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GEOCHEMICAL INTERPRETATION OF DIGITAL SATELLITE IMAGERY

Annotation
The article explains the geochemical interpretation of data from satellites such as Hyperion (EO-1), PlanetScope, Landsat, and others, as well as natural processes that have occurred and are occurring on the Earth's surface. It examines the chemical composition of materials-vegetation, water, soil, and minerals-through their spectral reflectance and absorption characteristics. In particular, it describes the interpretation of complex geochemical processes such as salinization, desertification, wildfires, and eutrophication using spectral indicators.
Keywords: Artificial satellite, space, electromagnetic radiation, interpretation, geochemical analysis, spectral range, infrared, mineralogical composition, photosynthesis, concentration, organic substances.

ГЕОХИМИЧЕСКАЯ ИНТЕРПРЕТАЦИЯ ЦИФРОВЫХ КОСМИЧЕСКИХ СНИМКОВ

Аннотация
В статье объясняется геохимическая интерпретация данных спутников Hyperion (EO-1), PlanetScope, Landsat и других, а также природных процессов, происходивших и происходящих на поверхности Земли. Рассматривается химический состав веществ - растительности, воды, почвы, минералов - через их спектральные характеристики отражения и поглощения. В том числе разъясняется интерпретация сложных геохимических процессов, таких как засоление, опустынивание, пожары и эвтрофикация, с использованием спектральных индикаторов.
Ключевые слова: Искусственный спутник, космос, электромагнитное излучение, интерпретация, геохимический анализ, спектральный диапазон, инфракрасный, минералогический состав, фотосинтез, концентрация, органические вещества.

RAQAMLI KOSMIK TASVIRLARNING GEOKIMYOVIY INTERPRETATSIYASI

Annotatsiya
Maqolada Hyperion (EO-1), PlanetScope, Landsat va boshqa sun’iy yo‘ldosh ma’lumotlarining, Yer yuzasida ro‘y bergan va berayotgan tabiiy jarayonlarning geokimyoviy interpretatsiyasi, moddalarining - o‘simlik, suv, tuproq, minerallarning spektral qaytish va yutilish xususiyati orqali kimyoviy tarkibi, shu jumladan sho‘rlanish, cho‘llanish, yong‘in va evtrofikatsiya kabi murakkab geokimyoviy jarayonlarning spektral indikatorlar orqali talqinlashi tushuntirilgan.
Kalit so‘zlar: Sun’iy yo‘ldosh, fazo, elektromagnit nurlanish, interpretatsiya, geokimyoviy tahlil, spektral diapazon, infraqizil, mineralogik tarkib, fotosintez, konsentratsiya, organik moddalar.

Introduction. Artificial satellites are high-tech devices created by humans that orbit the Earth and enable remote observation of natural processes. Space-based observations, particularly through the spectral analysis of the physical and chemical properties of materials, play a crucial role in studying processes occurring on the Earth’s surface. The launch of artificial satellites into space in the 20th century marked the beginning of the era of space research and opened broad opportunities for the remote investigation of the interaction between solid, liquid, and gaseous substances and electromagnetic radiation.

Literature review. The chemical and physical analysis of data obtained from artificial satellites has been widely studied by numerous researchers [1–8]. These studies primarily focus on identifying the spectral ranges of materials on the Earth’s surface. Each natural object-whether vegetation, water, soil, or minerals—is characterized by its ability to absorb or reflect electromagnetic radiation at specific wavelengths, depending on its molecular composition and electronic structure. From this perspective, digital satellite imagery is considered a valuable source of geochemical information.

Research Methodology. Data obtained from artificial satellites such as Hyperion (EO-1), PlanetScope, and the Landsat series are based on different regions of the electromagnetic spectrum: visible (0.5–0.8 µm), near-infrared (0.8–1.4 µm), and shortwave infrared (1.4–2.6 µm). Radiation in these spectral ranges is directly related to the chemical composition of materials:

1. Chlorophyll molecules absorb blue (≈0.52 µm) and red (≈0.71 µm) wavelengths while reflecting green light, which is why vegetation appears green.
2. In the near-infrared range (≈0.8–1.3 µm), the internal structure of plant cells strongly reflects radiation, providing information about biomass and physiological condition.
3. The shortwave infrared range is associated with the vibrational energy levels of water molecules, enabling the estimation of moisture content.

For example, the sensors used in Landsat-8 have a 12-bit radiometric resolution, allowing the detection of 4096 intensity levels. This high sensitivity makes it possible to distinguish even subtle spectral differences between materials.

Analysis and Results. The combination of spectral bands allows for revealing the chemical nature of various natural processes:

1. Natural color composite (Bands 2–3–4): Primarily based on optical reflectance properties and used for visual interpretation.
2. Infrared composite (Bands 4–5–6): Enables the assessment of chlorophyll concentration and photosynthetic activity in vegetation.
3. Shortwave infrared (Bands 6–7): Plays a key role in identifying soil moisture, mineral composition, and chemical changes caused by fires.

For fire analysis, the Normalized Burn Ratio (NBR) index is widely used:

NBR=(NIR−SWIR)(NIR+SWIR) NBR= (NIR+SWIR) (NIR−SWIR).

Where: NIR (near-infrared) is associated with strong reflectance from healthy vegetation; SWIR (shortwave infrared) is sensitive to moisture content and the thermal decomposition of organic matter. During fire events, organic matter undergoes pyrolysis, resulting in the formation of carbonized residues. These processes significantly alter spectral properties, which are effectively detected using the NBR index.

Using data from Hyperion (EO-1), PlanetScope, and Landsat satellites, the following chemical processes can be monitored:

1. Soil salinization: Increased spectral reflectance due to salt crystallization;
2. Desertification: Reduction of organic matter and dominance of mineral components;
3. Eutrophication in water bodies: Increased phytoplankton and chlorophyll concentration;
4. Atmospheric aerosols and smoke: Detected through scattering and absorption of electromagnetic radiation.

The geochemical basis of remote sensing relies on the electronic and molecular structures within mineral crystal lattices. With hyperspectral satellites such as Sentinel, MODIS, WorldView, and WorldView-3, the distribution of elements in the Earth’s crust can be determined using the following chemical indicators:

a) Iron oxides and hydroxides: Minerals such as hematite (Fe_2O_3) and goethite ($FeO(OH)$) strongly absorb radiation in the blue and green regions of the visible spectrum. This allows the evaluation of soil redox conditions and formation environments.

b) Hydroxyl groups and clay minerals: The shortwave infrared (SWIR) range is highly sensitive to Al, Ca, Na, and Mg bonds in clay minerals such as kaolinite and montmorillonite. Absorption features around 2.2–2.6 μm serve as key indicators for identifying aluminum-rich clays. These data are essential for assessing soil sorption properties and nutrient retention capacity.

Soil salinity is not merely a physical phenomenon but a complex geochemical system. Spectral analysis also enables the identification of salt types:

c) Sulfate salinity: Gypsum ($CaSO_4 \cdot 2H_2O$) contains crystallization water molecules that produce strong absorption features in the SWIR range (1.7–2.1 μm).

d) Chloride salinity: Although halides (e.g., NaCl) are not directly spectrally active, they significantly alter soil moisture capacity and structure, leading to an increase in overall albedo (reflectance).

Determining soil organic carbon is one of the key directions in geochemical monitoring. Organic matter increases absorption across the entire spectral range, particularly within 0.5–1.4 μm.

The ratio of humic and fulvic acids in soil can be analyzed through color and spectral gradients, providing insights into the degree of organic matter mineralization and overall soil chemical properties.

In geochemical exploration, remote sensing employs the “mineralogical indicators” approach. By analyzing reflectance ratios of different minerals and rocks, it is possible to localize potential deposits of natural resources.

Anthropogenic chemical pollution - such as mining waste, heavy metal contamination, and related environmental impacts - often leads to vegetation degradation. High concentrations of metals disrupt chlorophyll synthesis, causing a shift of the characteristic “red edge” (around 0.7 μm) toward shorter wavelengths.

This phenomenon makes it possible to detect invisible contamination zones remotely, without the need for direct chemical sampling.

Conclusion/Recommendations. Data obtained from artificial satellites represent not only a geographic resource but also an essential source for in-depth chemical analysis. Through spectral bands, it is possible to derive information about substances with diverse molecular and atomic properties. Therefore, remote sensing technologies have emerged as a key scientific tool in modern geochemistry, ecology, and environmental monitoring.

In this context, remote sensing data should not be considered merely as visual imagery, but rather as a *digital geochemical map* of the Earth’s surface. Each pixel contains fundamental information about the energy of chemical bonds, molecular structures, and elemental associations. Thus, space-based technologies serve as a crucial bridge between fundamental geochemistry and applied environmental science, enabling continuous and large-scale environmental monitoring.

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