Method of Remote Mineral Exploration Based on a Unique Satellite Image Processing Technology

1. TECHNOLOGY FOR REMOTE MINERAL EXPLORATION

We carry out a comprehensive set of studies aimed at detecting and delineating hydrocarbon and ore anomalies, as well as accumulations of groundwater and natural hydrogen, using innovative Earth remote sensing methods. We have developed a unique methodology and proprietary equipment (the *Poisk* complex) that have no analogues worldwide. This technology enables exploration work to be performed with high efficiency, within short timeframes, and at significantly lower cost compared to traditional methods.

The methodology is based on the principles of nuclear magnetic resonance, which involve the absorption of electromagnetic radiation by atomic nuclei, as well as on conventional and proprietary methods for the integrated use of space-based (or aerial) Earth sensing systems in combination with the resonance-testing electromagnetic *Poisk* complex.

During the research process, anomalies associated with mineral deposits are delineated through specialized processing of satellite imagery, including determination of burial depths, fault mapping, and recommendations for drilling locations. In some cases, an assessment of forecast resources of hydrocarbons, ores, groundwater, etc. is also carried out.

The application of this technology makes it possible to significantly (by a factor of 10–15) reduce both financial costs and the time required to perform exploration work (to as little as three months) compared with traditional geological exploration methods. At the same time, the probability of discovering mineral deposits increases substantially, while risks and uncertainties associated with identifying deposits of industrial scale are reduced.

The use of our technology has no climatic, geographic, or other limitations and provides reliable results for making decisions on the feasibility of further work at a given site.

We have successfully completed more than 300 projects (oil, gas, gold, groundwater, coal, diamonds, molybdenum, copper, lead, zinc, nickel, lithium, etc.) for commercial companies and government enterprises in countries including Russia, Ukraine, the UAE, the USA, Australia, Bulgaria, Cyprus, Mongolia, Ethiopia, the Democratic Republic of the Congo,

Scientific Background

In nuclear physics, special attention is paid to magnetic and electric moments. According to the works of Academician E. Zavadsky (1946), all nuclei with nonzero spin possess a magnetic moment μ_1 associated with the nuclear spin J, the nuclear magneton $\mu_{nu}c_l$, and proportional to the gyromagnetic ratio g_1:

$$\mu_1 = g_1 \cdot J \cdot \mu_{nu}c_l$$

The gyromagnetic ratio g_1 is a constant quantity and is equal to the ratio of the nuclear magnetic moment to the nuclear angular momentum. If an atomic nucleus with spin J and magnetic moment μ_1 is placed in a magnetic field of intensity H, magnetic interaction occurs, and the energy of interaction between the nuclear magnetic moment and the field W_m will be proportional to H:

$$W_m = \mu_1 \cdot H \cdot (m / J)$$

where *m* is the projection of the vector **J** onto the direction of the magnetic field intensity. Thus, the interaction energy is proportional to the magnetic field intensity.

According to quantum mechanics, only certain energy (quantum) levels of nuclear energy are allowed, and the difference between two neighboring energy levels is equal to:

$$\Delta W_m = g_1 \cdot \mu_{nu}c_l \cdot H$$

The frequency corresponding to this energy difference (called the Larmor frequency) is:

$$f^L = \Delta W_m / h$$

where *h* is Planck's constant.

If a material sample is placed in a constant, uniformly oriented magnetic field H (with nuclear spins aligned along the magnetic field) and, simultaneously, a varying rotating magnetic field H??? is applied perpendicular to the orientation of the nuclei in field H, then at a frequency of the alternating field equal to the Larmor frequency f?, resonant absorption and resonant scattering of energy by the material sample can be observed.

Thus, by having recorded resonance frequencies for each substance under nuclear magnetic resonance conditions and subsequently exposing the investigated medium to a generator producing these frequencies, the presence of the target substance at depth can be inferred based on the occurrence of a resonance effect. The target substance is considered present only when the modulated signal from the generator affects the receiving device along the magnetic field vector.

As a rule, the values of Larmor frequencies for various substances in the Earth's magnetic field lie in the terahertz range (100 GHz-100 THz).

Visualization of deposit boundaries is performed through specialized processing of satellite (or aerial) imagery in radiation fields and their interpretation in a rotating magnetic field (Kirlian effect).

Implementation of the Technology Includes the Following Main Stages:

Study of sample materials such as oil, gas, ores with various metal concentrations, or groundwater (drinking, low-mineralized, or saline geothermal waters), and recording their informational-energy spectra (atomic spectra of metals and non-metals over a wide spectral range) or the atomic spectra of reference (characteristic) metals contained therein.

- Transfer of informational–energy spectra of target substances (oil, gas, condensate, ores of various metals, groundwater, etc.) onto special "test" and "working" carriers (matrices) manufactured using nanomaterials and metal–organic compounds, followed by radiation–chemical processing ("cross-linking") and measurement of nanomaterial concentrations by the neutron activation method.
- Conducting satellite or aerial photographic reconnaissance of the surveyed area (or purchasing existing analog and digital photographic imagery of the study area).
- Processing satellite (analog and digital) or aerial photographs using special layers of gel solutions and luminophores, irradiating them with doses of 5×10^4 rad, and visualizing zones with anomalies of specific hydrocarbons (only one hydrocarbon type per image) or ore anomalies of various metals (only one specific ore type with a specific metal concentration per image). Similar processing of images is carried out for groundwater zones (a separate image for each salt concentration).
- Transferring the visualized anomalies from satellite imagery onto georeferenced base imagery (using mosaics such as Google, Landsat, etc., with coordinate grids), and then onto a map of the surveyed area. Determination of the areas of the identified anomalies.
- Determination of approximate depths of oil and gas reservoirs, metal ore bodies, or aquifers containing various types of water (fresh, low-mineralized, saline, geothermal). Depths are calculated based on the displacement of anomaly boundaries obtained simultaneously from two satellite images acquired with different satellite orbit inclinations.
- Construction of schematic cross-sections based on measurements of depths and thicknesses of oil and gas reservoirs (water-bearing horizons) or measurements of ore body depths at measurement points.
- Estimation of forecast resource volumes within the identified anomalies using the constructed schematic profiles, with spacing between measurement points ranging from 150 to 250 m (for ore anomalies, from 15 to 25 m).
- Recommendation of drilling locations within the identified target areas.

The timeframe for completing reporting work typically does not exceed three months and depends on the size of the territory, the volume of initial data, and other factors.

1. REQUIREMENTS FOR SAMPLES

Why do we need mineral samples?

An important and desirable element of the work process is the ability to obtain mineral samples, as samples help determine the concentration of reference elements (metals, non-metals) and additional components (impurities) in the rock containing the mineral. Measurement equipment is calibrated using amplitude–frequency spectra recorded from the provided samples. Direct recording of identification nuclear magnetic resonance (NMR) spectra is performed by exciting the atoms of the elements contained in the studied substance. It should be emphasized once again that the sample makes it possible to calibrate stationary (laboratory) equipment for each specific geological area of rock occurrence, which increases the accuracy of studies to maximum values.

Sample requirements

Before the start of studies, at least one of the conditions listed below must be met. To achieve maximum accuracy, it is necessary to provide data for each requirement. The reliability of detection will depend on the quality of the sample data provided.

When searching for solid mineral resources, please provide (if available and technically feasible):

Three types of samples:
a. A sample with the maximum content of the target mineral in the rock;
b. A sample with cut-off grade content;
c. A sample with industrial-grade concentration (the minimum concentration at which industrial development of the deposit becomes economically viable);

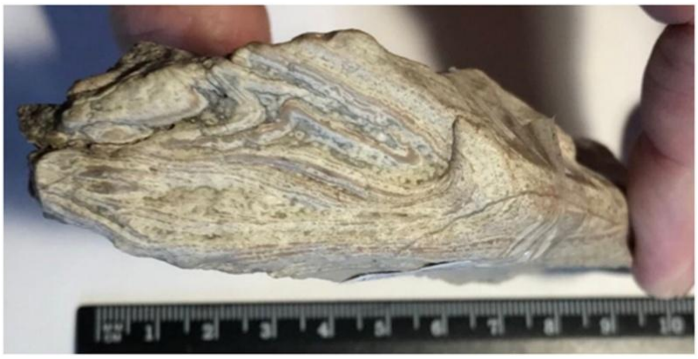
- Coordinates of the sampling locations from which the samples were taken;
- Depths at which the samples were collected;
- The weight of each sample should be approximately 150 g;

Before shipment, the client independently conducts a chemical analysis and provides the results indicating the type/composition of the ore and/or the composition of the target substance in the sample;
Before shipment, photographs of each sample must be provided to us for approval;
Shipping instructions will be provided after receipt of the photographs and chemical analysis results;
In addition to the sample, it is strongly recommended to provide a lithological description of the host rocks.

When searching for oil and/or gas and gas condensate, please provide (if available and technically feasible):

- 150 ml of oil and/or gas condensate taken from a well located within up to 500 km. The closer to the target search area, the better. It is preferable to have a sample from the same oil- or gas-bearing geological structure;
- Coordinates of the well from which the samples were taken;
- The depth from which the sample was collected;

Before shipment, the client independently conducts a chemical analysis and provides the results indicating the type/composition of the oil and/or the composition of the gas/gas condensate;
Before shipment, photographs of each sample must be provided to us for approval;
Shipping instructions will be provided after receipt of the photographs and chemical analysis results;
In addition to the sample, it is strongly recommended to provide a lithological description of the host rocks.

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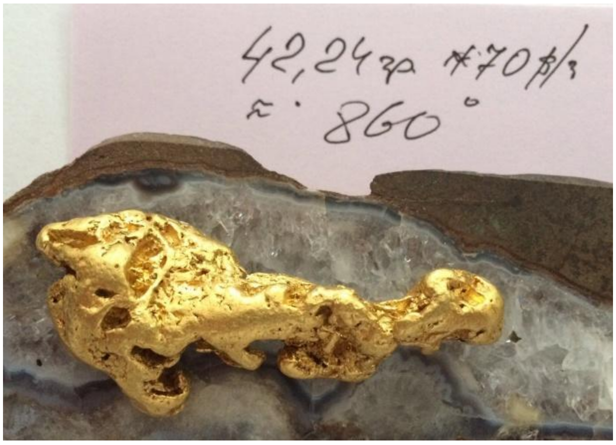
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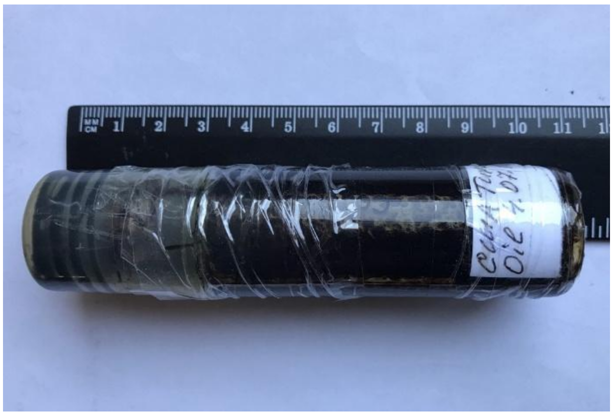

1. REMOTE DETECTION OF DEEPLY OCCURRING GROUNDWATER

The technology provides rapid detection, delineation, and determination of the depth of occurrence of underground fresh, saline, and geothermal waters.

The remote method for detecting groundwater resources is based on the identification of underground water using the nuclear magnetic resonance (NMR) phenomena of metal atoms contained in water, as well as on the "visualization" of the boundaries of underground water bodies with varying salinity on the Earth's surface. This visualization is achieved by interpreting characteristic informational and energy electromagnetic fields above accumulations and flows of underground water, recorded from analog satellite images.

At the initial stage of work, methods of interpreting a series of digital satellite images in various frequency ranges (ultraviolet, infrared, and visible) are used according to conventional techniques.

Subsequently, detailed analog satellite images are processed using special chemical gels, sensitizers, and luminophores, followed by exposure to a radiation field. The radiation field is generated by a high-power gamma installation (proprietary methodology).

As a result of interpreting the analog satellite images (using the proprietary technology), underground water flows and lenses are "visualized" in the form of "zones of increased brightness" on the analog satellite images. This makes it possible to determine the boundaries of deep underground water flows and water-saturated lenses located within the study area.

Subsequent calculation of the depths of occurrence of water-saturated reservoirs at measurement points within the anomaly areas (water-saturated lenses) is performed at two to three measurement points. The calculation is based on the magnitude of the "shift" of anomaly (lens) contour boundaries obtained from two satellite images captured from two spacecraft with different orbital inclination angles.

Identification of water with different salinity levels is carried out using recognition-based frequency electromagnetic tests recorded from reference metals (nuclear magnetic resonance spectra) that are part of a specific water sample.

On the ground surface directly above a water-bearing anomaly (lens), a characteristic high-frequency electromagnetic field is always generated within the Earth's magnetic environment. This field has specific frequency and amplitude parameters corresponding to the spectral characteristics of the metal atoms contained in the water.

To "visualize" a specific electromagnetic field spectrum on an analog satellite image, the image is предварительно processed with appropriate chemical reagents, sensitizers, and luminophores with the addition of nanopowders of reference metals.

The applied set of resonance-based recognition test signals makes it possible to identify the type of underground water (fresh, slightly mineralized, saline, including geothermal) and the following quantitative and certain qualitative characteristics of underground fresh, saline, and geothermal waters, as well as various water-saturated rocks of water-bearing reservoirs:

• salinity, temperature, and the presence of a gas (vapor) cap in the underground flow (in the presence of gaseous impurities such as CO_2, H_2S, CH_4, or steam);
• boundaries of contours of underground water accumulations and flows, with their georeferencing to terrain maps using GPS;
• networks of tectonic faults and the directions of migration of deeply occurring flows of fresh, saline, and thermal waters along these faults;
• depths of occurrence and thicknesses of each water-saturated horizon at measurement points (up to depths of 1,100 m for fresh water; up to 3,000 m and deeper for geothermal, weakly mineralized, and saline waters);
• width of underground water flows and the areas of water-saturated lenses;
• excess hydraulic pressure in the aquifer (determined by gas pressure in the aquifer cap, if gases are present);
• type and porosity of rocks within the water-saturated reservoir;
• selection of a drilling location with maximum well yield;
• construction of depth cross-sections of aquifers;
• estimation of forecast water reserve volumes in water-saturated lenses;
• assessment, prior to drilling, of the feasibility of developing the identified underground water-bearing lenses for a specific purpose.

When performing remote surveys using only geospace-based exploration methods, the reliability of detection of deeply occurring groundwater may reach **65–70%**.

The error in determining the depths of water-bearing reservoirs may be **2–4%**, depending on depth.

Advantages and Distinctive Features of the Technology

• **Universality** — the capability for remote exploration of all types of mineral resources (oil, gas, metallic ore bodies, diamonds, coal), as well as underground saline, thermal, weakly mineralized, and fresh waters;

• **High success rate** in detecting, delineating, and remotely determining the depths of underground water flows occurring at great depths (more than 1,000 m for fresh water and more than 3,000 m for saline water);

• **Capability for remote identification and preliminary delineation** of underground water-bearing flows and lenses on analog aerospace photographs, ensuring large-scale exploration coverage (by surveying large areas of up to 10 × 10 km), reducing exploration timelines, and enabling estimation of forecast groundwater resource volumes prior to drilling;

• **Capability to identify deep tectonic faults** filled with groundwater and to determine the direction of groundwater migration along these faults;

• **Low cost of operations** for detecting deep underground thermal and fresh waters, resulting from the exclusion of large volumes of conventional seismic and electrical surveys, as well as the avoidance of drilling non-productive wells;

• **Capability to remotely determine approximate quantitative and qualitative parameters of groundwater prior to drilling**, including forecast resources, salinity, depths of all horizons, water temperature, and excess pressure in aquifers, thereby eliminating financial risks associated with the exploration of deeply occurring (3,000 m and deeper) thermal and weakly mineralized waters;

• **High operational efficiency** in the initial identification of groundwater accumulation zones across large areas.

The technological workflow for the search, identification, and estimation of forecast groundwater volumes is carried out in the sequence shown in the diagram below (Fig. 1).

If necessary, the obtained results may be validated using conventional methods (electrical surveying, seismic surveying, and magnetic surveying), followed by the drilling of an exploratory well to уточнить the chemical composition and temperature of the water, as well as the well yield.

Step-by-Step Technology for Remote Detection of Deeply Occurring Groundwater Flows and Lenses (Drinking and Geothermal) Using Geospace and Geophysical Detection Methods

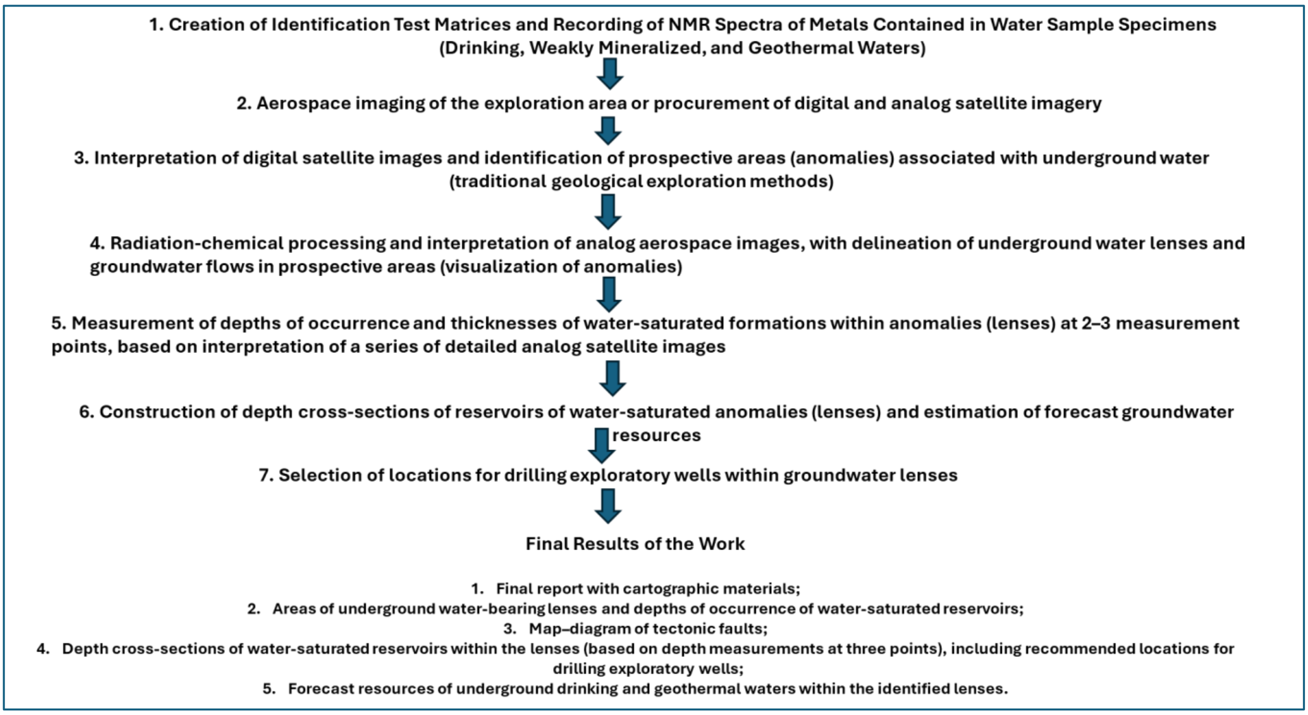

Fig. 1. Technological Flow Diagram

1. REMOTE DETECTION OF ORE ANOMALIES (DEPOSITS)

The technology provides rapid detection, delineation, and measurement of the depths of mineralization of various metals occurring beneath the soil cover at depths of up to 500 m and more.

The technology and the equipment used have been tested and patented. The remote ore anomaly detection technology is based on a combination of traditional methods for registering dispersion halos of metal atoms from a deposit on the ground surface through the interpretation of digital satellite images, as well as a proprietary method for "visualizing" electromagnetic fields above the deposit on analog satellite images in the form of "zones of increased brightness."

Zones of "increased brightness" are visualized on high-resolution analog satellite images (aerial photographs) after their processing with chemical reagents (gels). Each type of metal-bearing ore (mineral) in a deposit is characterized by specific amplitude–frequency spectra of electromagnetic radiation, which are recorded above the deposit by highly sensitive spectral geophysical equipment installed on aircraft. For reliable identification of "zones of increased brightness" characteristic of a specific ore, analog satellite images are preliminarily processed with chemical reagents.

The reagents include luminophores, sensitizers, and finely dispersed nanopowders of rare metals possessing the required properties, as well as lithium niobate powder. The chemical reagents are selected experimentally to identify the target metal in the ore at a specific concentration (background or industrial grade—minimum, average, or maximum). Ore sample specimens are provided by the Client.

The stationary equipment set of the complex makes it possible to study the composition of ores and to record, from core samples of ores and host rocks, informational-energy electromagnetic spectra (recognition spectra) and nuclear magnetic resonance (NMR) spectra of the principal metals contained in the ores. Highly sensitive units of the stationary equipment are used to interpret analog satellite images (delineation of "zones of increased brightness") after chemical treatment and exposure to gamma radiation fields (to increase the intensity of "luminescence" depending on the metal concentration in the ore).

To calculate the depth of mineralization within an anomaly using geospace-based geological exploration methods, it is necessary to determine the magnitude of the "boundary shift" of the anomaly. This shift is determined from two analog satellite images acquired from two aircraft with different orbital inclination angles. Depth calculations are performed at two to three points within each anomaly with industrial-grade metal content (it is not possible to determine depth for background-level concentrations).

Based on the measurement points, depth cross-sections of the anomaly are constructed, and forecast ore resources are estimated.

The step-by-step technology for remote detection of ore anomalies, their delineation, and determination of mineralization depths consists of the sequential execution of the following stages (the workflow is shown in Figure 2).

1. **Procurement of required consumables, equipment, and auxiliary technical tools; configuration and calibration of geophysical equipment prior to the start of operations.** Acquisition of maps of the exploration area.
2. **Delivery of metal-bearing rock samples** characteristic of the survey area from the nearest deposits. Recording of informational–energy spectra of ores and NMR spectra of atomic elements contained in the target ore and selected as reference markers (with characteristic identification spectra) from core samples. Calibration of stationary and field equipment for registering rock samples containing specific metals in mineralization, as well as a range of different metal concentrations.
3. **Manufacture of carrier materials for "test" matrices;** recording of resonant electromagnetic spectra from ore samples (cores) and NMR spectra of reference (marker) metal atoms. Activation of the matrices using radiation-chemical technologies at a research nuclear reactor or a high-power gamma installation.
4. **Aerospace imaging of the surveyed area** (aircraft, drone, spacecraft) or procurement of high-resolution digital and analog satellite imagery from specialized Earth remote sensing and environmental monitoring centers (Russia, EU, USA).
5. **Acquisition of analog satellite images** covering an area with a control well, in order to assess the feasibility of registering anomalies with different mineralization concentrations occurring at great depths.

6. **Radiation processing of the acquired series of satellite images** (after application of chemical reagents) and their interpretation using stationary geophysical equipment (the equipment is предварительно tested on a control well or outcrop).
7. **Visualization and delineation on analog satellite images** of the boundaries of metal mineralization halos at the ground surface, followed by identification within them (using a new series of high-resolution satellite images) of anomalies with industrial (specified) metal concentrations in the form of "zones of increased brightness." Each concentration level requires a separate interpretation of the prepared images with individually selected chemical reagents and additives.
8. **Evaluation of the results** of detection, identification, and delineation of ore areas with industrial-grade anomalies. Preparation of a map of the survey area indicating the boundaries of identified ore and placer anomalies of the target metal.
9. **Determination of the depths of occurrence of industrial-grade ores** at 2–3 measurement points within the anomalies using geospace-based detection methods (to depths of 500–600 m).
10. **Preparation of the final report**, including cartographic and tabular materials. The reliability of the obtained results reaches **65–70%**. The error in determining mineralization depths is **up to 2%**.

Possible Limitations When Performing Operations Using Only Geospace-Based Methods for Deposit Exploration:

- The **maximum depth of ore occurrence** is 500–600 m; certain ores with high metal concentrations may be detected at depths of up to 1,000 m or more (e.g., uranium, copper);
- **Determination of the depths of industrial-grade mineralization** is possible only at 2–3 measurement points within an ore anomaly, which is determined by the inclination angles of satellite orbits;
- **Difficulty in identifying thin mineralized layers** (thickness < 1 m) along the strike direction, since in top-view observations ("projection – plan view") they merge into a single mineralization zone;
- **Difficulty in registering minor faulting and discontinuities** within mineralized zones along the strike direction, as measurements are carried out only at 2–3 points;
- **Difficulty in measuring the depth of mineralization with very low metal concentrations**, since it is challenging for the equipment to delineate precise anomaly boundaries and, in particular, their "boundary shifts" on satellite images (weak luminescence of the zone due to small thickness or low mineral concentration in the ore);
- **Difficulty in accurately determining the dip angle of mineralized zones**, as surface relief is not taken into account at the depth measurement points, and depth measurements on satellite images are made simply from the ground surface;
- **Complexity in selecting chemical reagents and determining the required volumes of finely dispersed metal powders** needed to simultaneously establish concentrations of multiple metals in an ore; this is the most complex and costly procedure. Therefore, **3–4 core samples are required**: one with subeconomic ("background") concentration for dispersion halos, and samples with industrial-grade concentrations (minimum, medium, and maximum) for only the primary target metal.

Advantages and Distinctive Performance Indicators of the Technology:

o **Universality** — the capability for remote exploration of all types of mineral resources (oil, gas, gas condensate, gold- and uranium-bearing ores, diamonds, ores of various metals), as well as deeply occurring underground geothermal and fresh waters;

o **High detection success rates** (hydrocarbons — more than 70%; metal ores — 65–70%), with the ability to determine deposit depths and estimate forecast (preliminary) volumetric resources prior to drilling;

o **Capability for remote detection of deeply occurring anomalies that do not outcrop at the surface**, and their preliminary delineation on digital satellite images, ensuring large-scale exploration coverage (survey areas up to 60 × 60 km), reducing exploration timelines, and enabling preliminary estimation of forecast ore resources in deposits;

o **Reduction in operational costs** for detecting and identifying industrial-grade anomalies (deposits) due to the exclusion of large volumes of seismic exploration and exploratory drilling, especially for deep and hard-to-access deposits;

o **No requirement for a full suite of traditional geological surveys** of the exploration area (magnetic, seismic, radiation, geochemical, and electrical surveys), since this technology directly identifies and determines the type and geometry of the deposit (ore body), i.e., actual hydrocarbon traps or ore bodies with industrial-grade metal content, rather than indirect geophysical indicators traditionally used to select drilling targets for opening identified structures.

o **Capability to remotely determine approximate quantitative parameters and quality of mineral resources prior to drilling** (volumes, presence of contaminating impurities and gases, depths of occurrence of all hydrocarbon horizons and ore bodies, gas pressure in hydrocarbon horizons, and average metal concentration in the ore body), thereby eliminating financial risks associated with opening non-prospective ore "deposits" or empty hydrocarbon "traps."

The technology has been **successfully applied for the exploration of various mineral resources in many countries**, including Australia, the Democratic Republic of the Congo, Indonesia, Kazakhstan, Mongolia, the United States, Sierra Leone, Russia, Peru, and others. The technology can be **integrated with other geophysical exploration methods** for the exploration of various mineral resources.

Step-by-Step Technology for Remote Detection of Ore Anomalies Using Geospace and Geophysical Exploration Methods

1.Creation of identification test matrices and recording of NMR spectra of metals contained in ore sample specimens with varying metal concentrations.

2. Aerospace imaging of the exploration area and procurement of digital and analog satellite imagery.

3.Interpretation of digital satellite images and identification of prospective areas (anomalies) based on mineral dispersion halos on the ground surface (traditional geological exploration methods).

4.Radiation-chemical processing and interpretation of detailed analog satellite images, with delineation of subsurface mineralization in prospective areas and "visualization" of anomalies in the form of "zones of increased brightness."

5.Measurement of depths of occurrence and thicknesses of mineralization within anomalies at 2–3 measurement points (based on interpretation of a series of detailed analog satellite images).

6.Construction of depth cross-sections of mineralization and estimation of volumetric forecast ore resources within the anomalies.

7. Selection of locations for drilling exploratory w ells to intersect mineralized zones

Final Results of the Work

1. Final report with cartographic materials;
2. . Areas of mineralization within the anomaly and depths of occurrence of ore bodies;
3. Map–diagram of tectonic faults within the surveyed area;
4. Depth cross-section of mineralization within the anomaly (based on depth measurements at three points), including locations for drilling exploratory wells for core sampling.
5. Forecast volumetric ore resources within the identified anomalies

Fig. 2. Technological Flow Diagram.

REMOTE DETECTION OF HYDROCARBON (HC) DEPOSITS

The technology for remote detection of hydrocarbon (HC) anomalies combines Earth remote sensing (ERS) data with a unique method for processing satellite images that enables visualization of the boundaries of prospective anomalies.

The technology makes it possible to identify and delineate HC anomalies associated with hydrocarbon accumulations, assess the depths of HC reservoirs, identify tectonic faults, and perform a forecast evaluation of resources within the identified anomalies.

The technology for remote detection of hydrocarbon deposits is based on several important physicochemical processes occurring in the Earth's environment:

• **Diffusive migration of volatile hydrocarbons and gases** from the deposit to the ground surface. As a result of these processes, hydrocarbons and gases accumulate in the near-surface soils, followed by the formation of dispersion halos of hydrocarbons and various metals on the ground surface. These dispersion halos are well registered by space-based exploration methods.

• **Formation of metal oxides and metal-bearing minerals** as a result of physicochemical processes and various chemical reactions in host rocks caused by hydrocarbon accumulations. These processes generate characteristic electromagnetic fields within the Earth's magnetic field and lead to changes in the magnetic properties of the geological environment. Such changes can be recorded as frequency–amplitude spectra of electromagnetic fields at the ground surface (directly above the deposit). These fields manifest on analog satellite images as zones of "increased brightness" and are registered using highly sensitive spectral instrumentation. The spectral equipment employs measuring modulation radiometers with automatic depth modulation, which eliminates the influence of noise signals.

To directly register hydrocarbon dispersion halos at the ground surface and the characteristic spectral amplitude–frequency features of electromagnetic fields above the deposit, patented methods are used to "visualize" electromagnetic fields on analog satellite images after their special chemical treatment (to enhance the "zones of increased brightness").

For reliable identification of zones of "increased brightness" on analog satellite photographs, chemical reagents, luminophores, sensitizers, finely dispersed metal powders, and lithium niobate are applied to photographic media. This makes it possible to enhance luminescence ("zones of increased brightness") on the analog satellite image directly above the hydrocarbon anomaly. The satellite images are interpreted after exposure to gamma radiation fields.

For each type of identified hydrocarbons and hydrocarbon reservoir rocks, as well as deeply occurring saline waters, different types of sensitizers and powders of required rare metals are selected experimentally. High-purity nanopowders are produced using microbial technologies or purchased from foreign suppliers.

The stationary equipment suite allows for the study of the chemical composition of oil samples, determination of concentrations of nickel, tungsten, and other metals and impurities in oil, recording of informational–energy (electromagnetic) spectra of oil samples (with specific metal compositions), hydrocarbon gases (methane, ethane, propane), oil and gas reservoir rocks, and saline water-bearing formations. It also enables the transfer of recorded nuclear magnetic resonance (NMR) spectra onto organometallic carrier matrices. The stationary equipment is further used to delineate HC anomalies during interpretation of high-resolution analog satellite images and to perform their preliminary radiation-chemical processing.

The software enables calculation of the depths of hydrocarbon (HC) deposits based on the results of satellite exploration. To calculate the depths of HC reservoirs within identified anomalies (at 2–3 measurement points) using satellite exploration alone, it is necessary to determine the values of the "boundary shifts" of the anomalies, which are derived from two analog satellite images acquired from two satellites with different orbital inclination angles (Fig. 4).

To calculate the depth of hydrocarbon deposits (H_2), specialized software is used that takes into account the orbital inclination angle $\Delta\beta_0$ and the flight altitude of satellites No. 1 and No. 2. At the depth measurement points, cross-sections are constructed showing the average effective thicknesses of HC horizons, and a preliminary resource assessment is performed.

Work using this technology may be carried out as follows:

Study of oil samples and recording of their informational–energy spectra and nuclear magnetic resonance (NMR) spectra of metals contained in the oils;

Identification and delineation of each type of HC anomaly (oil, gas, gas condensate) and determination of their depths through interpretation of a series of high-resolution digital and analog satellite images acquired in various electromagnetic spectra (visible, infrared, ultraviolet, and non-visible ranges). Visible reflected spectra are used to identify primary areas with indications of HC deposits (hydrocarbon dispersion halos), while non-visible spectra of characteristic electromagnetic fields are "visualized" on high-resolution analog satellite images in the form of "zones of increased brightness" directly above HC deposits;

Processing of analog satellite images to visualize the boundaries of HC fields in the form of "zones of increased brightness";

Measurement of depths of occurrence and thicknesses of HC reservoirs within HC anomalies;

Construction of schematic cross-sections of HC anomalies at the measurement points, indicating the number of HC reservoirs and their thicknesses;

Estimation of forecast HC resources within each identified anomaly based on calculated deposit parameters (at 2–3 measurement points);

Selection of locations for drilling wells;

Preparation of the final report and supporting materials.

The step-by-step technological workflow is shown in **Figure 3**. The following activities are carried out:

1. **Procurement of required chemical reagents, consumables, and auxiliary technical equipment;** setup and calibration of the stationary equipment included in the geophysical complex. Acquisition of maps of the exploration area and ordering of the initial series of digital satellite images in various frequency ranges covering the exploration area.
2. **Receipt from the Client of oil samples** characteristic of the study area (light, light-colored, heavy oils, oils with paraffin impurities, etc.), as well as the coordinates of a reference well from the nearest field.
3. **Analysis of oil composition** and recording of informational–energy spectra and nuclear magnetic resonance (NMR) spectra of metal atoms contained in the oil samples.
4. **Manufacture of "test" and "working" organometallic matrices** for recording identification informational–energy spectra of oil samples and NMR spectra of reference metal atoms.
5. **Activation of the "working" and "test" matrices** using radiation-chemical technologies and recording of identification electromagnetic spectra (informational–energy spectra and NMR spectra of reference metal atoms) using recording units of the stationary integrated equipment.

6. **Functional testing and calibration of the stationary equipment** for selective registration of different types of the provided oil samples using the “working” and “test” matrices, as well as anticipated types of reservoir rocks (from the Contractor’s database).
7. **Acquisition of digital satellite images and their interpretation** using conventional methods to determine the boundaries of prospective areas with primary indications of hydrocarbons.
8. **Acquisition of analog satellite images** covering prospective areas with primary hydrocarbon indicators.
9. **Acquisition of analog satellite images** covering the location of the test well from a nearby field. The well coordinates are provided by the Client.
10. **Processing of the acquired analog satellite images with gamma radiation** and their interpretation using the patented technology for visualization of “zones of increased brightness” above a specific type of hydrocarbon anomaly located around the test well.
11. **Calibration of the stationary integrated equipment** for clear identification of a known oil or gas deposit around the reference well and determination of the depth of hydrocarbon accumulation.
12. **Radiation processing of analog satellite images and their interpretation using the proprietary technology** to determine the type of hydrocarbon anomaly within the surveyed area, delineate the anomaly, and transfer its boundaries onto satellite images with a coordinate grid. The dimensions of the anomaly are determined. Chemical reagents, luminophores, and sensitizers are individually selected for each type of hydrocarbon anomaly.
13. **Radiation processing of an additional series of analog satellite images** to determine the depths of hydrocarbon reservoirs within the anomaly based on the magnitude of the “boundary shift” of anomaly contours, determined from two satellite images acquired from two satellites with different orbital inclination angles. Typically, six high-resolution analog satellite images are used for each anomaly, since depths are determined at 2–3 points within each anomaly.
14. **Radiation processing of analog satellite images and interpretation of infrared (IR) digital images** to identify and map tectonic fault networks with migration of high-temperature fluid flows along them.

The **reliability (statistical accuracy)** of the obtained information (identification of prospective anomalies, number of hydrocarbon deposits, their depths and thicknesses) is **70% or higher**. The error in determining the depths of hydrocarbon reservoirs may be **up to 2–3% on land** and **up to 4% offshore**. The achievable depth of hydrocarbon reservoir determination both on land and offshore is **up to 7,000 m**.

Advantages and Distinctive Features of the Technology

• **Universality** — the capability for remote exploration of all types of mineral resources (oil, gas, metallic ore bodies, diamonds, coal, rare metals, etc.), as well as underground saline, thermal, weakly mineralized, and fresh waters;

• **High success rate (statistical accuracy)** in hydrocarbon detection (>70%), with the ability to determine hydrocarbon depths and perform a preliminary resource assessment prior to exploratory drilling;

• **Capability for remote identification and preliminary delineation of hydrocarbon deposits** on digital satellite images (primary visualization) in the form of hydrocarbon dispersion halos, ensuring large-scale exploration coverage (areas up to 60 × 60 km) and reducing the duration of geological exploration operations;

• **High economic efficiency**;

• **Ability to determine the required scope of geological exploration work without the use of multiple traditional methods** (magnetic, seismic, radiation, geochemical, electrical surveys, etc.), since this technology directly identifies and determines the type and configuration of the deposit or hydrocarbon-filled trap, rather than indirect geophysical indicators traditionally used to select drilling locations for confirming identified geological structures;

• **Capability to survey hard-to-access areas** (wetlands, forests, mountainous terrain) as well as offshore shelf areas;

• **Detection and identification of hydrocarbon anomaly types** (oil, gas, gas condensate) and delineation of their boundaries without seismic surveying or drilling;

• **Capability to identify tectonic faults** filled with hydrocarbon fluids, groundwater, and geothermal waters, and to determine the direction of migration of hydrocarbon fluids and geothermal waters along these faults;

• **High efficiency at the initial stage** of identifying hydrocarbon and groundwater accumulations across large territories;

• **Capability to select the most prospective areas with hydrocarbon deposits** (the most promising hydrocarbon anomalies) and optimal drilling locations for productive wells prior to exploratory drilling, exceeding the capabilities of traditional geophysical exploration methods.

Step-by-Step Technology for Remote Detection of Hydrocarbon Anomalies Using Geospace and Geophysical Exploration Methods

1. Creation of identification test matrices and recording of NMR spectra of metals contained in oil sample specimens of various compositions and with different metal concentrations.

2. Aerospace imaging of the exploration area and procurement of digital and analog satellite imagery.

3. Interpretation of digital satellite images and identification of prospective areas (anomalies) based on hydrocarbon dispersion halos on the ground surface (traditional geological exploration methods).

4. Chemical processing and interpretation of detailed analog satellite images, with delineation of hydrocarbon (HC) anomalies in prospective areas through “visualization” in the form of zones of increased brightness.

5. Measurement of depths of occurrence and thicknesses of hydrocarbon reservoir rocks at 2–3 measurement points (based on interpretation of a series of detailed analog satellite images).

6. Construction of depth cross-sections of hydrocarbon reservoirs and estimation of volumetric forecast hydrocarbon resources (oil, gas, condensate).

7. Selection of locations for drilling exploratory wells within prospective anomalies.

Final Results of the Work

1. Final report with cartographic materials
2. Areas of hydrocarbon (HC) anomalies, depths of hydrocarbon occurrence, and thicknesses of hydrocarbon reservoirs
3. Map–diagram of tectonic faults within the surveyed area
4. Depth cross-section of hydrocarbon reservoirs within the anomalies, including prospective locations for drilling exploratory wells
5. Forecast volumetric hydrocarbon resources in deposit-type anomalies

Fig. 3. Technological Flow Diagram

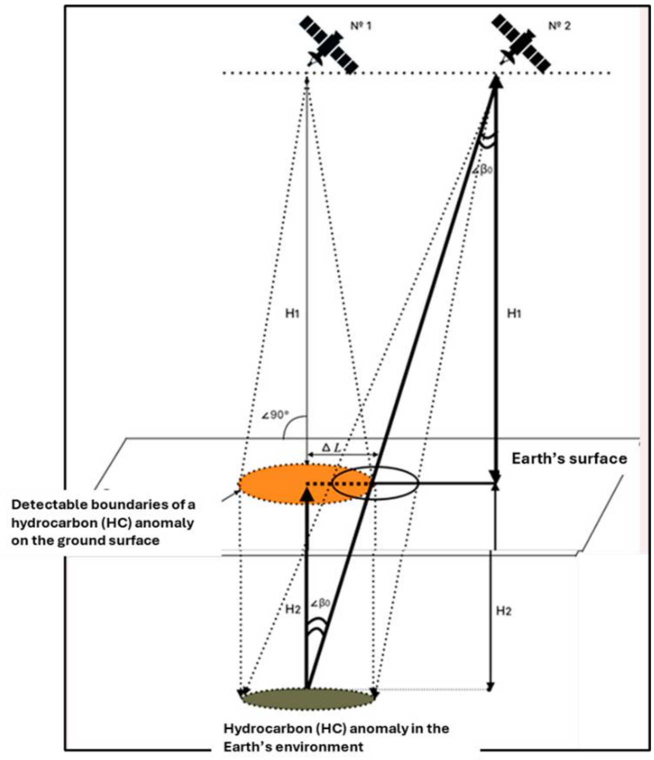

Fig. 4. Depth Determination Scheme

1. IDENTIFICATION OF NATURAL HYDROGEN ACCUMULATIONS

Principles of Hydrogen Anomaly Identification

Hydrogen is a gas present in the atmosphere in trace amounts that are insufficient to support life. It is synthesized from hydrocarbons and water. Hydrogen constitutes the lightest component of the H_2O molecule and is simultaneously the lightest and most fundamental of all elements. It is a fairly reactive gas that forms chemical compounds with most elements and is only weakly affected by magnetic forces.

Natural hydrogen can be found in underground deposits and is typically extracted in a manner similar to natural gas.

A significant branch of physics is devoted to the study of effects that arise in various materials when a magnetic field is applied. In a hydrogen atom, the nucleus consists of a single positively charged proton, around which a single negatively charged electron revolves. This configuration may create the impression that hydrogen possesses strong magnetic attraction; however, this is not the case. Gaseous hydrogen is, in fact, very weakly magnetic.

The reason for this is that hydrogen atoms do not exist in isolation. They bond together to form a molecule whose chemical energy is lower than that of individual atoms. Within this molecule, the momentum of one electron moves in the opposite direction to that of its neighboring electron. As a result of this phenomenon, the molecule is weakly magnetic and is considered to have no permanent magnetic moment.

Hydrogen is a **diamagnetic substance**. Diamagnetism arises in materials whose atoms contain paired electrons. According to Faraday's law, when a hydrogen molecule is subjected to a magnetic field, its orbiting electrons slightly alter their momentum. As the magnetic field increases, an induced field is created, which the electrons of the molecule perceive as a force. Due to this physical principle, the hydrogen molecule acquires an induced magnetic moment.

The photoelectric effect provided indisputable evidence of the existence of the photon and, consequently, the particle-like behavior of electromagnetic radiation. However, the concept of the photon emerged from experiments with thermal radiation—electromagnetic radiation emitted as a result of the temperature of a source—which produces a continuous energy spectrum. More direct evidence was required to confirm the quantum nature of electromagnetic radiation. In this section, we describe how experiments with visible light provided such evidence.

While objects at high temperatures emit a continuous spectrum of electromagnetic radiation, a different type of spectrum is observed when pure samples of individual elements are heated. For example, when a high-voltage electric discharge passes through a low-pressure sample of gaseous hydrogen, the resulting isolated hydrogen atoms—formed due to the dissociation of H_2—emit red light. Unlike blackbody radiation, the color of the light emitted by hydrogen atoms depends only weakly on the temperature of the gas in the tube.

When the emitted light passes through a prism, only a few narrow lines appear. These are known as **line spectra**, representing emission or absorption of light at specific wavelengths rather than over a continuous range. The light emitted by hydrogen atoms appears red because, of the four characteristic spectral lines, the most intense lies in the red region of the visible spectrum at 656 nm.

The properties of hydrogen described above form the basis for the principles of the natural manifestation of hydrogen on the Earth's surface and its subsequent identification and delineation as anomalies.

Remote Approach to the Detection of Hydrogen Anomalies

We use a patented remote sensing data processing technology for the accurate identification and mapping of anomalies associated with various minerals and substances (oil, gas, gold, uranium, copper, water, hydrogen, etc.).

Remote sensing has been used in mineral exploration for many years. It involves the acquisition of information about the physical world by measuring electromagnetic radiation, particle signals, and fields emitted or reflected by objects. Today, satellite imagery is widely used as an exploration tool.

Remote sensing relies on **spectral signatures**. For any material, the amount of solar radiation it reflects, absorbs, transmits, and emits depends on wavelength. When the amount of radiation or electromagnetic energy of an object is plotted across a range of wavelengths, the connected points form a curve known as the **spectral signature** of the material.

More than 4,000 naturally occurring minerals can be found on Earth, each with a unique chemical composition and characteristic frequency. The amount of solar radiation that a mineral or substance reflects, transmits, and emits due to its chemical composition acts like a fingerprint, commonly referred to as its spectral signature. By measuring minute wavelength variations using remote sensing, the spectral signature of a mineral or substance can often be identified from space.

All objects possess unique spectral characteristics. Once the spectral signature of an object has been identified, the same signature can be searched for in other datasets to detect patterns and locate similar objects.

Intrinsic Electromagnetic Fields and Depth Estimation

Distinct electromagnetic fields (spectra) exist above each type of accumulation (oil, gas, water, hydrogen) or deposit (gold, uranium, copper, etc.). These electromagnetic fields, characterized by specific frequencies, form above accumulations or deposits and manifest at the Earth's surface as a result of various chemical, thermal, and electrochemical processes occurring in rocks during the long-term migration of oil, gases (or metals in ores) from great depths to the surface.

Accumulations, ore deposits, and the minerals or substances they contain possess characteristic properties that can be observed using different wavelengths of light beyond the visible spectrum. These unique properties can be analyzed to map the spatial distribution of specific minerals.

We analyze spectral images obtained from Earth observation satellites to identify and map mineral signatures (electromagnetic fields). Certain satellites provide sufficiently high spectral and radiometric quality to allow measurement of gas leakage into the atmosphere after appropriate atmospheric corrections have been applied to the data.

Satellite image processing is a well-established procedure used by many companies. We utilize both digital and analog types of satellite imagery, with the latter being mandatory, as they preserve full wavelength information. In addition to standard processing of satellite images in the visible, infrared (IR), and ultraviolet (UV) spectral ranges, we apply a patented innovative image-processing method in the non-visible range of the electromagnetic spectrum.

The invisible spectra of characteristic electromagnetic fields are "visualized" on high-resolution analog satellite images in the form of **zones of high brightness**. The processing involves the application of special chemical reagents (nanogels), luminophores, and sensitizers, selected individually for each type of accumulation (deposit), followed by treatment in a compact nuclear reactor. This enhances the detected anomalies, making them visible and suitable for geological interpretation. The nuclear reactor improves anomaly visualization by establishing resonance between the frequencies of reference elements in the nanogels and the satellite images.

Depth Estimation

The method for predicting depth is based on changes in the position of anomaly boundaries (shifts in the boundary of maximum signal energy) resulting from different satellite orbital inclinations and geometric parameters of satellite positioning relative to the anomaly.

At the first stage, the depth of occurrence is estimated using at least two satellite images acquired from two satellites with different orbital inclinations. Based on analysis of these images, the magnitude of the anomaly boundary shift is determined. Knowing the orbital inclination angles (i.e., the angles at which the anomaly is recorded) and one geometric leg (the magnitude of the boundary shift), the second geometric parameter—namely, the depth of occurrence—is then calculated (see below).

During object assessment, a defined number of satellite images acquired from different viewing angles are processed (Fig. 5).

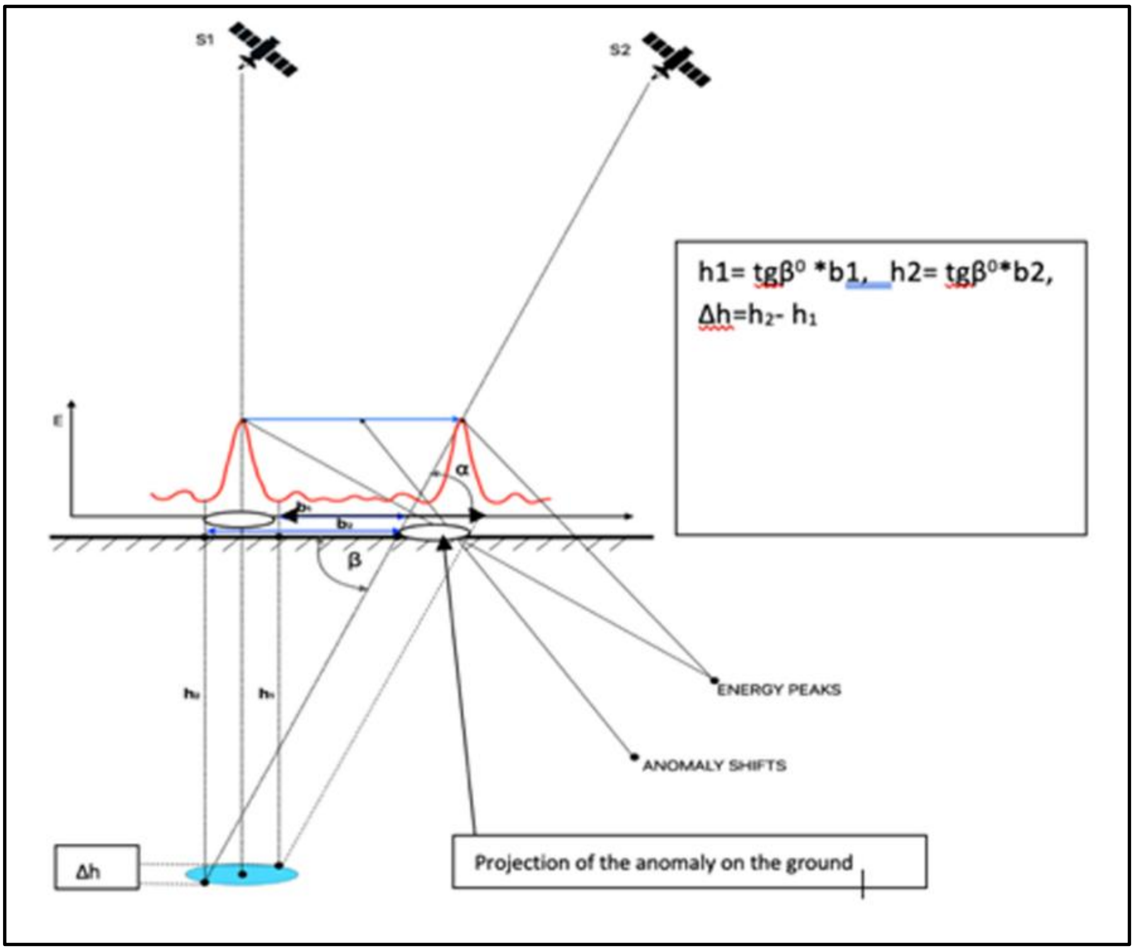

Fig. 5. Depth Estimation

Knowing the angle at which a satellite image was acquired, the depth of occurrence can be calculated as follows. By analyzing several images, the magnitude of the anomaly boundary shift is determined. For each image, the tangent of the satellite inclination angle is calculated, the satellite altitude is taken into account, and then the depths of the top and base of the geological body are estimated:

1. $\mathbf{h_1 = tg\,\beta_0 \times b_1}$
2. $\mathbf{h_2 = tg\,\beta_0 \times b_2}$
3. $\mathbf{\Delta h = h_2 - h_1}$

Where:

- $\mathbf{h_1}$ – depth to the top of mineralization;
- $\mathbf{h_2}$ – depth to the base of mineralization;
- $\mathbf{\Delta h}$ – thickness of the mineralized zone;
- $\mathbf{\beta_0}$ – inclination angle of the orbital axis of satellite **S2**;
- **b** – distance from the initial point of increase ($\mathbf{b_1}$) and decrease ($\mathbf{b_2}$) of the maximum signal amplitude to the intersection with the satellite observation line of the anomaly boundary recorded by satellite **S2**;

- **S1** – satellite positioned closest to the vertical observation line above the anomalous zone.

Geological Prerequisites

The most promising geological environments where the discovery of natural hydrogen deposits is most likely include:

1. **Magmatic rocks**, which create a wide range of hydrogen-rich environments in the form of free gas, dissolved gas, and trapped fluid inclusions in ophiolites, rift zones, faults, and through atmospheric degassing in volcanic gases, geysers, hot springs, and surface gas seeps.
2. **Kimberlite pipes**, which are rarely associated with hydrogen-rich gas; however, record flow rates of natural hydrogen have been discovered in a kimberlite pipe in Russia, where production reached **100,000 m³ per day**.
3. **Ore bodies**, which often serve as accumulation sites in both magmatic and sedimentary rocks.
4. **Coal seams and/or carbonates**, which have high hydrogen accumulation potential.
5. **Fluid inclusions within rocks**; the older the rock, the higher the H_2 content, as time is a key controlling factor.
6. **Evaporite sulfates**, which can store large volumes of H_2 (up to 20–30% by volume), and potassium-rich halite (e.g., potash deposits), which also represents a radiogenic hydrolytic source of H_2 through an intermediate compound—metallic calcium—which, together with salt, provides effective sealing for hydrogen accumulation.
7. **Oil and gas fields**, which typically do not contain large amounts of H_2; however, in deposits with elevated H_2 concentrations, hydrogen production may be economically viable, especially in conjunction with liquefied gas extraction.

The high reactivity of H_2 affects the structure and chemical composition of rocks it migrates through—for example, it reduces the mechanical strength of carbonates and can accelerate fault development under stress conditions, creating additional migration pathways. The H_2 content in wells generally increases with depth.

At present, only three types of seals for H_2 accumulations are considered viable: **mafic sills** (identified in Mali, where the only currently known natural hydrogen generation is located beneath dolerite), **salts**, and **shales**.

The most important criteria for H_2 accumulation include the following:

The following criteria are considered the most important for H_2 accumulation:

- **Presence of iron-rich ultramafic and mafic rocks**, especially within Archean basement complexes, which may serve as potential sources of both radiolytic and hydrolytic H_2;
- **Deep-seated faults** that facilitate the migration and concentration of diffuse H_2 sources;
- **Reservoir potential at depth** along the boundary between basement and sedimentary rocks. For example, natural gas from the Mount Kitty 1 well (Amadeus Basin)

contains **11 mol.% H_2** within fractured igneous basement directly overlain by sedimentary strata;

- **Areas with closed isometric depressions**, which are not themselves concentrators of natural hydrogen accumulations but indicate ongoing natural hydrogen degassing within the area.

Knowledge of the environmental setting and the geological framework of the area of interest is essential for a preliminary assessment of its hydrogen potential and for developing the most effective exploration strategy.