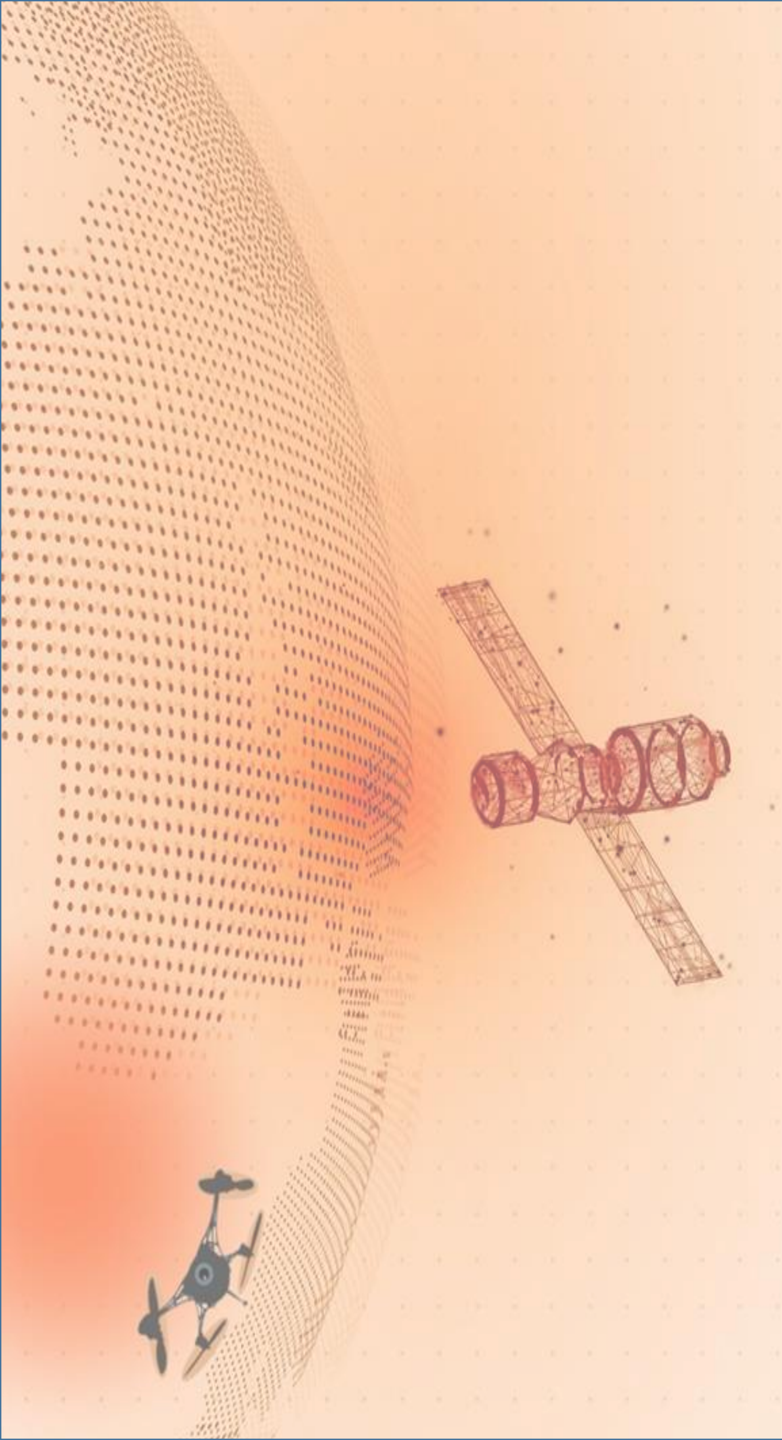
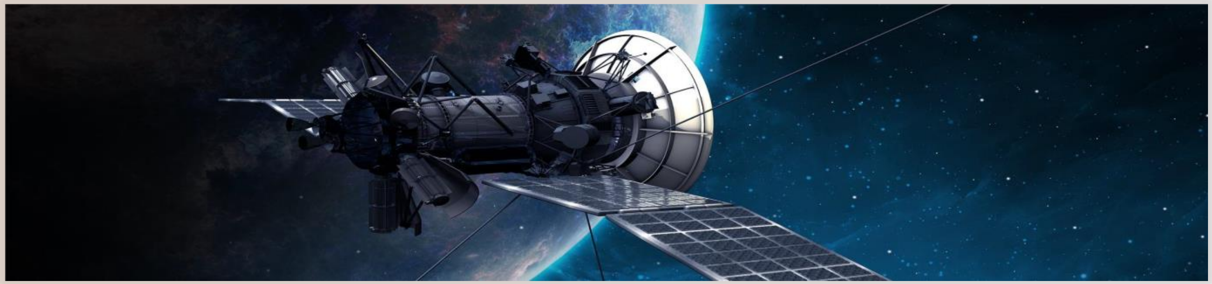


# Center of Aerospace Technologies ltd

## Radio-Thermal Imaging Technologies for searching and mapping ore minerals

# Center of Aerospace Technologies ltd

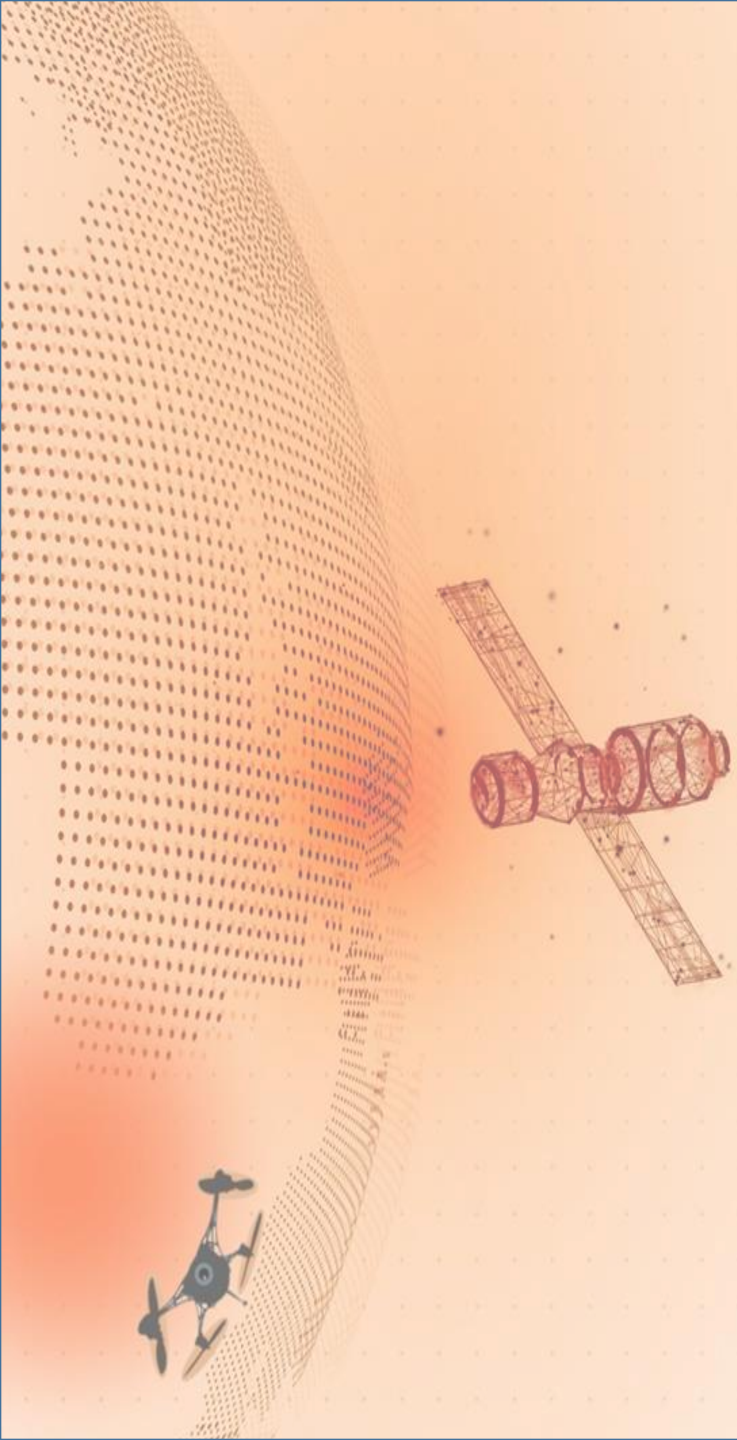


All over the world, one of the newest methods for studying the geological and tectonic structure, forecasting and searching for mineral deposits is Earth remote sensing (ERS). Radio-Thermal Imaging Technology (RTT), which our company owns and is an element of ERS, has been used for more than 10 years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

Today at the Center of Aerospace Technologies ltd. extensive research experience has been accumulated to identify beneficial mineralization of metallic minerals. RTT has established itself as a working tool for studying the structure of the geoenvironment, as well as a method for identifying geothermal anomalies, which are prototypes of zones of mineralization of specified metals (search objects) containing ore deposits.

# Center of Aerospace Technologies ltd

## Geography of completed work :



# 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.

To solve geological problems: searching for zones of mineralization containing ore deposits, 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)

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.

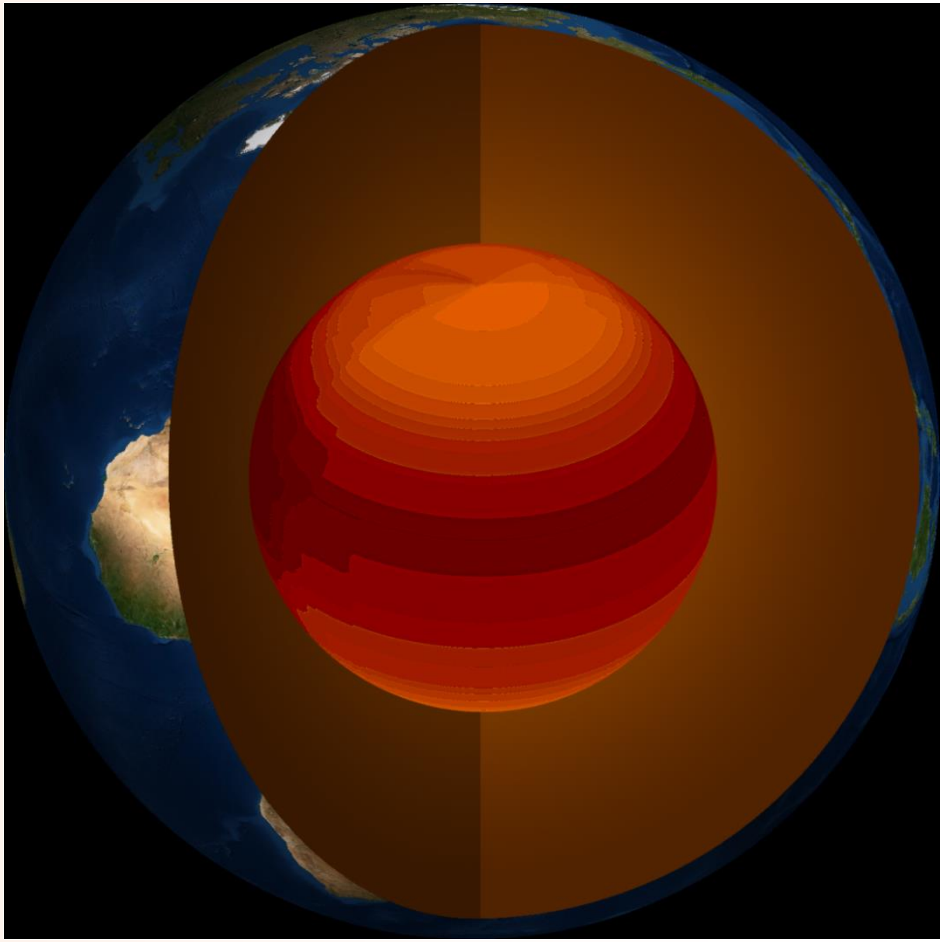
The initial data is information received from Earth satellites in the radio-thermal range of electromagnetic waves (Landsat 8 (OLI/TIRS), GCOM-W1 (AMSR-2), ASTERGDEM, Sentinel, etc.).

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.

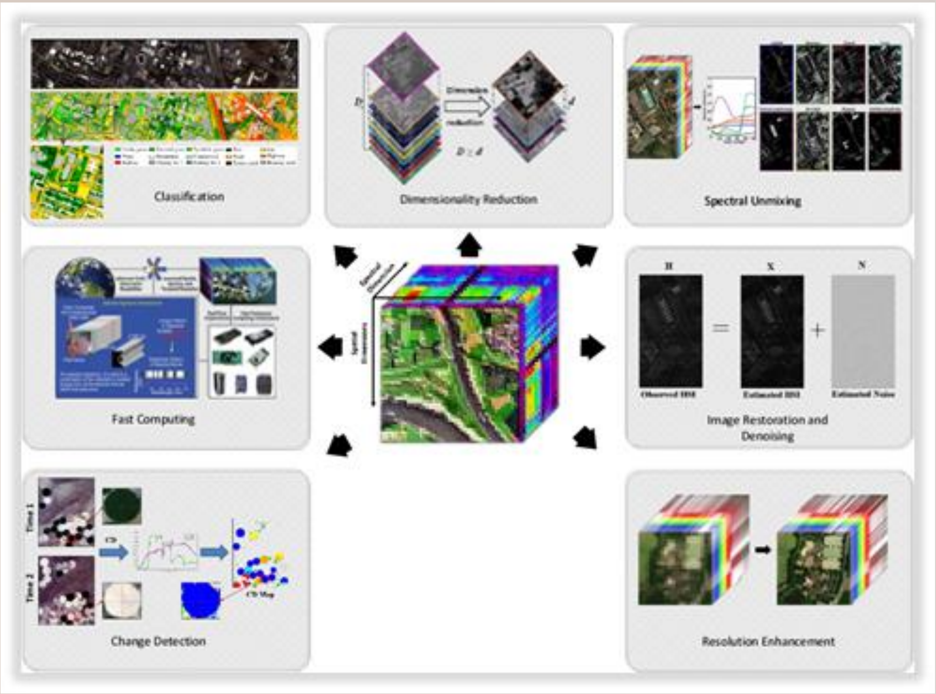
Processing of space images is carried out in the Software (through a training sample) with the construction of a 3D cube model.

# RADIO-THERMAL IMAGING TECHNOLOGIES (RTT)

A significant difference of 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 ore-controlling faults of various ranks. In addition, the processing program allows you to enter an infinite number of points, carrying initial a priori information about geology, increase temperature sensitivity and resolution of surveying, 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

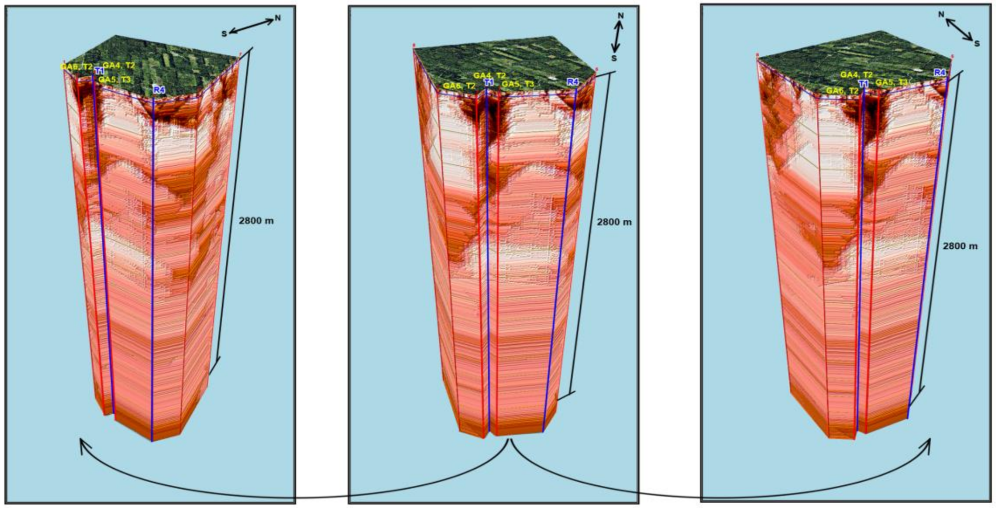



Fig 5.38 Объемный вертикальный разрез 3DV2. Построен по данным геотермического 3D куба масштаба 1:25 000.

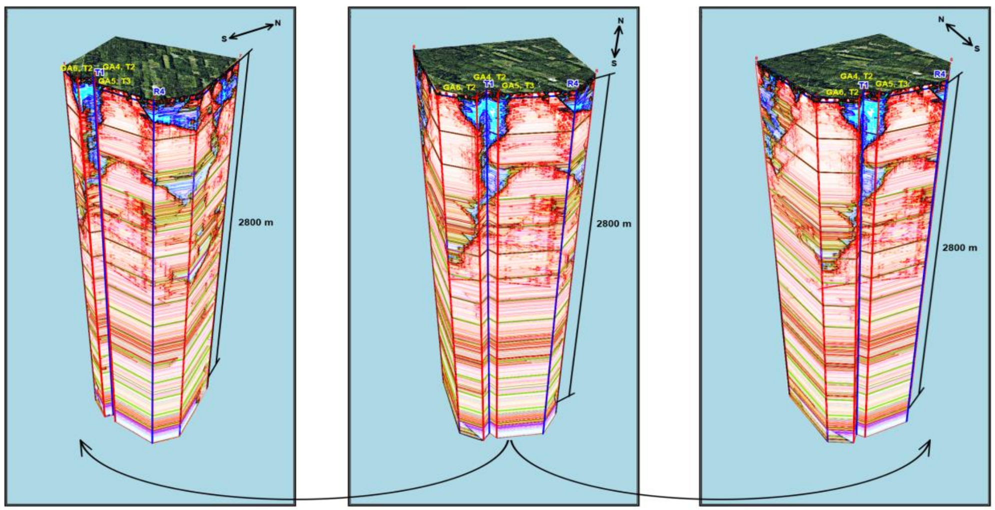



Fig 5.39 Объемный вертикальный разрез 3DV2. Выполнено тематическое контрастирование.

**Легенда**

- Проекция линии вырезки фрагмента 3D куба, используется для построения объемных вертикальных разрезов.
- Расположение лицензионной площади Välikorpi
- R1 ● Расположение буровых скважин GTK
- T1 ● Точка, соответствующая группе скважин GTK R358-R372
- GA6, T2 ● Расположение рекомендуемых скважин для первоочередного бурения на лицензионной площади Välikorpi. По данным вертикальных геотермических разрезов GA5, GA6.
- GA6, T2 Рекомендуемые скважины для первоочередного бурения на лицензионной площади Välikorpi. По данным вертикальных геотермических разрезов GA5, GA6.
- R4 Буровые скважины GTK
- Угловая стрелка, показывающая разворот разреза

**Примечания:**

1) Описание горных пород геологического разреза приведено на рисунках 5.25, 5.26 ( Лист №12 "Приложения 5" Книги 2)

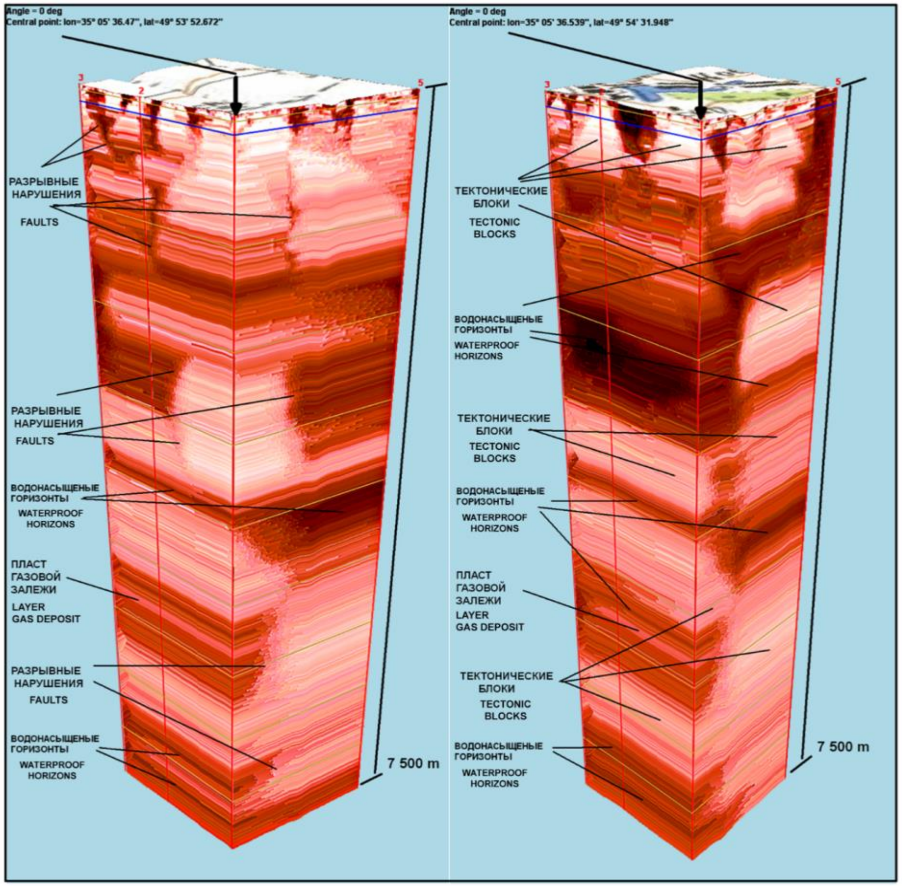
2) Координаты и глубины скважин, рекомендуемых для первоочередного бурения на Лицензионной площади Välikorpi приведены на Рис. 5.27-5.33 ( Лист №13 "Приложения 5" Книги 2)

An example of constructing and interpreting 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. It 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

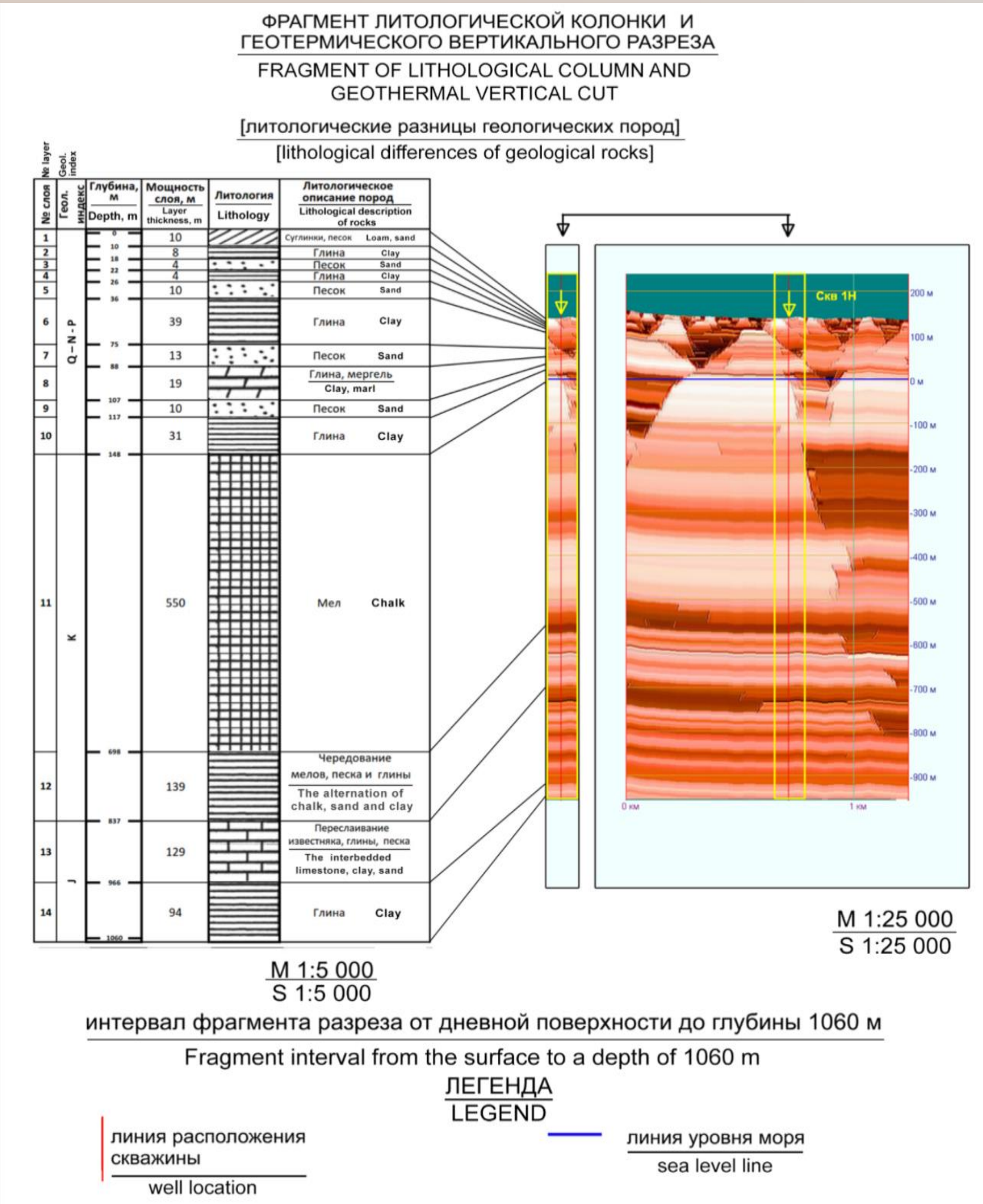
The detail of near-surface skin layers depends on the detail of thermal IR images. For example, IR images of the Landsat-8 thematic cartographer are considered correct for work scales no larger than M 1:25,000 horizontally and no larger than M 1:10,000 vertically. IR images from the Aster thematic cartograph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

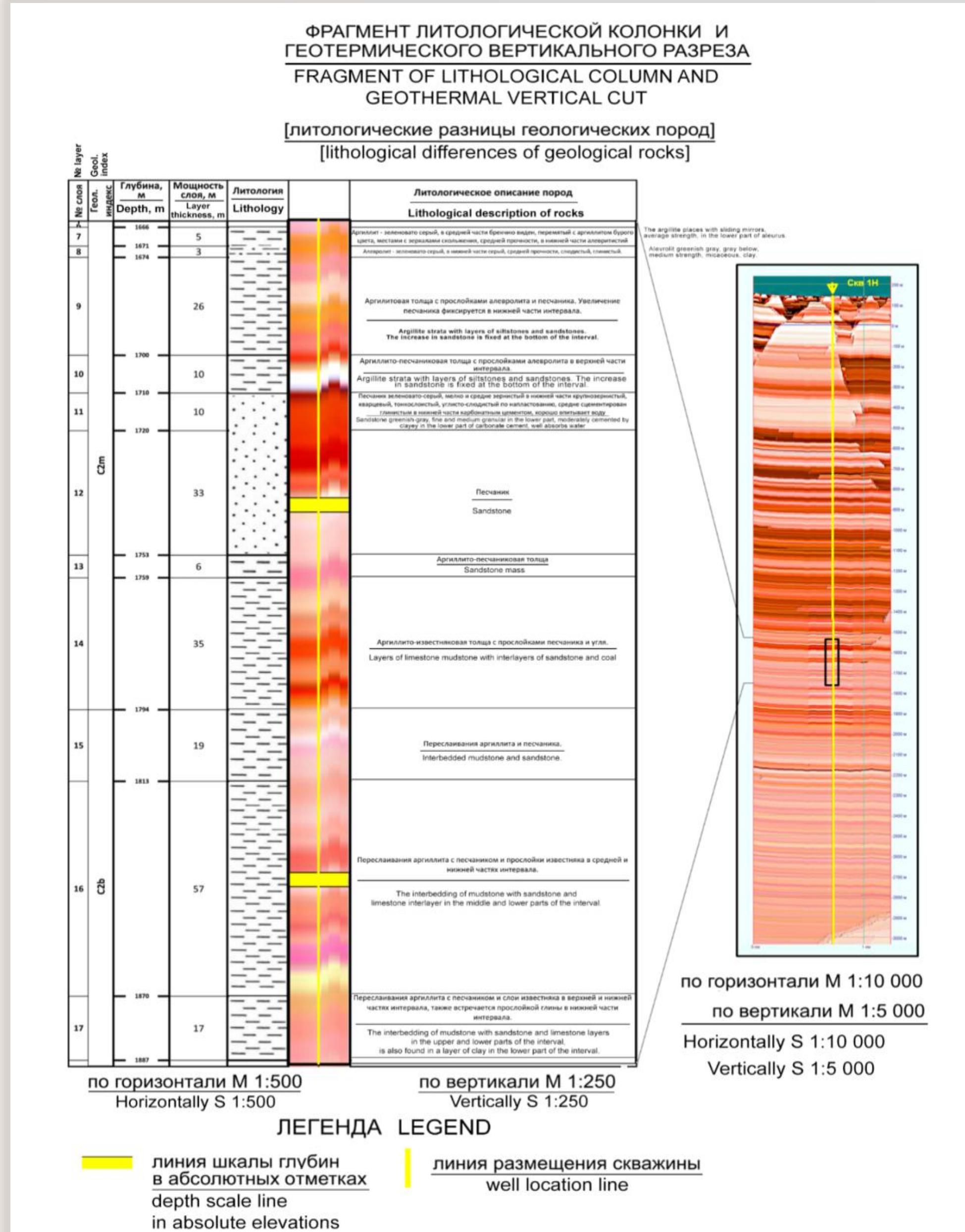
For these and larger scales, satellite radiometers can also be used: AVHRR, MODIS, AMSR, SSMI, WINDSAT, VIIRS, ATMS and others.

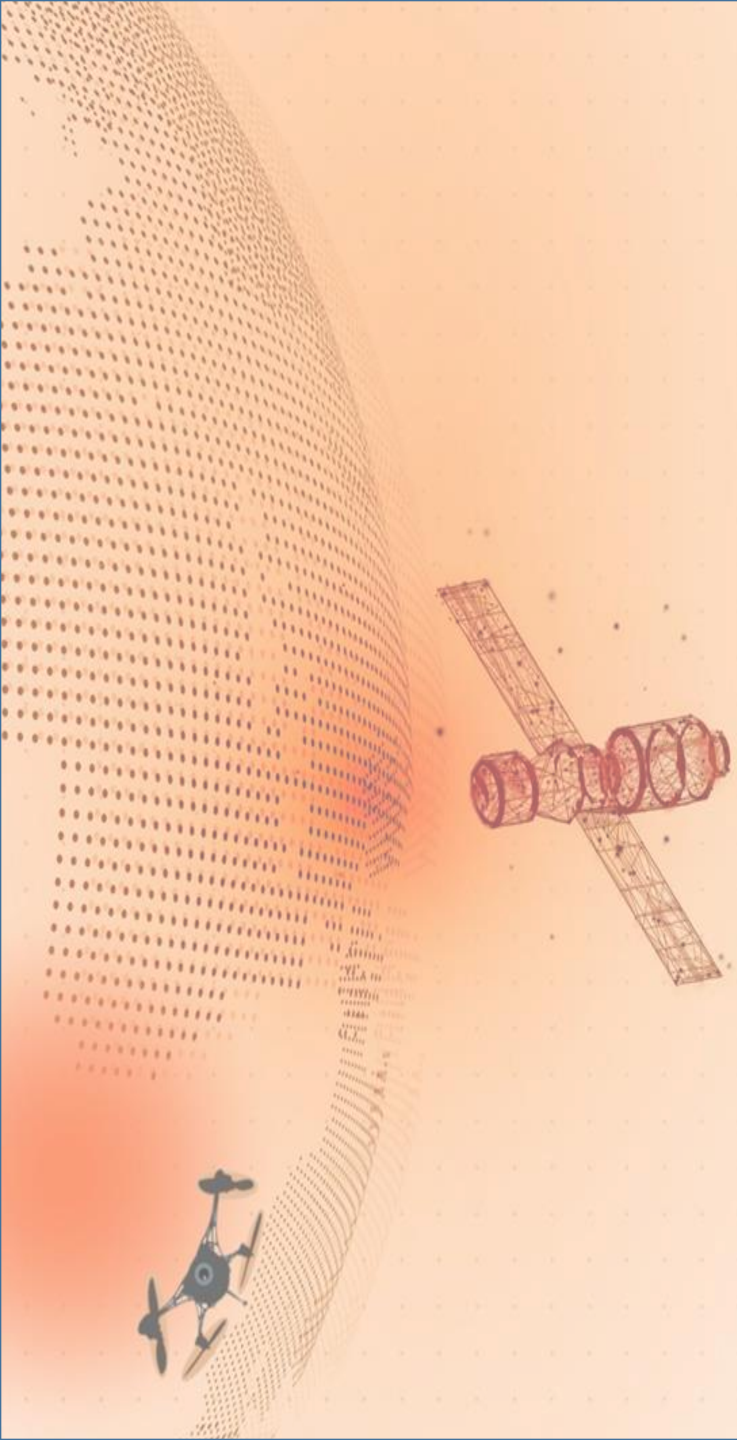
There are technologies for restoring image resolution: IR images can be realized on a scale of work 2-5 times more detailed (using technologies for restoring resolution and image detail). Detail decreases with depth. But it can also be restored using image restoration technologies. It is practically 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 17***, 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





# 2. SEARCHING AND MAPPING ORE MINERAL RESOURCES

# Model calibration

Calibration of the 3D cube model is carried out to clarify the position and depth of structural heterogeneities of the proposed ore deposit, by comparison with a reference object, for example, an explored deposit. For these purposes, information from existing geological wells or operating mines 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 about more than 500 test sites - the most famous endogenous deposits of gold, silver, antimony, diamonds, examples of successful exploitation of which are known in the world. In the absence of exploratory drilling data or other geological studies for a given area, the method of analogies is used.

# Basic approaches to RTT research for searching for ore minerals. Deep factors

The work uses a classic approach to searching for ore minerals - from general to specific, from regional to local, from studies of large mantle faults to detailed mapping of individual fragments of fault zones: the scale of research is from 1:50,000,000 to 1:25,000 with detailing of useful structures in scale 1:5 000.

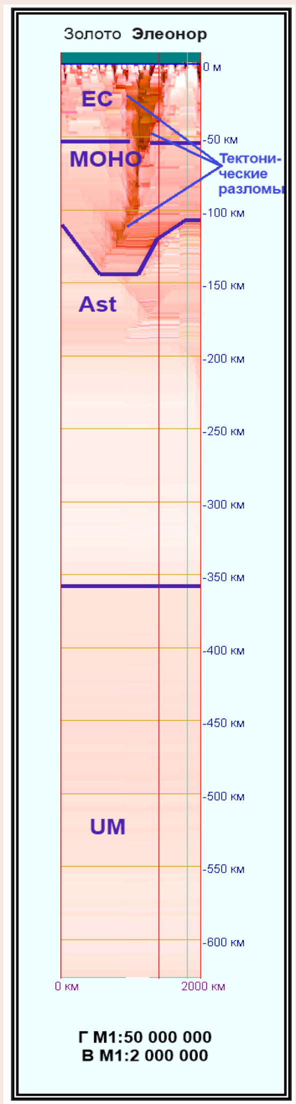
Based on the accumulated experience in studying gold deposits, diamonds and other minerals of endogenous origin, a connection between the deposits and mantle (root) faults has been established, which is confirmed by the work of many world known scientists.

The result of regional studies of the deep structure of known primary deposits (gold, platinum, silver, copper, base metals, diamonds) is the construction of geothermal sections based on calculation models: 3D cubes of deposits. Known areas serve as test sites for studying the deep factors of the formation of ore-bearing geological formations, spectral analysis and retrospective forecast of metal mineralization in the rank of the proposed ore cluster.

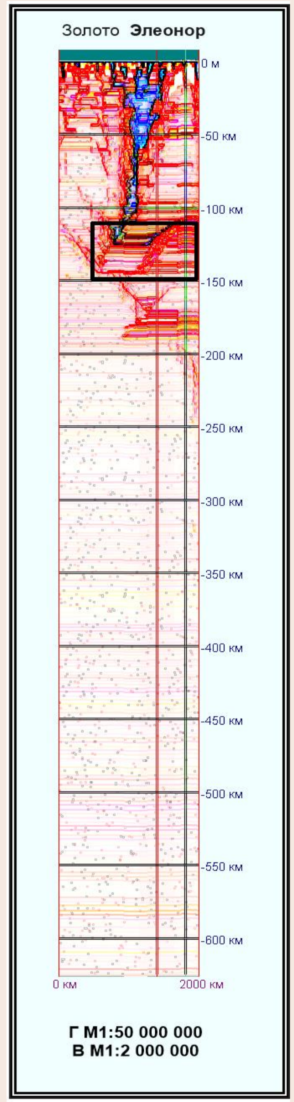
Below are examples of regional studies of some known metal deposits (***slides 17-19***).

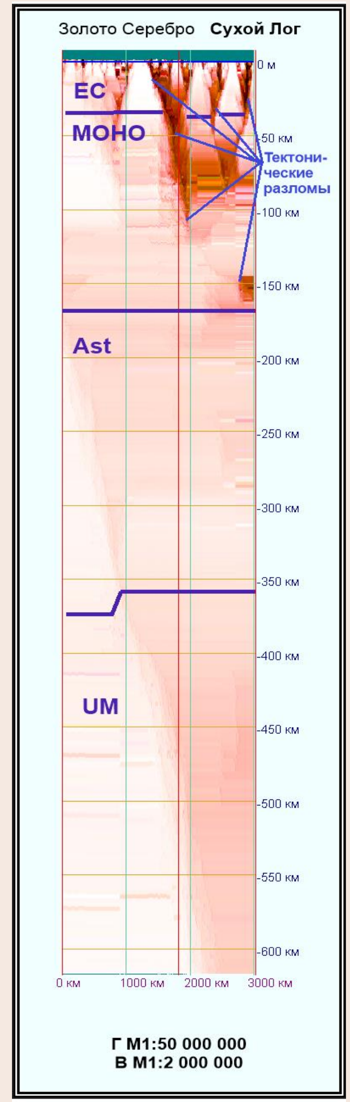
# Examples of test areas for model calibration and analysis of deep factors when searching for metal ore deposits

Test sites “Eleanor” (Canada) - gold, “Sukhoi Log” (Russia) - gold, silver




Выполнено
тематическое контрастирование

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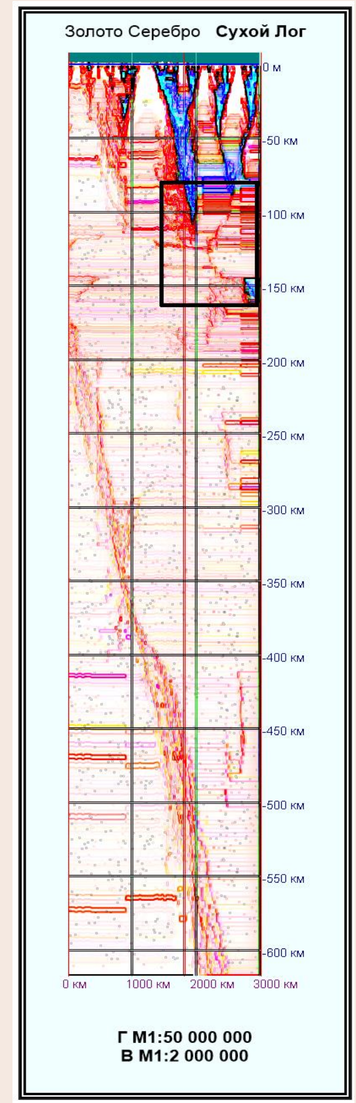
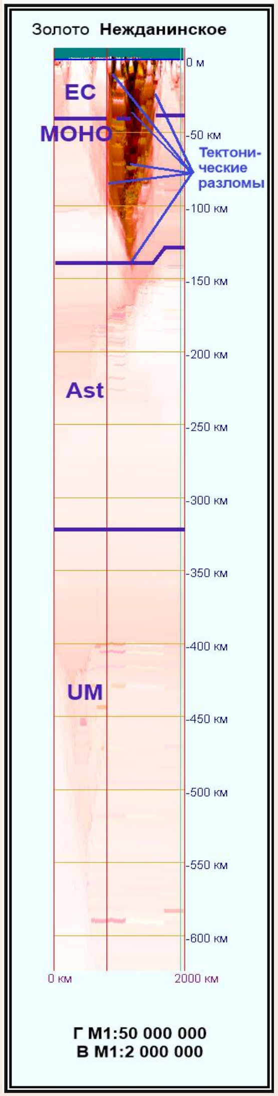



Условные обозначения:

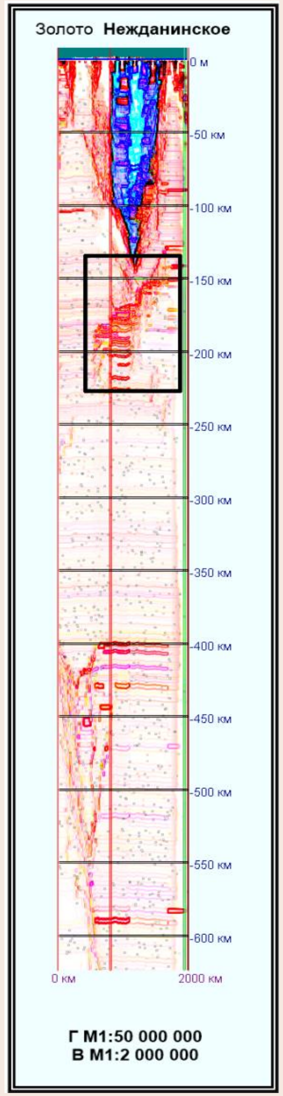
| | |
|---|---|
| EC | Земная кора |
| MOHO | Граница земной коры |
| Ast | Астеносфера |
| UM | Верхняя мантия |
| (синяя линия) | Линия уровня моря |
| (красная линия) | Линия расположения месторождения |

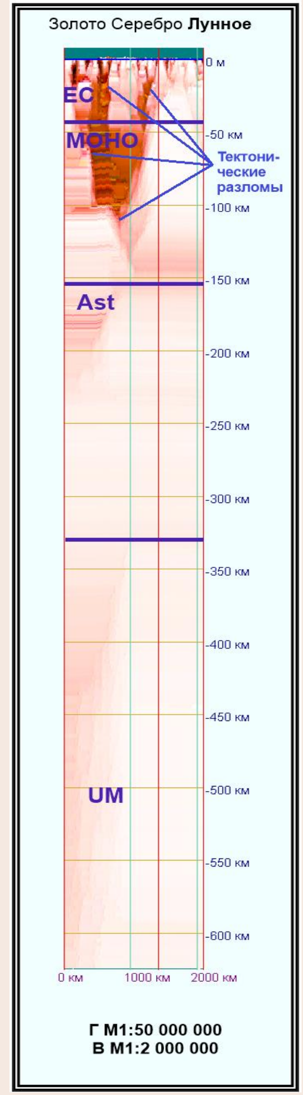
# Examples of test areas for model calibration during searches metal ore deposits

Test sites "Nezhdaninskoye" (Russia) - gold, "Lunnoe" (Russia) – gold, silver

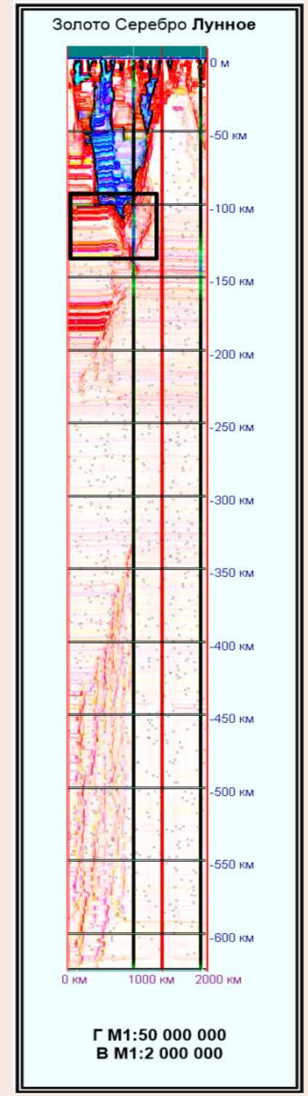



Выполнено тематическое контрастирование




Выполнено тематическое контрастирование

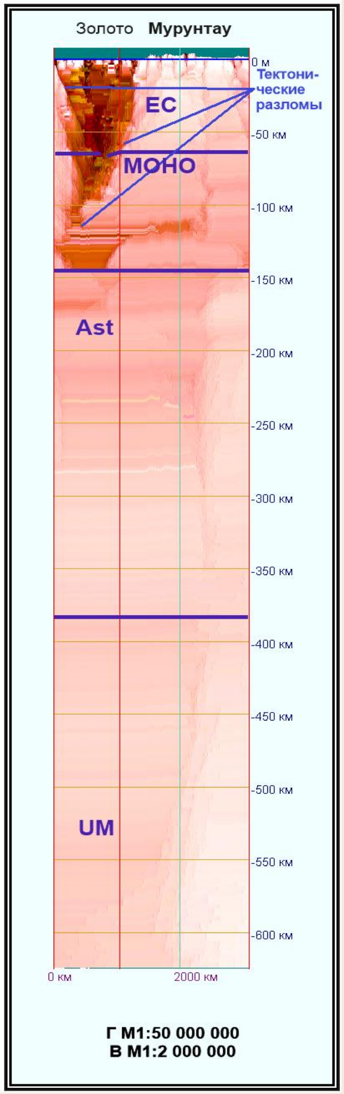



**Условные обозначения:**

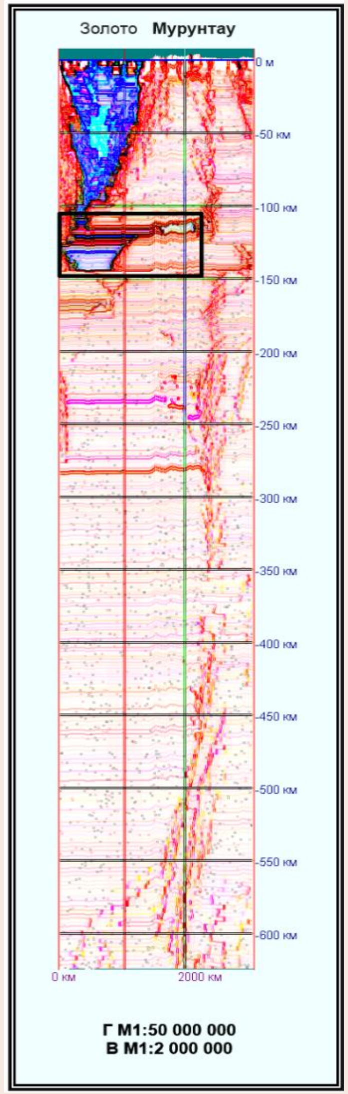
- ЕС — Земная кора
- МОНО — Граница земной коры
- Ast — Астеносфера
- UM — Верхняя мантия
- Линия уровня моря
- Линия расположения месторождения

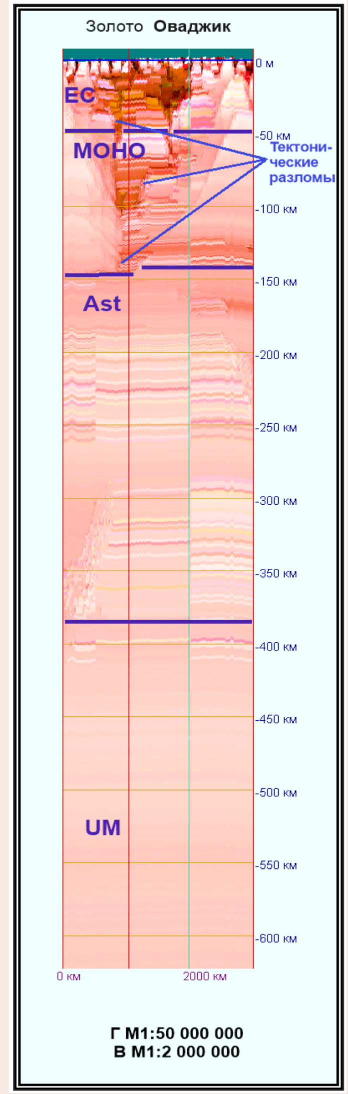
# Examples of test areas for model calibration during searches metal ore deposits

Test sites “Muruntau” - gold (Uzbekistan), “Ovacik” (Turkey) - gold




Выполнено
тематическое контрастирование




Выполнено
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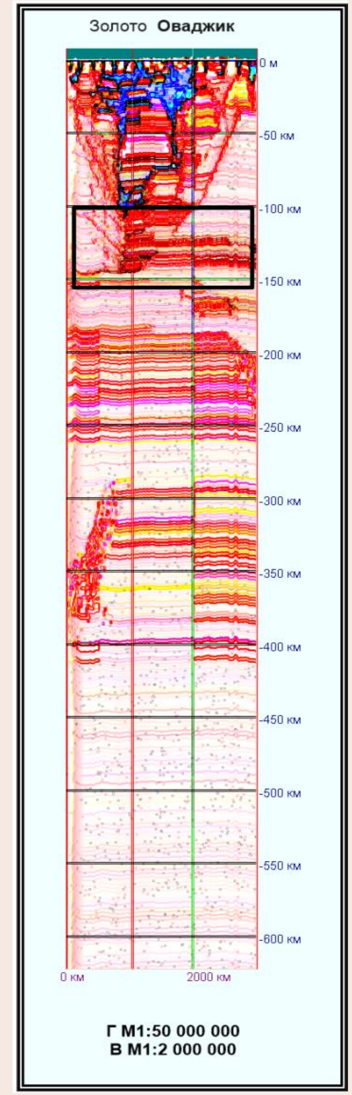


**Условные обозначения:**

| | |
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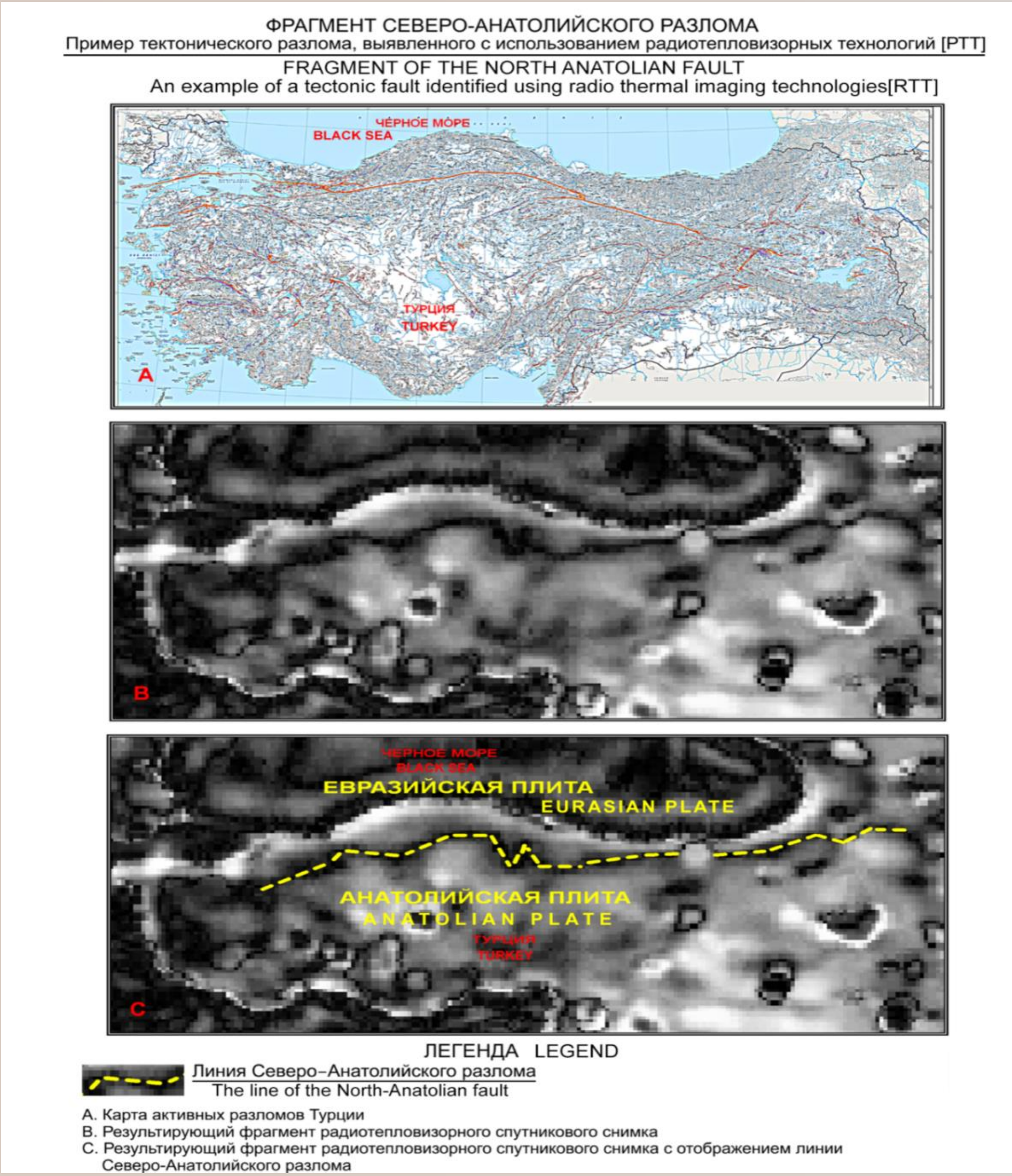
| — | Линия уровня моря |
| — | Линия расположения месторождения |

# Faults identified by the RTT method



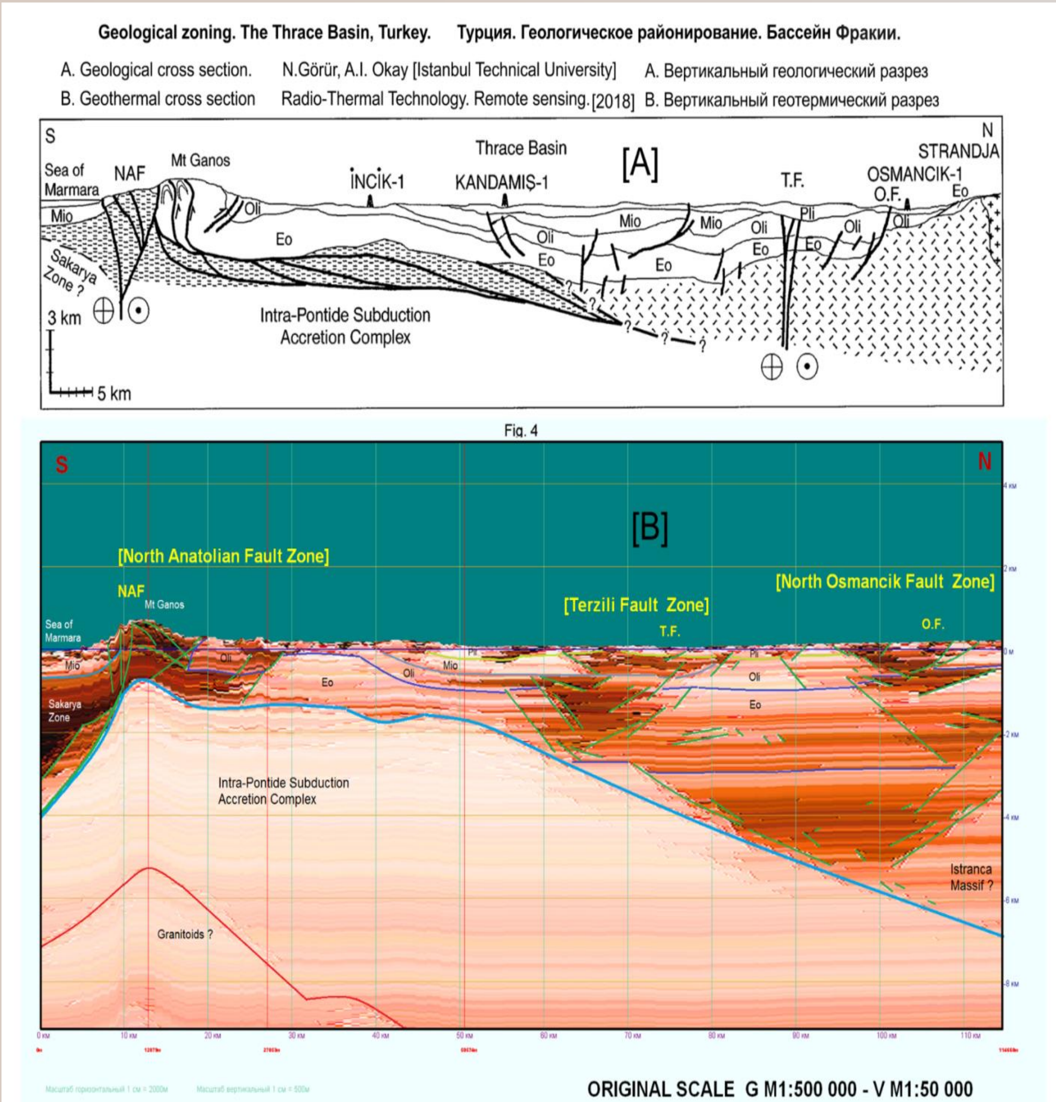

Mapping of deep faults of mineral deposits is the basis of searches using the Radio-Thermal Imaging Technology of remote sensing of the Earth, since the structural and tectonic heterogeneity of the ore-bearing environment controls the spatial localization of mineralization.

Faults are a striking example of geothermal field inhomogeneities.

The algorithm of the Space Image Processing Program provides for the block structure of the Earth's crust.

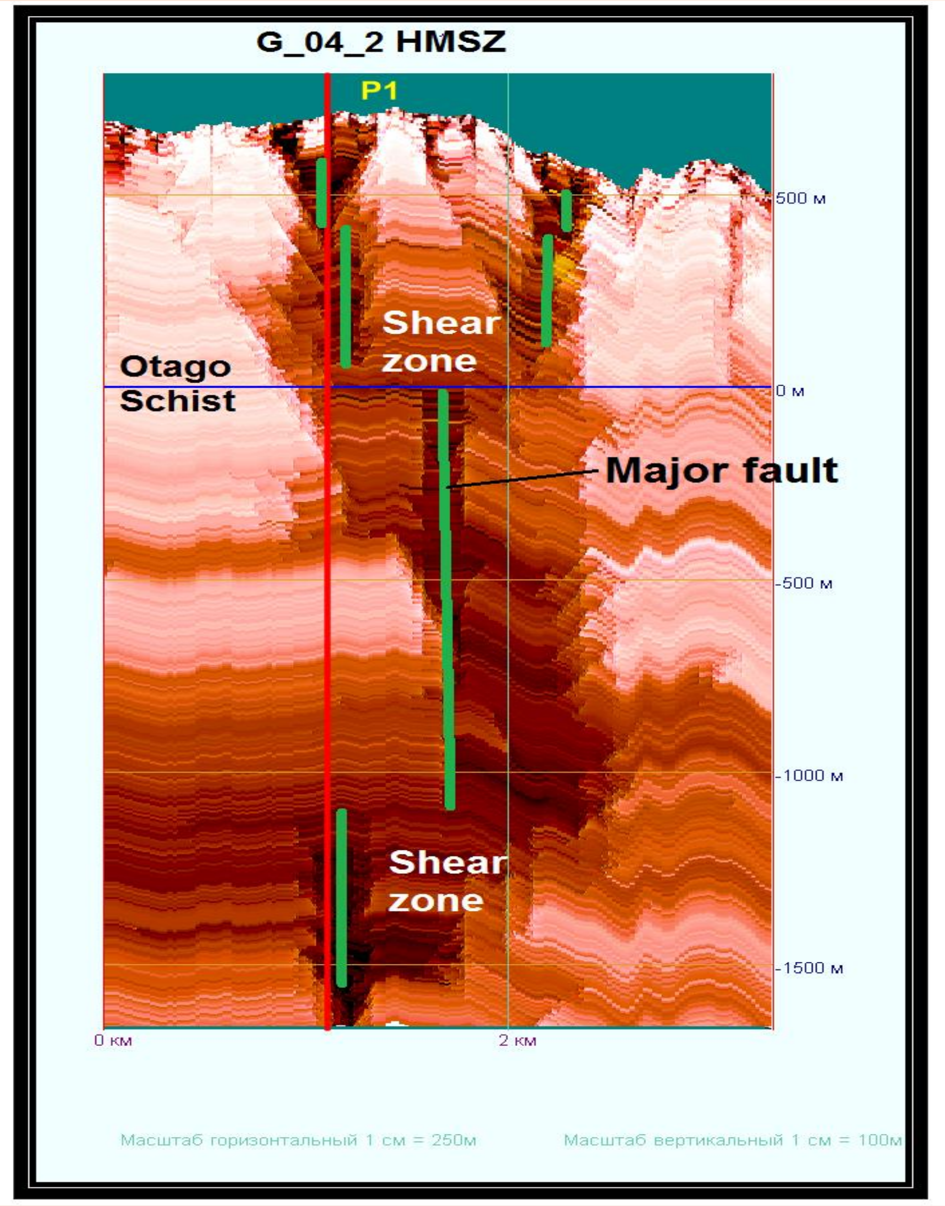
Blocks of any order are separated from each other by discontinuities.

# Faults identified by the RTT method




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

# Faults identified by the RTT method




An example of constructing and interpreting vertical sections based on geothermal 3-D cube data highlighting tectonic fault zones

# Main criteria for identifying zones of metal mineralization in a geological massif

**1** Ore-bearing zones are in the range of the emissivity spectrum of given metals (**slide 25**). Elements of primary scattering halos and accompanying metals may also be present in this range;

**2** Ore-bearing structures are steeply dipping zones of faults and faults and their intersection points, confined to regional faults of a higher order, as well as zones of shearing adjacent to the fault, horizontal and subhorizontal occurrence;

**3** Tectonic position of the area in the zone of a deep mantle fault - an ore-supplying structure.

As a rule, industrial mineralization accumulates in mobile tectonic blocks (interblock space), which have experienced variable movements throughout the geological history of the area. Thus, the determining factors in the location of zones of useful mineralization and ore deposits are tectonic factors, and, first of all, the location of the deposit in the zone of a large deep fault - the main regional ore supply channel. Large faults associated with the fault zone are considered to be the most important ore-distributing structures.

# Examples of using the RTT method to search for metal ore deposits

The capabilities of Radio-Thermal Imaging Technologies for searching for metal ore deposits are outlined in the articles "***Using the Radio-Thermal Imaging Technology method to search for ore deposits of platinum group metals, including palladium***" (**link**) and "***Using the Radio-Thermal Imaging Technology method to search for lithium ore deposits***" (**link**), where, using the "Physics of the recognition process of ore formations using RTT technologies," the features of decoding, visualization and recognition of ore deposits using the emissivity of rock elements and the ore component are revealed. A table of typical emissivity coefficients of materials [ε] is presented (**slide 25**) and the corresponding color-synthesized scale of a volumetric geothermal model of a section of a geological massif. The contrast of radio brightness temperature, $\Delta Tb = \varepsilon \Delta Te$, records the filling of the ore component with "hotter" metals, in comparison with the "cool" host granites. It is shown that the calibration of the model and subsequent interpretation were carried out based on materials from prospecting and exploration work at the field, including data from drilling wells.

# Examples of using the RTT method to search for metal ore deposits

Typical emissivity of materials [ε]

| Шкала | Качественная цветосинтезированная шкала | Обозначение | Материал / Элемент | Коэффициент излучения (λ = 8..14 μм) Min | Max |
|---|---|---|---|---|---|
| 0,01 | | Au | Золото | 0.01 | 0.1 |
| 0,02 | | Ag | Серебро | 0.02 | 0.2 |
| | | Mg | Магний | 0.02 | 0.1 |
| | | Cr | Хром | 0.02 | 0.2 |
| | | Cd | Кадмий | 0.02 | |
| | | W | Вольфрам | 0.03 | |
| | | **Li** | **Литий** | **0.04** | **0.09** |
| 0,05 | | Pd | Палладий | 0.05 | |
| | | Cu | Медь | 0.05 | 0.1 |
| | | Hg | Ртуть | 0.05 | 0.15 |
| 0,08 | | Fe | Железо | 0.05 | 0.2 |
| 0,1 | | Ni | Никель | 0.07 | 0.08 |
| | | Pt | Платина | 0.08 | |
| | | Mo, Zn | Молибден, Цинк | 0.1 | |
| | | Al | Алюминий | 0.1 | 0.3 |
| | | Be | Бериллий | 0.18 | |
| | | Sb | Сурьма | 0.28 | 0.31 |
| | | Bi | Висмут | 0.34 | |
| | | Pb | Свинец | 0.4 | 0.43 |
| 0,5 | | | Гранит | 0.4 | |
| 0.7 | | Ti | Титан | 0.5 | 0,6 |
| | | | Базальт | 0.7 | |
| | | | Уголь | 0.8 | 0.9 |
| 0,9 | | | Песок | 0.9 | |
| | | | Вода, Кварц | 0.93 | |
| 0,95 | | | Глина, Гравий, Мрамор белый | 0.95 | |

# Using the Radio-Thermal Imaging Technology method to search for ore deposits of platinum group metals, including palladium

The work (**link**) examines the possibilities of the Radio-Thermal Imaging Technology method for searching for ore deposits of platinum group metals, especially palladium, using the example of the Elan deposit of the Voronezh crystalline massif. Geothermal sections show the columnar geological structure (intrusion) of the main ore body containing palladium and other platinum group elements. The deep origin of ore deposits of platinum-copper-nickel-palladium deposits and the connection of ore structures with dikes were traced.

Information received from Earth satellites in the radio-thermal range of electromagnetic waves was used as initial data. The interpretation of thermodynamic anomalies was carried out using the research results of Corresponding Member of the RAS Chernyshov N.M. and Chernyshova M.N. "Sulfide platinoid-copper-nickel deposits of the Elan type (geology, patterns of placement, mineralogical and geochemical features of ores). Geological-genetic model of formation. (Chernyshov N.M. 1998)", "Mamon and Elan types of sulfide platinoid-copper-nickel VKM deposits (Chernyshov N.M., Chernyshova M.N. 2008) “and others.

Based on the results of research using the RTT method at a scale of 1:5,000 (horizontal and vertical), a three-dimensional cube and 18 vertical sections with a step of 100 m were built on the area of the Elan field. The research step can be different, based on the scale of the research, the tasks set and the spatial dimensions of the mapped structures in a geological massif. Research depth: to the horizon -3000 m in absolute elevations.

# Using the Radio-Thermal Imaging Technology method to search for ore deposits of platinum group metals, including palladium

As an illustration, this work shows vertical sections G 3 and V 5 (**slides 28, 29**), passing through the intrusion, which includes the main ore body containing palladium and associated metals. In addition, 3 horizontal sections (slices) were built along the horizons: +100 m, -500 m, -2200 m in absolute elevations (**Slide 30**).

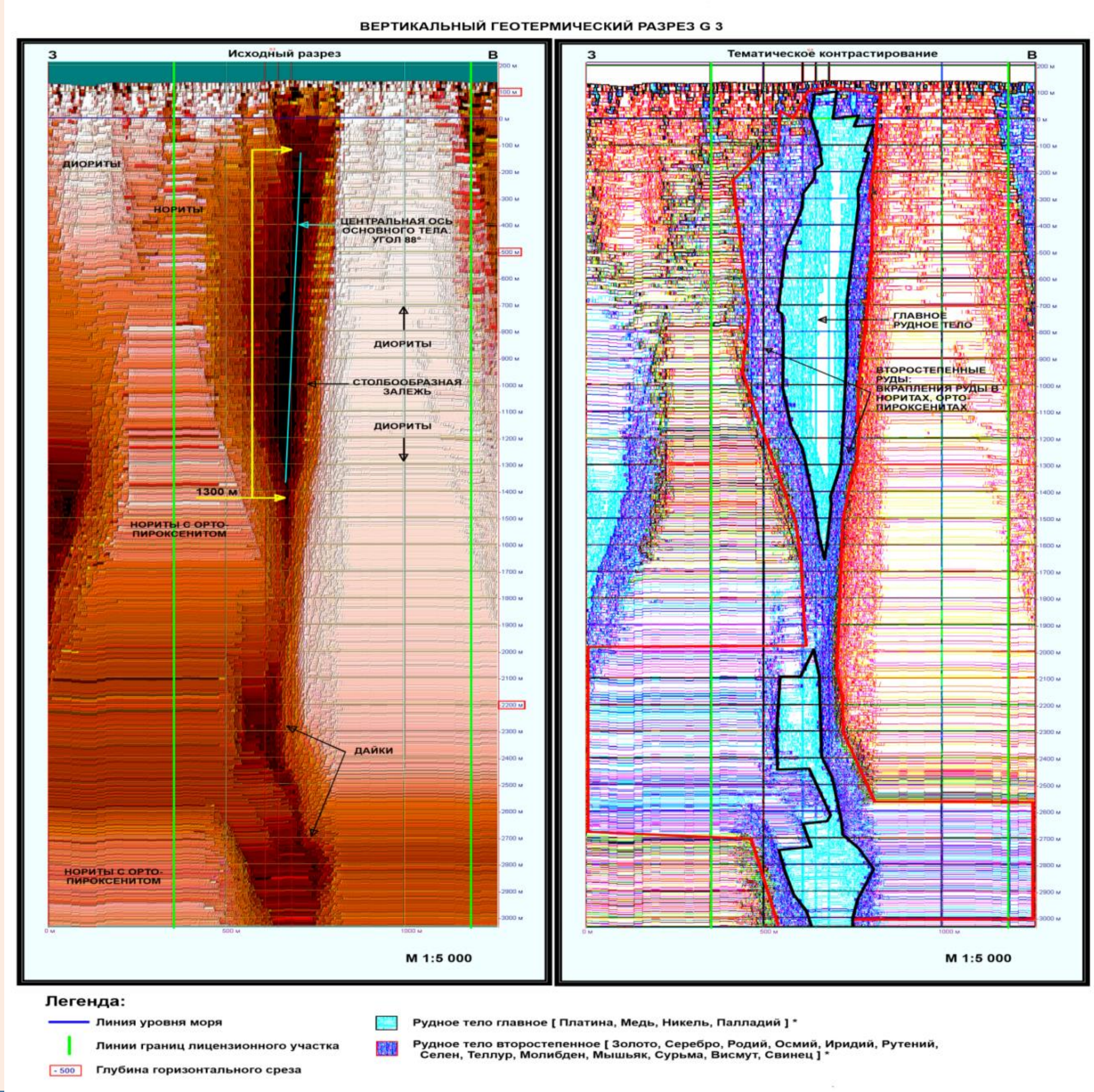
The main ore body is well delineated by the results of spectral analysis in the form of a geothermal anomaly corresponding to a columnar deposit of the norite-diorite phase. The ore body dips to the east at an angle of - 88°. To the north - 86°, i.e. almost vertical. Vertical size of the anomaly: 900-1300 m, cross-section 100-300 m in the depth range – 120÷-1420 m (in absolute levels). Host rocks: norites, norites with orthopyroxenite, diorites, granodiorites.

Along the periphery of the deposit, ore inclusions in norites and orthopyroxenites are distinguished. Below the ore body, a dike was recorded, which confirms the multiphase nature of the intrusion, and the deep (mantle) nature of the formation of the deposit is well illustrated in a horizontal section (**Slide 29**), where the “root” of the ore body extends to a depth of -2200 m or more.

It should be noted that the columnar nature of the ore bodies and zones of the Elan deposit has been confirmed by geological studies to a depth of 1500 m.

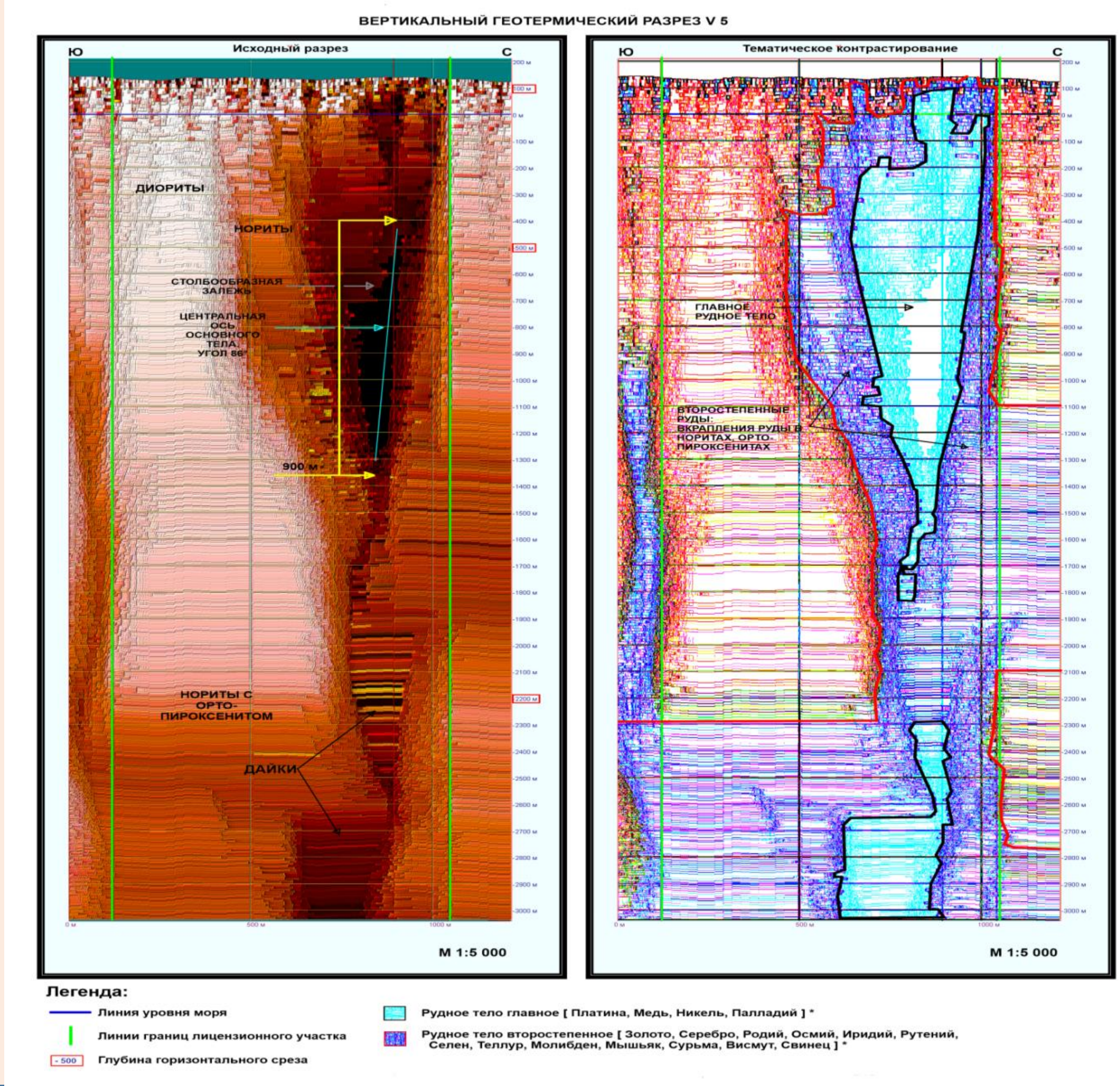
# Using the Radio-Thermal Imaging Technology method to search for ore deposits of platinum group metals, including palladium

Elan field.
Vertical geothermal section G 3 West-East



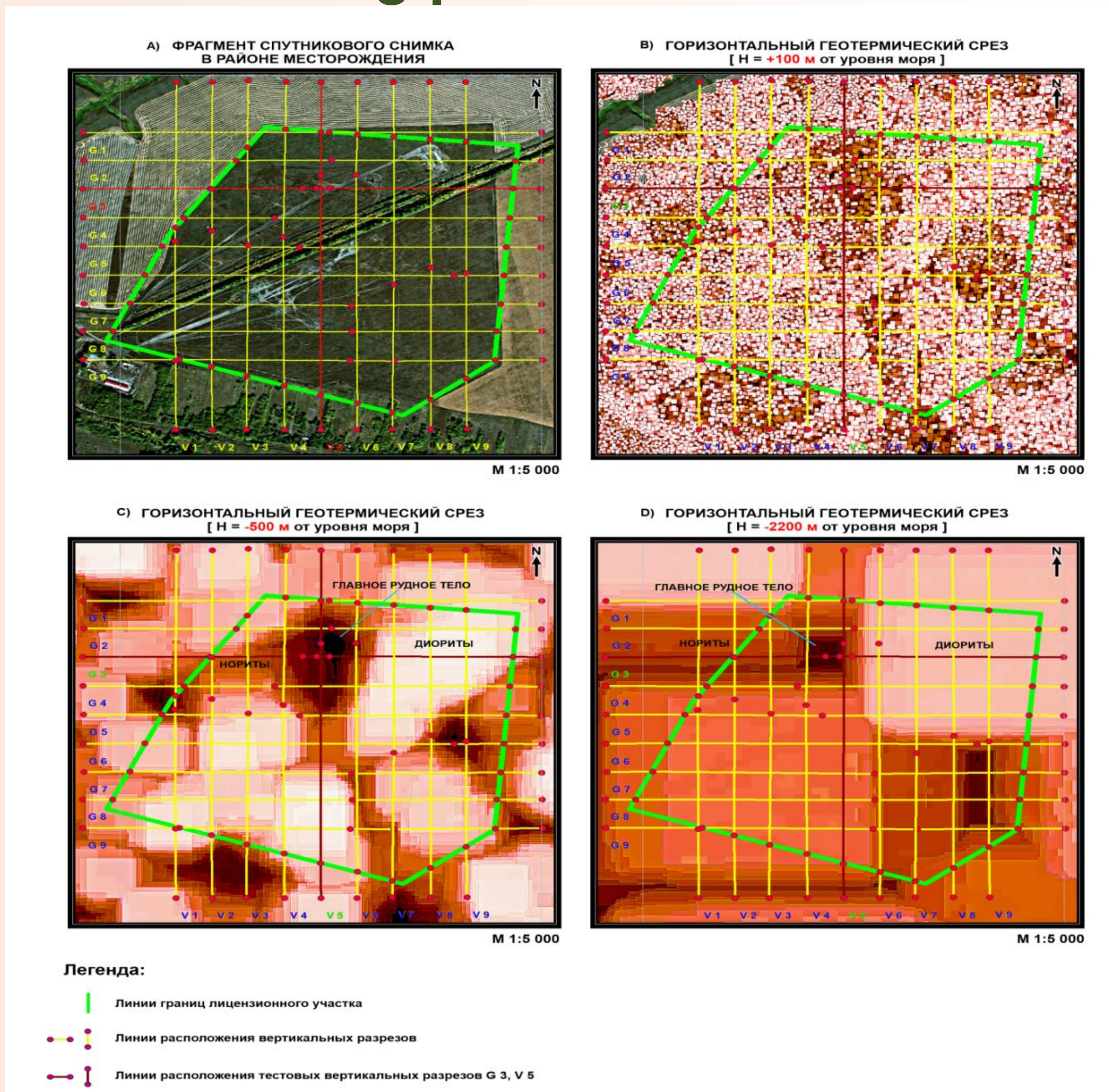
# Using the Radio-Thermal Imaging Technology method to search for ore deposits of platinum group metals, including palladium

Elan field. Vertical geothermal section V 5 South-North



# Using the Radio-Thermal Imaging Technology method to search for ore deposits of platinum group metals, including palladium

Elanr field. A – section lines on a satellite image, B, C, D – horizontal geothermal sections



# Using the Radio-Thermal Imaging Technology method to search for ore deposits of platinum group metals, including palladium

The results of the presented work allow us to state that the RTT remote sensing method is capable of identifying ore deposits, including platinum-copper-nickel-palladium and other associated metals. This is clearly demonstrated by vertical geothermal sections (**slides 28, 29**) and horizontal sections (**slide 30**).

A complete analysis of the materials allows us to draw the following conclusions:

- deep, more than one kilometer structure, in the form of a columnar deposit in diameter - round in shape;
- the central axis of the main ore body is within close to an angle of 90 degrees;
- the deposit was formed along a guide in the form of a spiral, counterclockwise;
- the path of formation of an ore deposit from the mantle depths of the Earth is tracked;
- Based on the emissivity of the elements of the geological section and the corresponding spectra of the color scale, it can be assumed that the geological structure has an ore formation and contains elements of the platinum group of metals.

# Using the Radio-Thermal Imaging Technology method to search for lithium ore deposits

The work (**link**) examines the possibilities of the Radio-Thermal Imaging Technology method for searching for lithium ore deposits using the example of one of the largest deposits in Europe - the Polokhovo deposit of the Polokhovo crystalline massif of the Ukrainian Shield.

Over the area, 2 vertical geothermal sections were built on a scale of 1:5,000 to a horizon of -1200 m at an absolute elevation, illustrated on **slides 33, 34**. Section line 5-5, combined with the geological section, which makes it possible to compare the geothermal anomaly with drilling data. Contrast was used to visualize the ore deposit.

Geothermal sections show the vertical geological structure (intrusion) of the main ore body containing lithium and other associated elements. The deep origin of ore deposits of lithium deposits and the connection of columnar ore structures with aplite-pegmatite granites were traced.

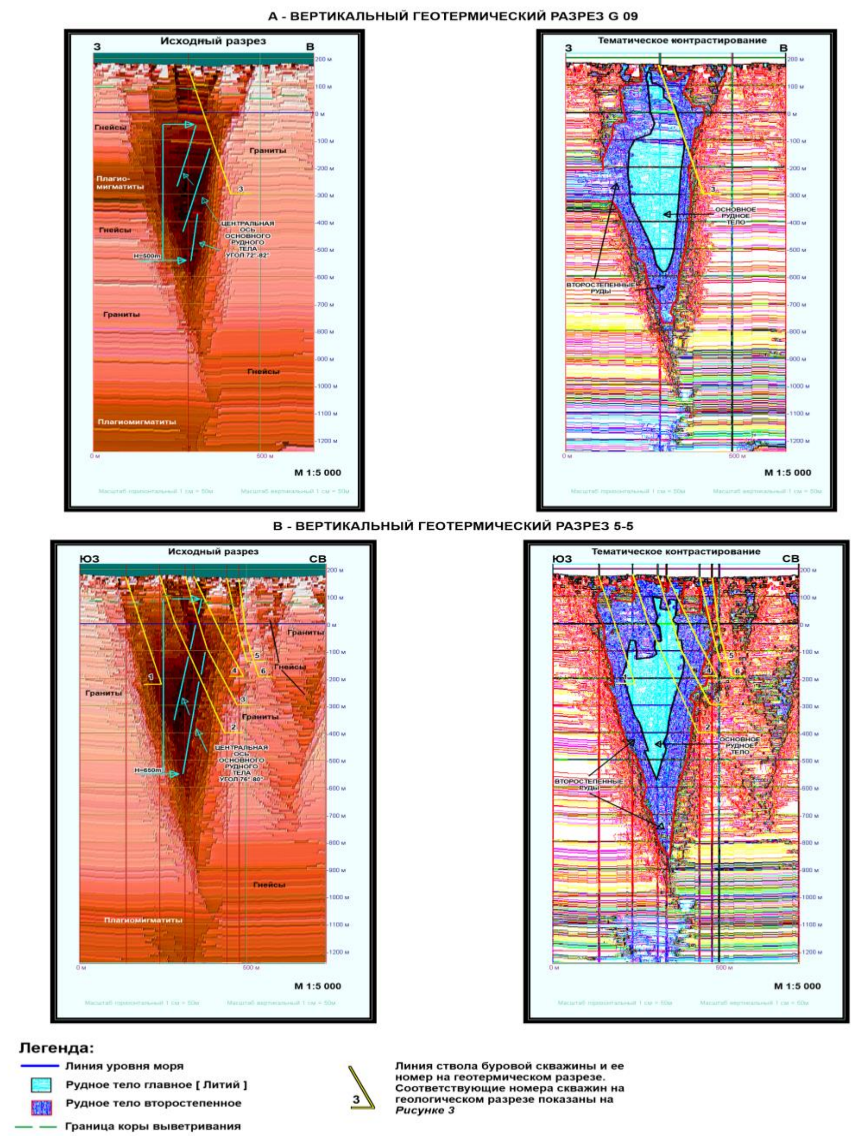
Information received from Earth satellites in the radio-thermal range of electromagnetic waves was used as initial data.

Calibration of the model and interpretation of thermodynamic anomalies in this work were carried out using the results of geological prospecting and exploration, including data from drilling wells based on materials from the DNVP "Geoinform of Ukraine", as well as the results of research by scientists: Bakarzhieva A.Kh., Ivanova B.N. , Kalashnik A.A., Kurilo S.I., Starostenko V.I., Gintova O.B. and etc.

In general, taking into account the deep factors of the formation of deposits of lithium and associated metals on the upper structural horizons of the earth's crust from mantle ore-forming components, the capabilities of the RTT method for spatial mapping of ore deposits, metallogenic zoning, and tracing rare metal mineralization in depth are clearly demonstrated.

# Using the Radio-Thermal Imaging Technology method to search for lithium ore deposits

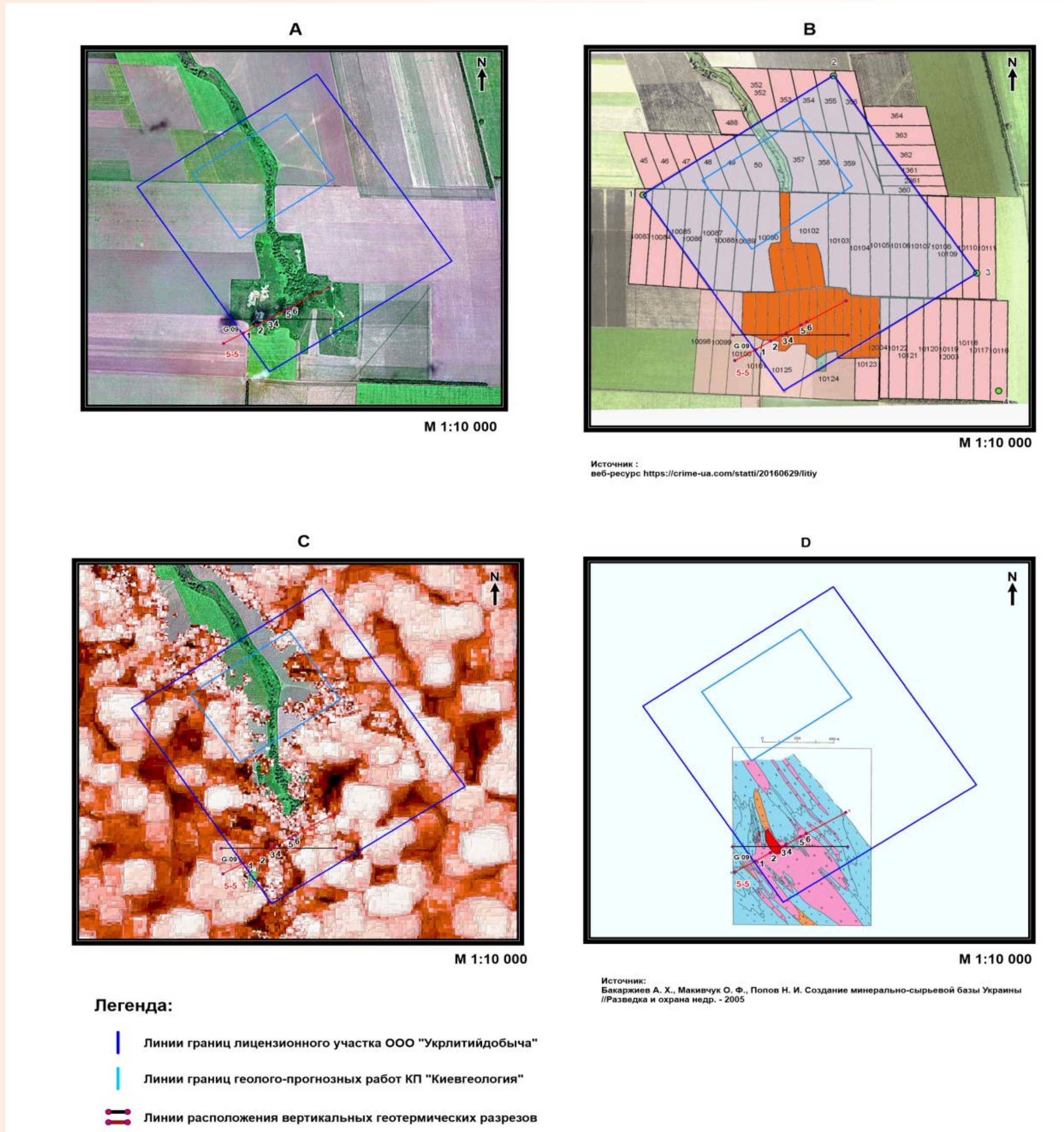
Polokhovo field. Vertical geothermal sections G 09 (A) West - East, 5-5 (B) South-West – North-East



# Using the Radio-Thermal Imaging Technology method to search for lithium ore deposits

Polokhovo field.

A – Section lines on a satellite image, B – section lines on licensed areas, C – horizontal geothermal section at + 160 m from sea level, D – section lines on a geological map of the field



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