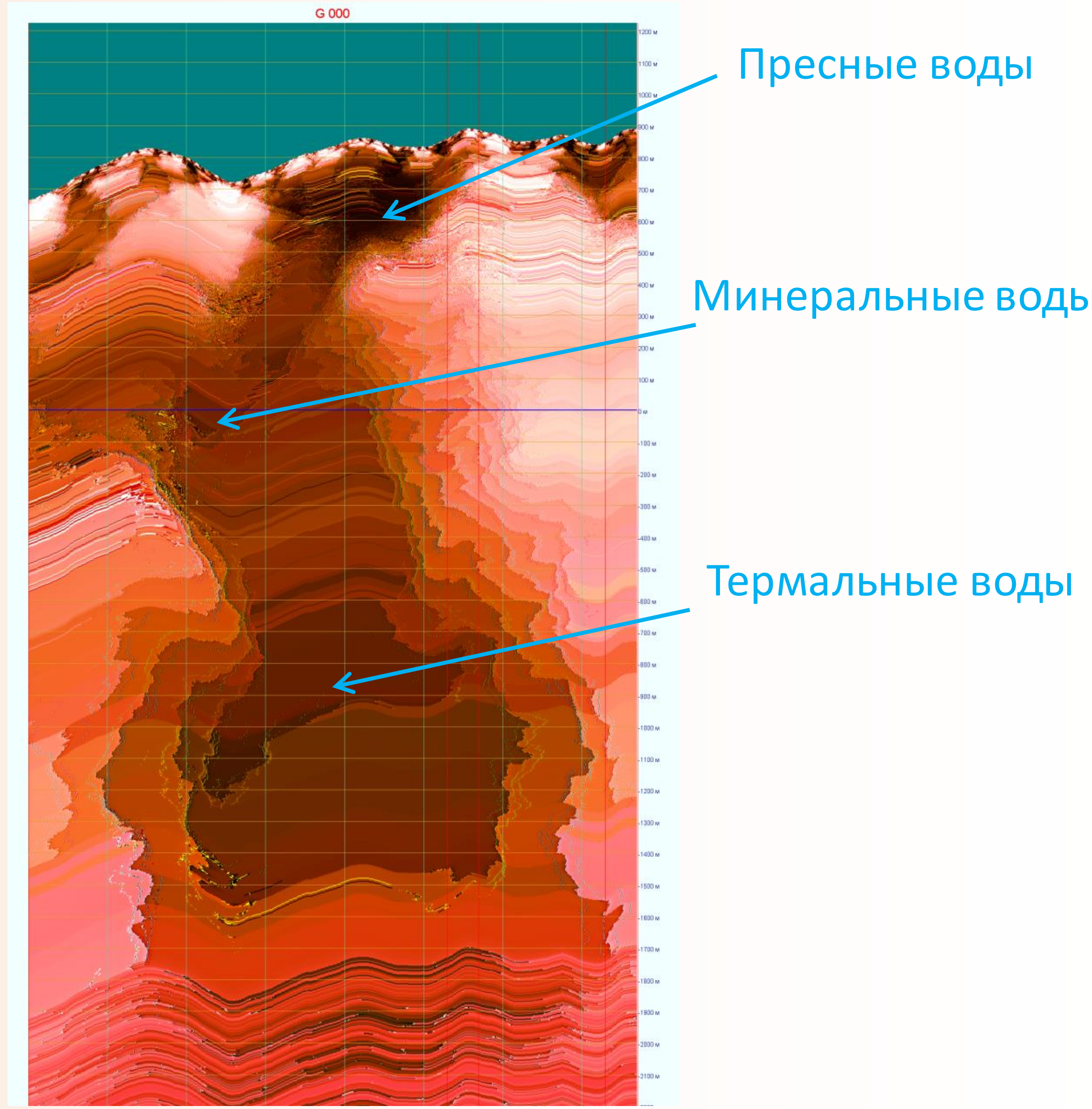
As a result of research, aquifers, interstratal waters and underground natural reservoirs are identified on thematic maps and geothermal sections :

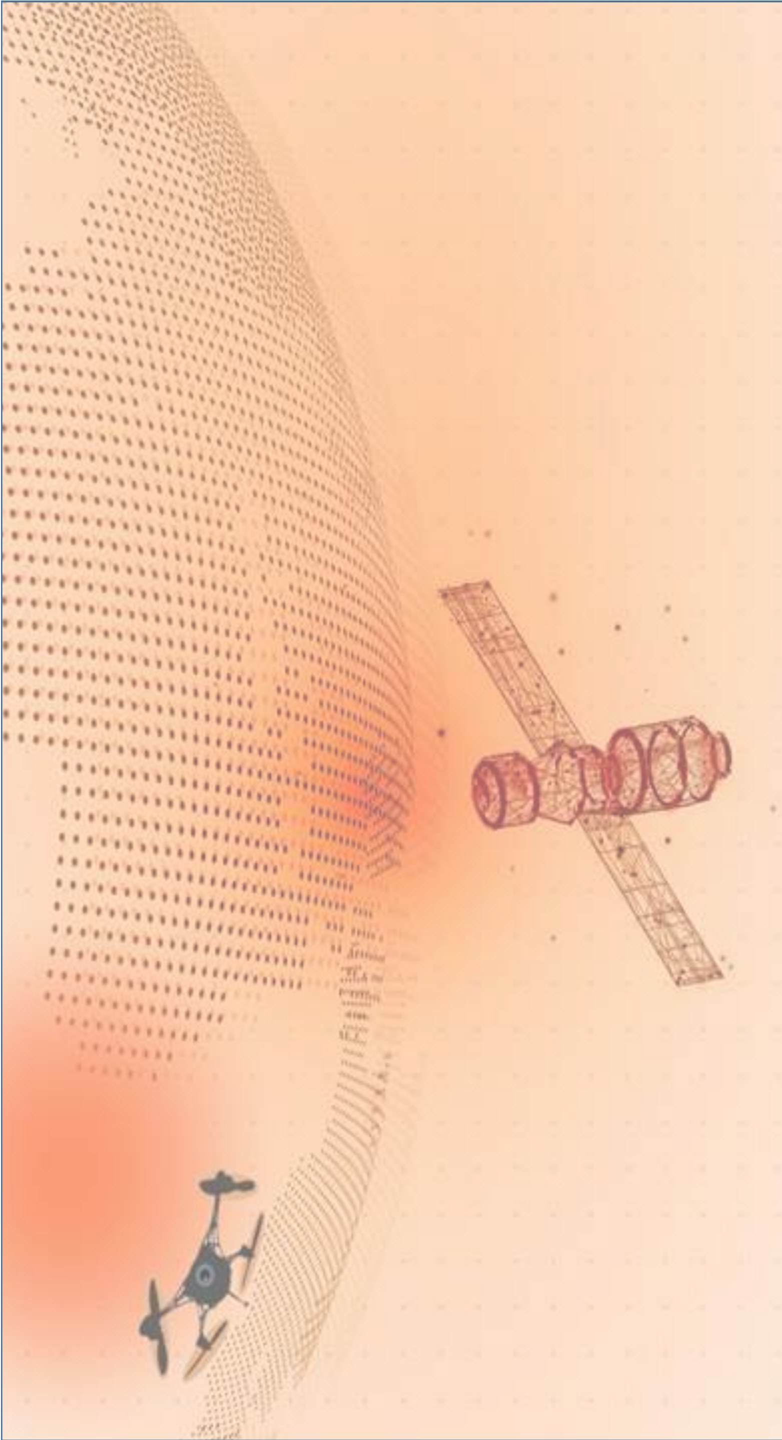
- ➢Quaternary and pre-Quaternary deposits;
- ➢fractured zones of non-carbonate and carbonate rocks;
- ➢flooded fault and fissure zones in rocks.

Identification of aquifers and groundwater reservoirs

Vertical geothermal section in the Carpathian region:

- **fresh water** at a depth of 180 m;
- **mineral waters** at a depth of 800 m;
- **thermal waters** at a depth of 1600 m





3. EXAMPLES OF WORK ON SEARCHING FOR GROUNDWATER

Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

Based on the results of research using the RTT method on a scale of 1: 5,000, on an area of 1x1 km in the Eastern Carpathians, a three-dimensional cube was built - a model of the geological environment, on the basis of which the following were constructed: 21 vertical geothermal sections in the **W-E** direction (**G 01-G 21**) and 21 vertical geothermal sections **S-N** directions (**V 01-V 21**) to a depth of 3 km with a step of 50.0 m.

Horizontal and vertical scales are 1: 5,000. In addition, 32 horizontal sections were built across the area along horizons from +850 m to -1500 m in absolute elevations. The satellite image combined with the cadastral map of Ukraine shows projections of the 1st and 2nd aquifers identified in the study area.

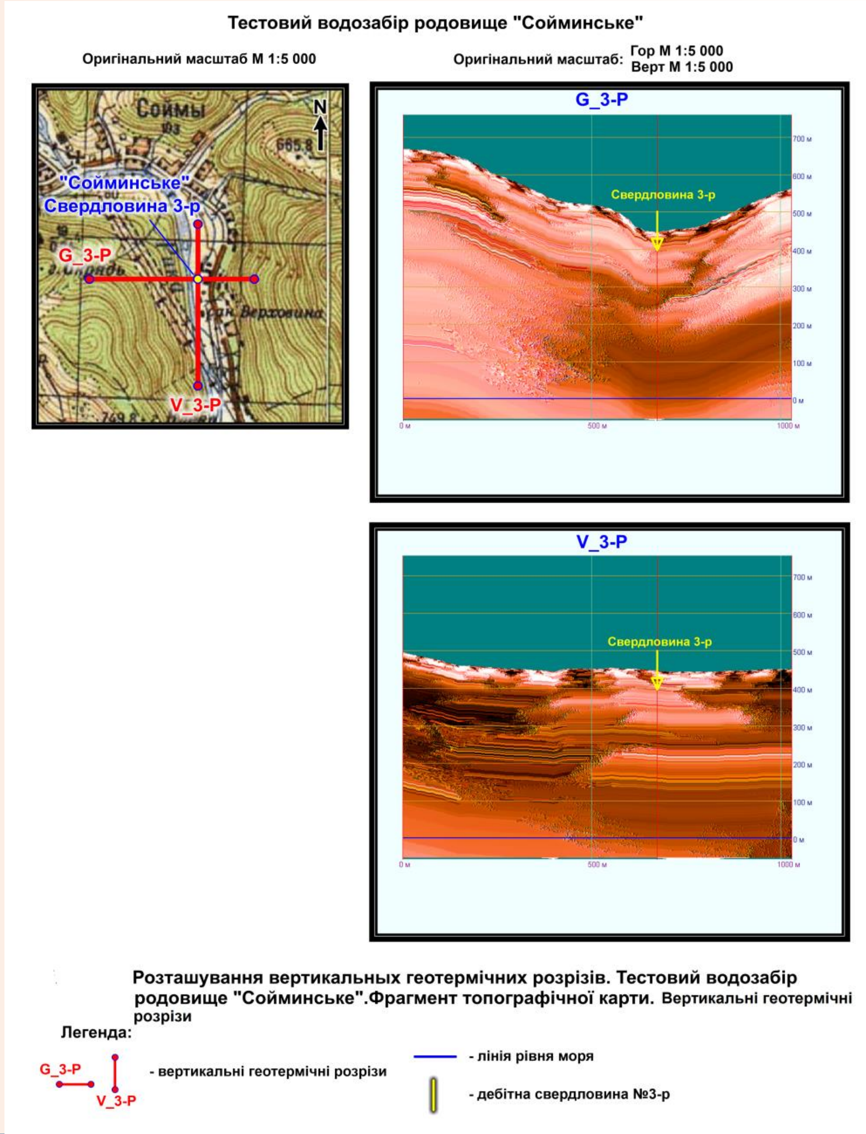
A structural and metric analysis of the geoenvironment was performed, its internal structure was studied: the main geoblocks and the destructive zones separating them were identified. Geothermal anomalies in the geoenvironment are identified, which are associated with water-flooded faults, fault zones and fracturing zones. Exploration wells are recommended (**slide 38**).

On vertical geothermal sections down to a depth of 3000 m, the geological massif of dense waterproof rocks of the Eocene-Oligocene is shown in light colors, and fault destructive zones - anomalies corresponding to flooded zones - are shown in shades of brown.

Calibration of the 3D cube model was carried out to clarify the position and depth of structural heterogeneities of the supposed flooded zones, by comparison with reference objects - test water intake of the Soyminskoye field (**slide 28**), test fresh water source No. 2 of the Shutin section of the Menchul-Verkhnebistryanskoye field, test fresh water source No. 1 Sukharovets (**slide 29**) in the village of Verkhniy Bystry, where sampling was used based on the actual mineralization of groundwater. Interpretation of geothermal data was carried out using information from test sites and other materials from geological studies in the Folded Carpathians region.

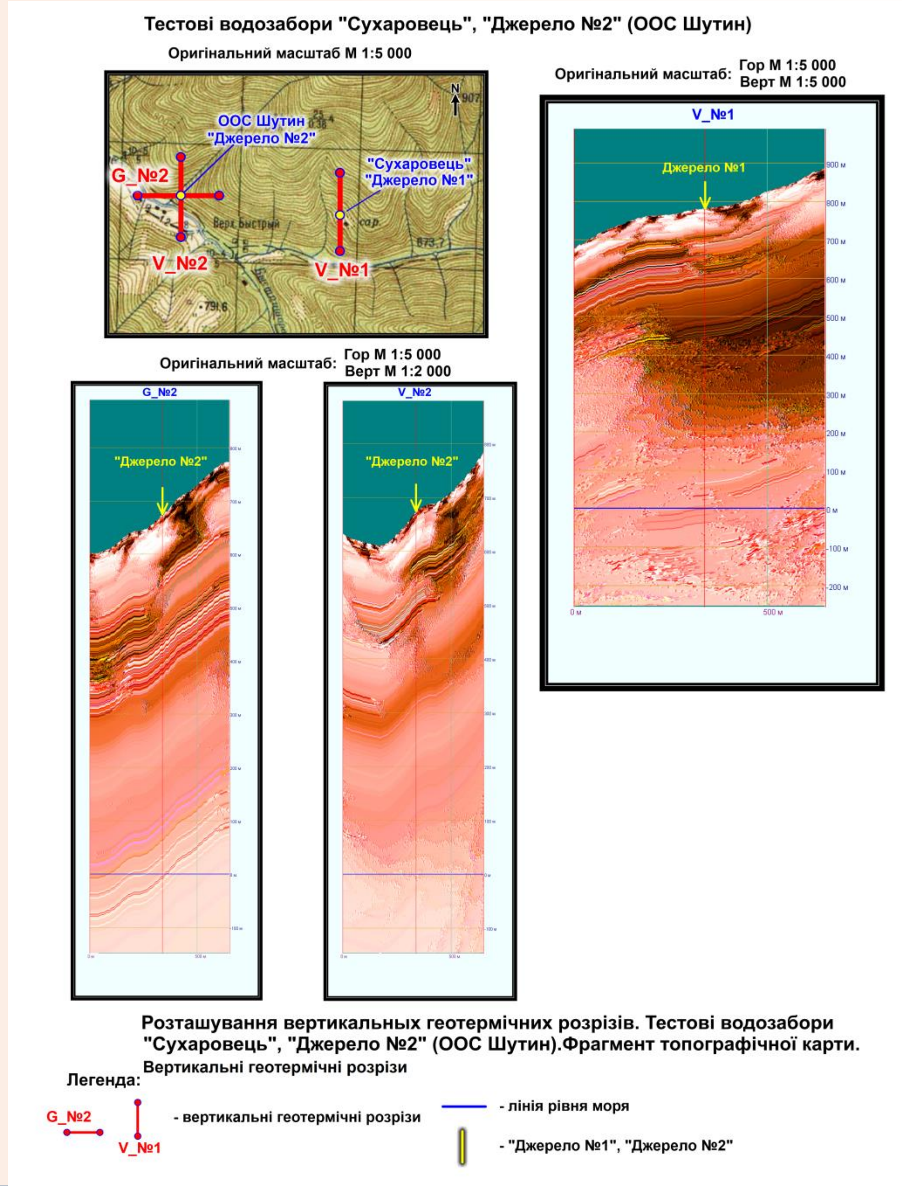
Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

Test water intake of the Soyminskoye field. Vertical geothermal sections through exploration well 3-r



Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

Test sources of groundwater deposits. Vertical geothermal sections through Source No. 1 Sukharovets, Source No. 2 Shutin



Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

All groundwater deposits in the Folded Region of the Carpathians are associated with tectonic faults and their intersection points, fault zones, fracture zones, including exogenous fracturing.

A characteristic feature of the geological structure of the study area is the presence at the base of a block of dense waterproof Eocene-Oligocene rocks, about 1000 m thick, limited from the north, south and west by destructive fault zones. On horizontal and vertical geothermal sections, the indicated dense rock massif is shown in light colors.

The upper part of the geological section is broken by faults to a depth of 50-150 m, absolute elevation +750 m.

The western part of the site falls into the marginal zone of a deep tectonic fault, which is recorded on geothermal sections down to an absolute elevation of -1500 m. Feathering faults up to a depth of 600 m are associated with this zone.

Features of the formation and distribution of groundwater are determined mainly by structural and tectonic zoning. Almost all fault zones adjacent to the study area, faults and fracture zones identified in the upper part of the geological section are flooded areas.

Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

In the study area, three aquifers were identified in the flysch Cretaceous-Paleogene deposits.

The first aquifer from the surface lies in the subsurface zone of Oligocene fractured rocks. Exogenous fracturing extends to a depth of 100 m on average. The water-bearing materials are fractured sandstones, limestones, marls, and gravelites. The water content of flysch is associated with fractured reservoirs, which are characterized by limited capacitive parameters, which excludes the possibility of the formation of significant groundwater reserves. The horizon is fed mainly by infiltration and depends on meteorological factors. The waters are mostly fresh. Increased mineralization is possible in areas where the aquifer is recharged with groundwater from tectonic faults.

The satellite map combined with the cadastral map of the study area, **slide 30**, shows the contours of the area of distribution of the first aquifer from the surface.

As an example, two promising areas have been identified in the territory (**1-1, 1-2**).

Sections 1-1, 1-2 (slide 31. Horizontal geothermal section at **+800m).**

The size of the anomaly in plan is 200x60 m, 100x60 m, respectively, the depth of distribution is up to 100 m. (Fig. 7. Vertical geothermal sections **G 10-G 12**, **slide 32**.

Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

Projections of the first aquifer from the surface onto a satellite image and cadastral map of the study area

ОБЛАСТІ РОЗПОВСЮДЖЕННЯ ПЕРШОГО ВІД ПОВЕРХНІ ВОДОНОСНОГО ГОРИЗОНТУ

Оригінальний масштаб М 1:5 000

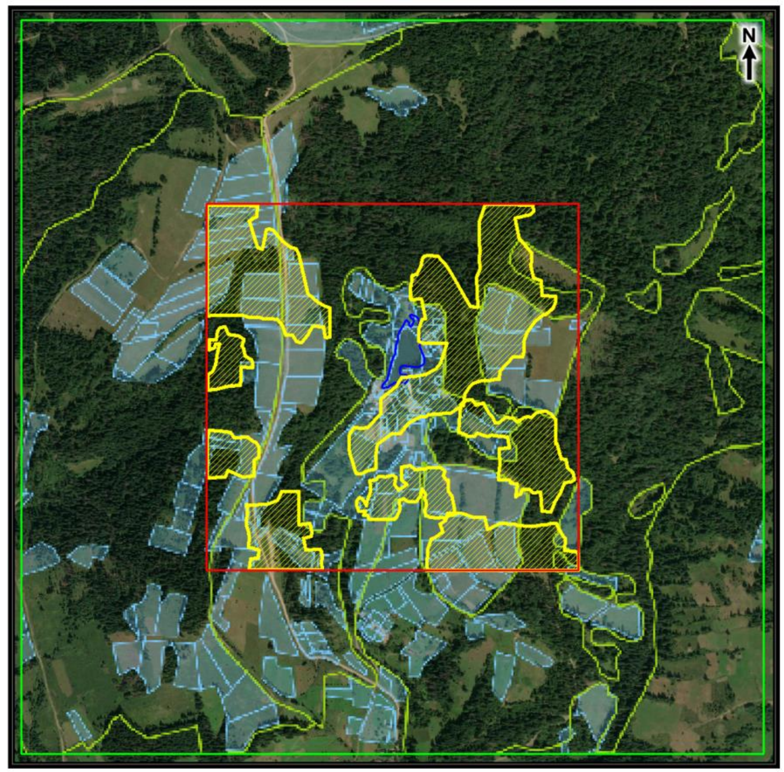


***Рис. 50.** Проекції першого від поверхні водоносного горизонту на супутниковий знімок і кадастрову карту території досліджень*

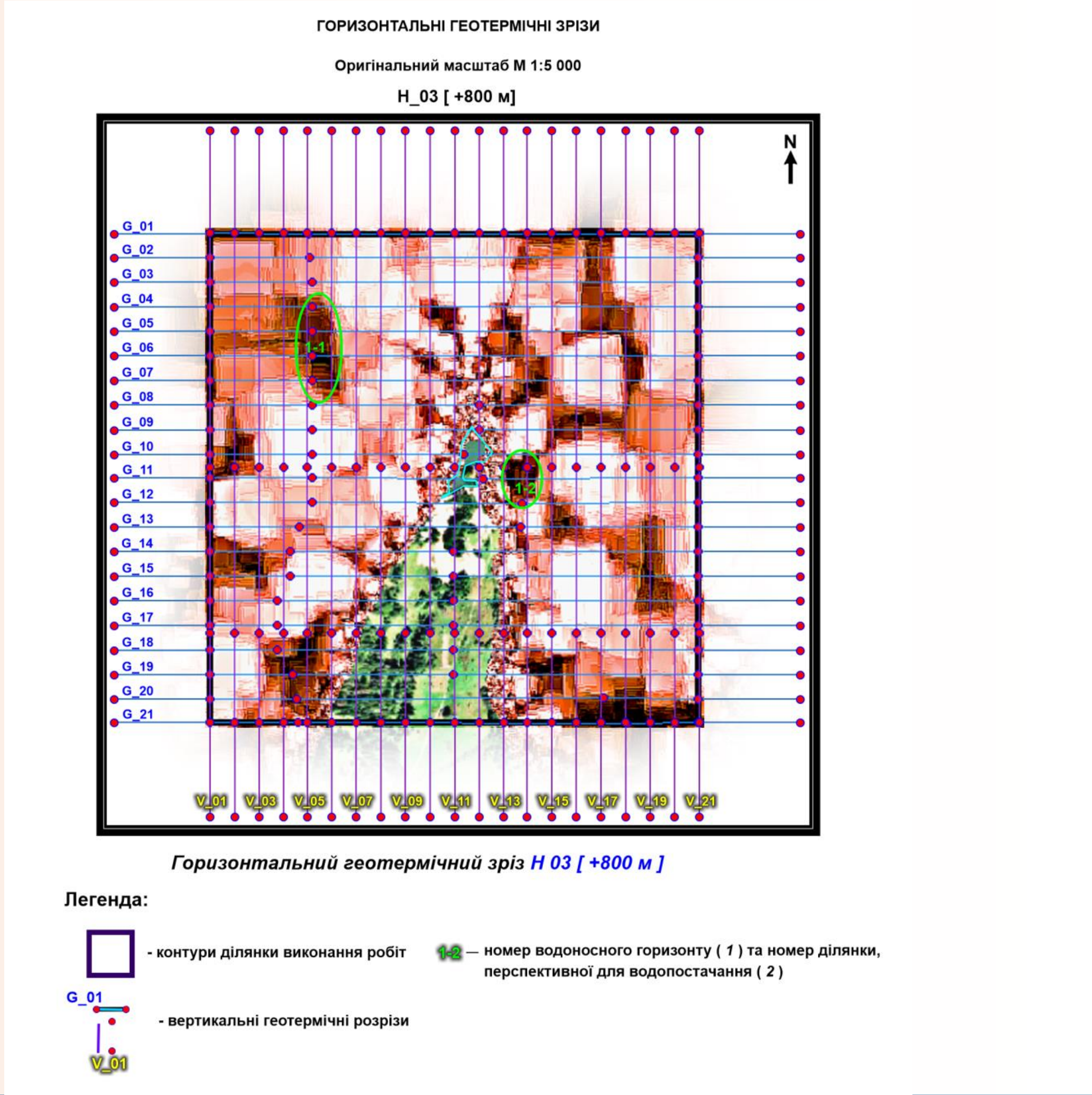
Легенда:

- контури ділянки виконання робіт

- контури проекції водоносного горизонту

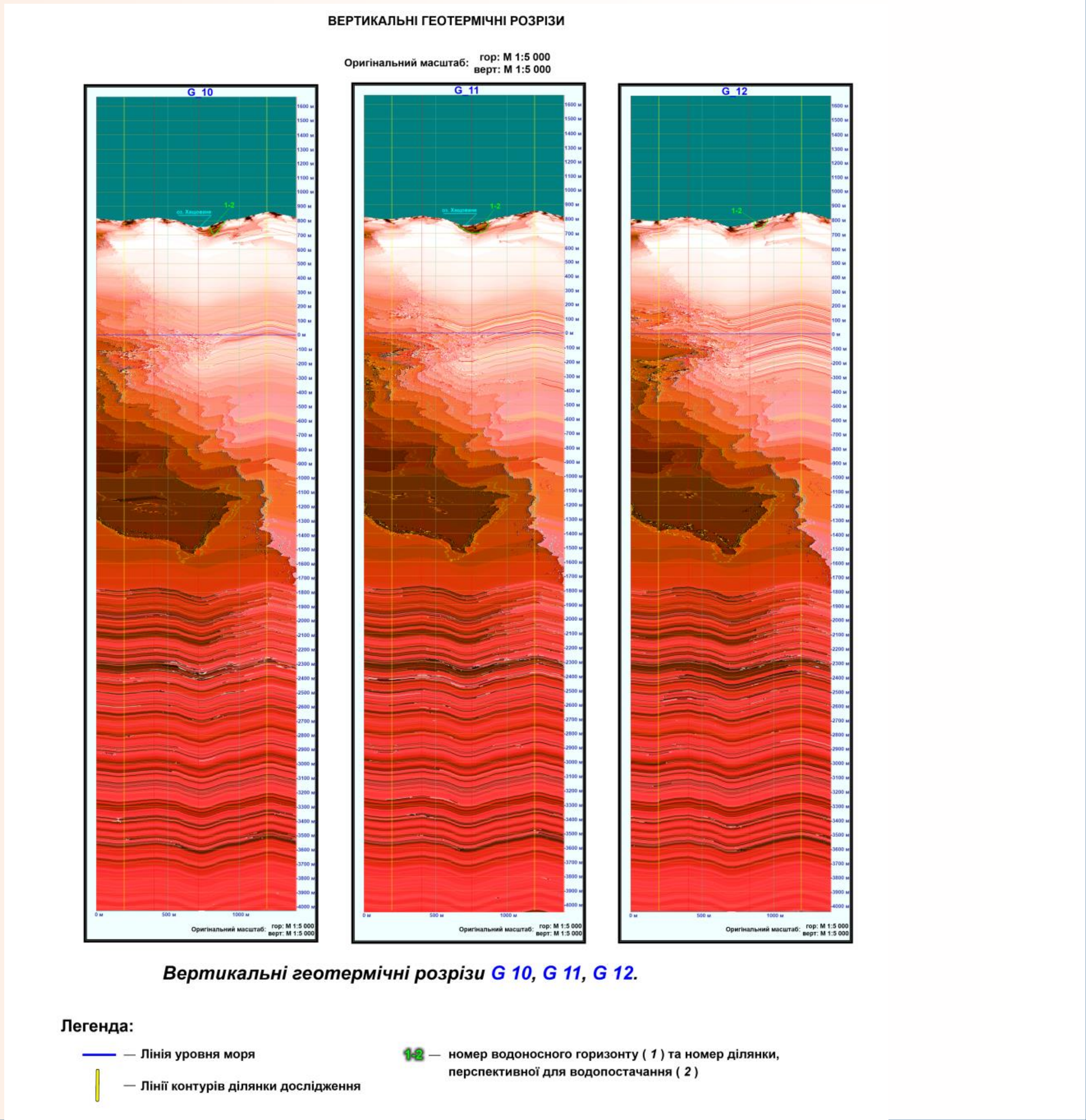
Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

Horizontal geothermal section at an absolute elevation of +800 m. The first aquifer from the surface. Areas promising for water supply.



Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

Vertical geothermal sections **G 10 - G 12** through promising area No. 2. First aquifer from the surface.



Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

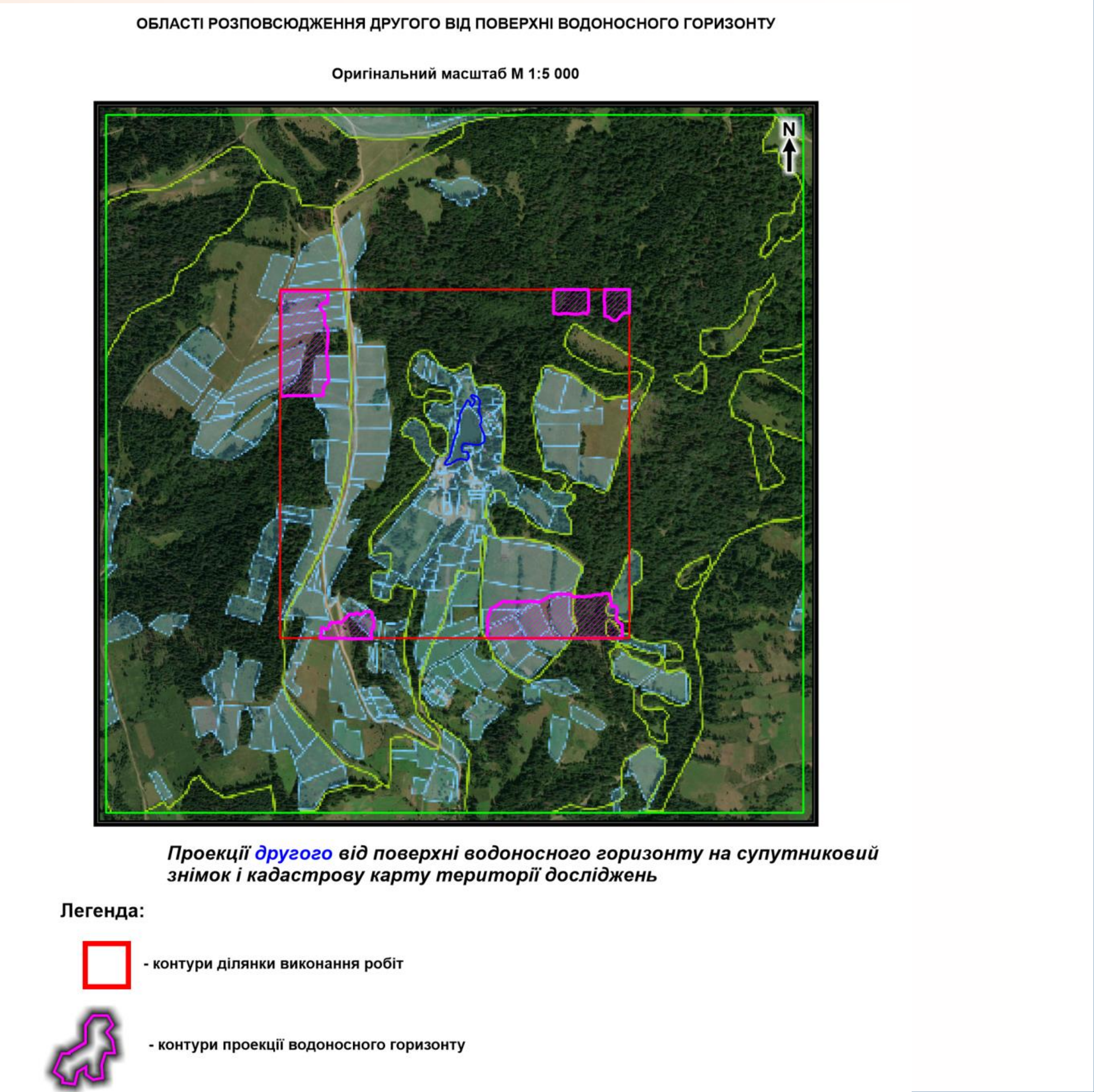
The second aquifer from the surface lies in the fault zones of fractured rocks of the Eocene-Oligocene, has a significant distribution in plan and to a depth of an average of 300-400 m. The water-bearing horizons are fractured sandstones and limestones. Mineral waters. Due to its high water abundance and shallow depth, this aquifer is recommended for water supply as the most promising. In addition, this aquifer is fed by groundwater from a deep fault, which eliminates depletion due to significant water withdrawal. Directly on the study area of 1x1 km, this aquifer is located to a limited extent in the marginal zones.

The satellite map, combined with the cadastral map of the study area, **slide 34**, shows the contours of the area of distribution of the second aquifer from the surface.

As an example, two areas have been identified in the adjacent territory: **2-1, 2-2**, (**slide 35**). Horizontal geothermal section at elevation **(+700m**), which shows the direction of distribution of flooded zones to the northwest and south-southeast from the border of the study area. Vertical geothermal sections **G 01-G 03** (**slide 33**) show area **2-1**. In both areas, only marginal zones of flooded tectonic faults are observed.

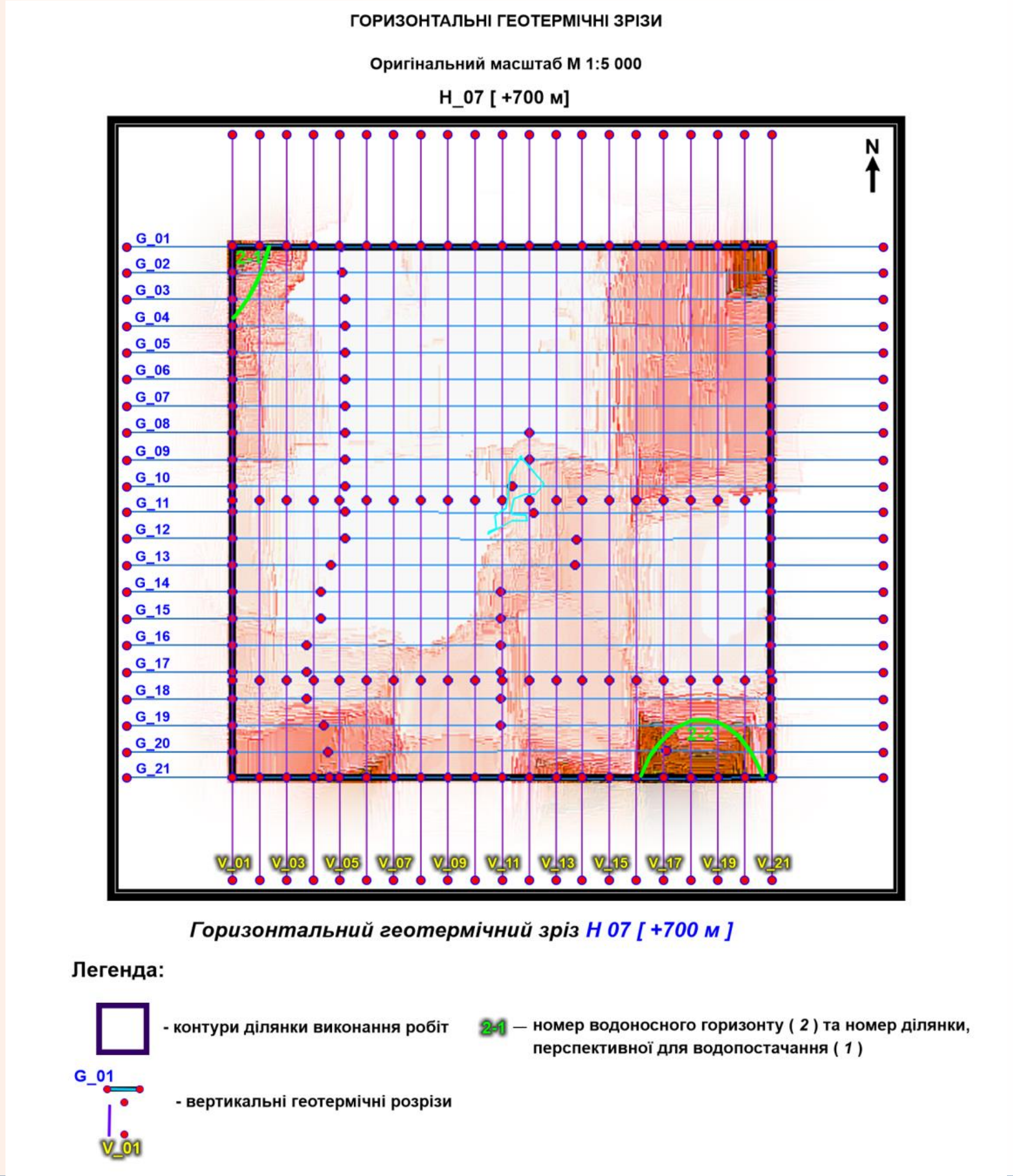
Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

Projections of the second aquifer from the surface onto a satellite image and cadastral map of the study area



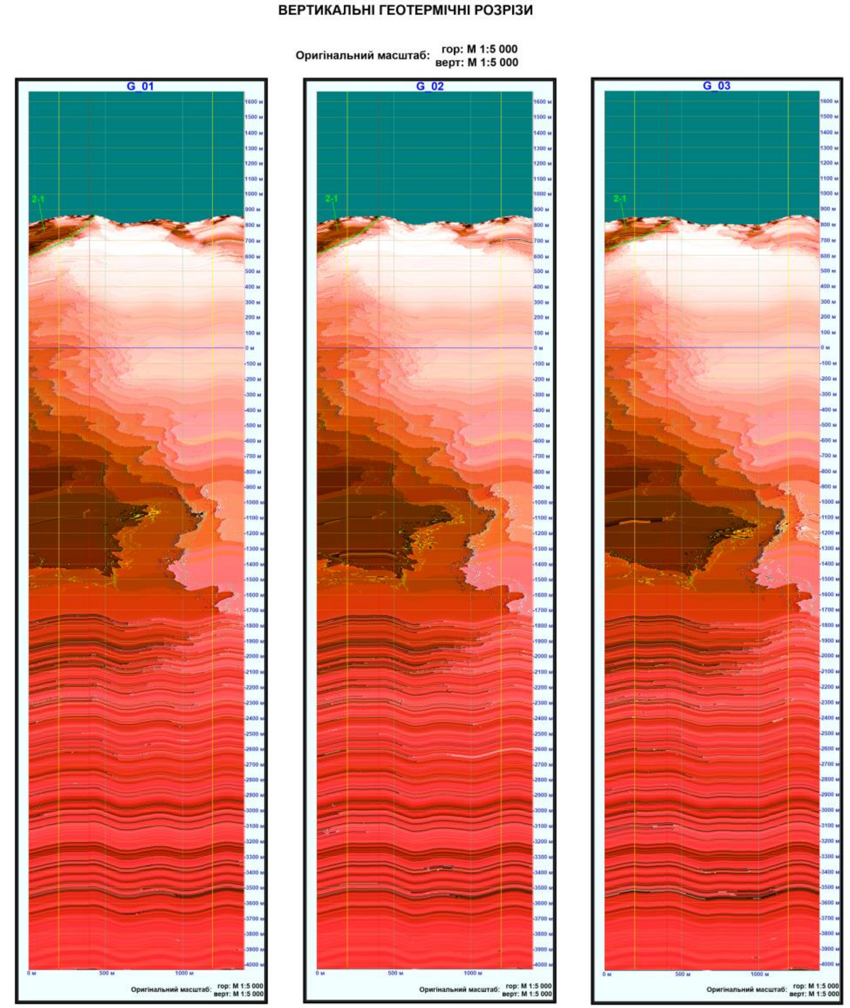
Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

Horizontal geothermal section at an absolute elevation of +700 m. The second aquifer from the surface. Areas promising for water supply.



Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

Vertical geothermal sections **G 01 - G 03** through promising area No. 1. The second aquifer from the surface.



Вертикальні геотермічні розрізи G 01, G 02, G 03.

Легенда:

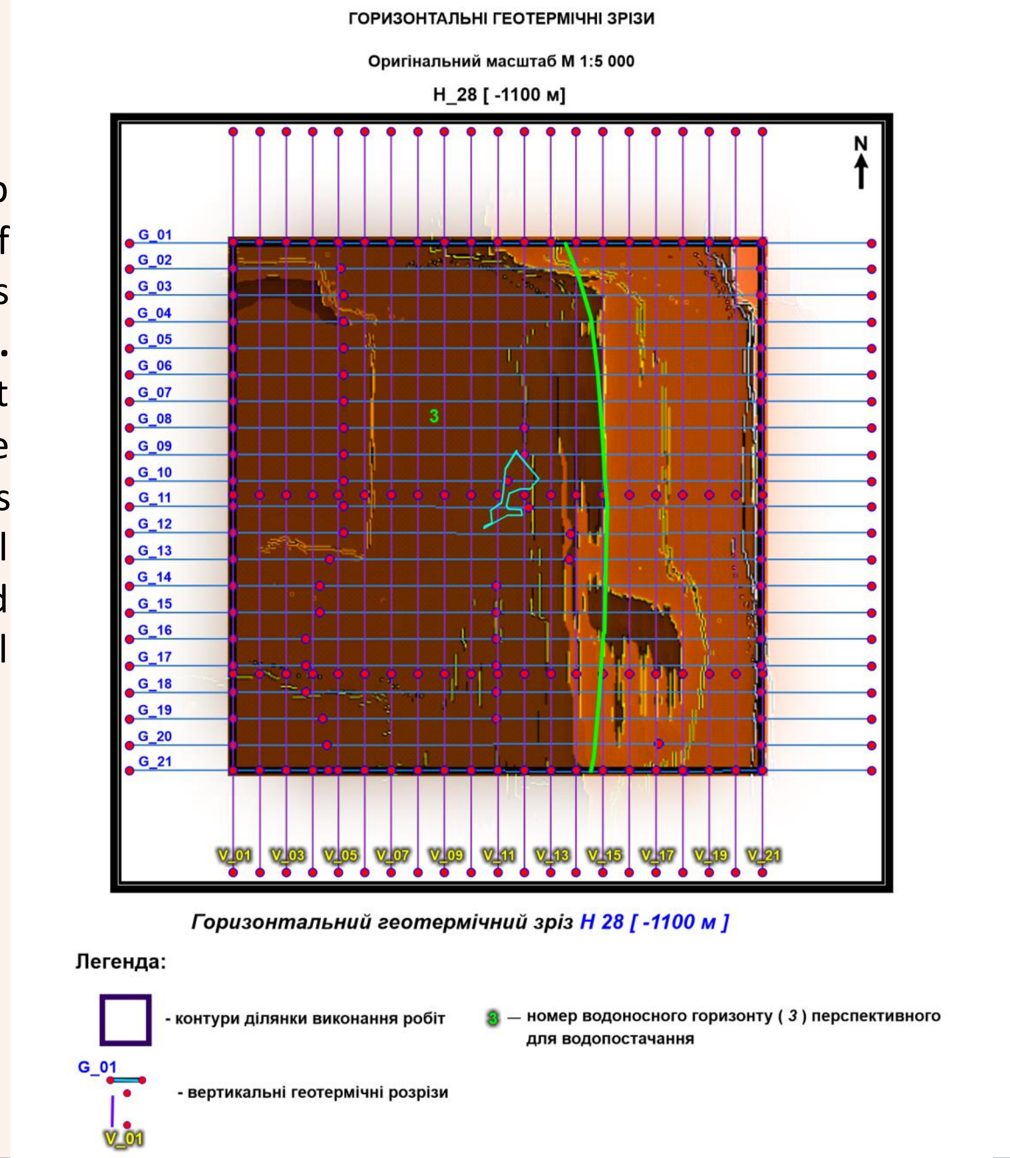
— Лінія уровня моря

— Лінії контурів ділянки дослідження

2-1 — номер водоносного горизонту (*2*) та номер ділянки, перспективної для водопостачання (*1*)

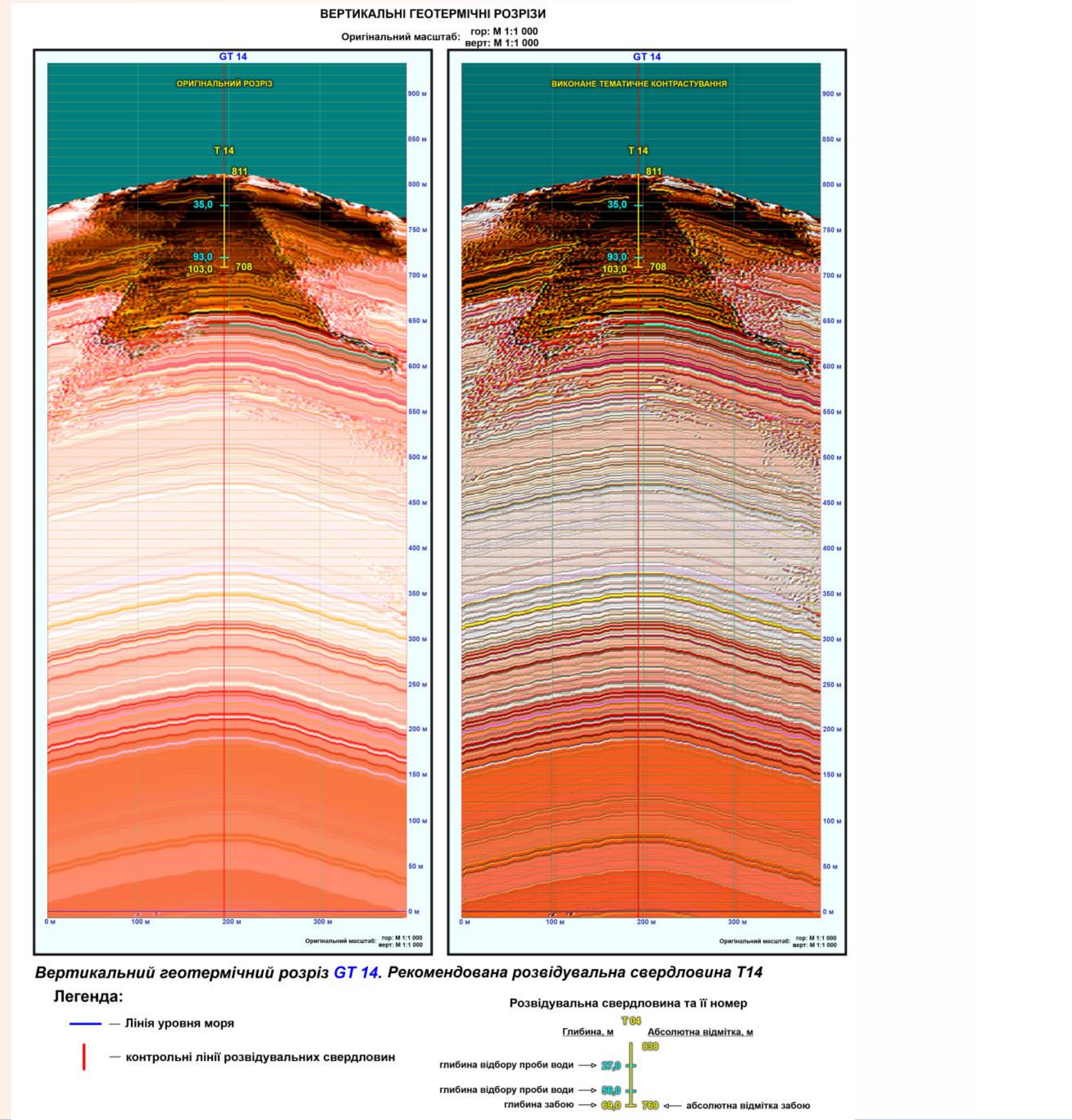
Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

The third aquifer from the surface lies in the deep fault zone of Cretaceous-Paleogene rocks at a depth of 1600-2300 m, which corresponds to absolute elevations of -800 - -1500 m. **Thermal mineral waters are forecast.** The greatest distribution is recorded in the western part of the study area with a maximum distribution to the west-northwest to the axial fault zone. The aquifer is shown as number **3** on the horizontal geothermal section **-1100 m**. An anomaly corresponding to the third deep aquifer is observed on all vertical geothermal sections.



Detection of the main sources of fresh, thermal, mineral waters in the area in the Eastern Carpathians

Vertical geothermal section through the recommended exploration well T 14. The first aquifer from the surface.



Recommendations for finding groundwater

As demonstrated above, volumetric images (geothermal cubes), consisting of successive scenes of the radio brightness temperature gradient (or thermal contrast) contain information about the deep structure of the geoenvironment (tectonic faults, blocks, structures, lithological contacts), as well as the location of aquifers, interstratal artesian waters and underground reservoirs, which are the main object of search, which allows us to recommend the RTT method for searching for groundwater.

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 geophysical methods and hydrogeological surveys.

Center of Aerospace Technologies ltd

Address: 26, Antim Pervi str., Burgas, 8000, Bulgaria;

tel.: +38 067 632 91 01

tel.: +359 89 462 00 30

e-mail: vl.bagrian@gmail.com