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Indexing in Scopus and Web of Science ensures high international visibility of publications, promotes citation growth, and reflects the editorial board's commitment to publishing relevant, original, and scientifically significant research in the fields of geology and technical sciences.

«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылымиметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылмды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

Индексирование в Scopus и Web of Science обеспечивает высокую международную востребованность публикаций, способствует росту цитируемости и подтверждает стремление редакционной коллегии публиковать актуальные, оригинальные и научно значимые исследования в области геологии и технических наук.

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SOME ASPECTS OF PREDICTING UNDERGROUND HYDROCARBON RESERVES BASED ON MULTISPECTRAL SATELLITE IMAGERY

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Abstract. *Relevance.* At present, considerable attention is being paid to methods for predicting oil and gas reserves through the use of multispectral satellite imagery. Among the various research areas in this field, particular importance is attached to the study of fluids generated by microseepage of oil and gas to the Earth's surface. Two types of hydrocarbon seepage are generally distinguished: macroseepage and microseepage. Macroseepage of oil is visible to the naked eye and appears on the Earth's surface in relatively large quantities. Due to environmental and economic considerations, such seepages usually require remediation and disposal measures. In most cases, macroseepages are observed only within the boundaries of major oil-bearing regions. Microseepage, by contrast, is characterized by a much lower intensity of hydrocarbon migration. Nevertheless, the analysis of anomalies generated by these processes may provide valuable information for forecasting the hydrocarbon potential of the areas where they occur. *Objective.* The present study examines thermal anomalies associated with hydrocarbon microseepage and demonstrates the applicability of research methods aimed at detecting and preliminarily assessing such manifestations. *Methods.* The investigation was based on satellite imagery acquired from the Landsat 9 system, while image processing was carried out using the ERDAS IMAGINE and ENVI software packages. The study area covered the Gobustan region of Azerbaijan. *Results.* The study found that there was match between the seismic lineaments obtained from

satellite data and those obtained from ground data. The analysis of the seismic lineaments was approximately 65% reliable in predicting hydrocarbon potential, with the intersection of fault zones being of greater importance. Thermal infrared measurements showed temperature differences of 1.5-3.0°C in the areas affected by the microseepage. *Conclusion.* This research work provides useful information for assessing the hydrocarbon potential of the study area, using the application of remote sensing methods for the detection and initial assessment of thermal anomalies associated with hydrocarbon microleakage.

Keywords: hydrocarbon exploration, thermal radiation, microseepage, multispectral imagery, fluid seepage manifestations, image processing software

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КӨП СПЕКТРЛІ СПУТНИКТІК БЕЙНЕЛЕРГЕ НЕГІЗДЕЛГЕН ЖЕРАСТЫ КӨМІРСУТЕК ҚОРЛАРЫН БОЛЖАУДЫҢ КЕЙБІР АСПЕКТІЛЕРІ

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Аннотация. *Өзектілігі.* Қазіргі уақытта көп спектрлі спутниктік суреттерді пайдалану арқылы мұнай мен газ қорларын болжау әдістеріне айтарлықтай көңіл бөлінуде. Бұл саладағы әртүрлі зерттеу бағыттарының ішінде мұнай мен газдың Жер бетіне микросүзілуі нәтижесінде пайда болған сұйықтықтарды зерттеуге ерекше мән беріледі. Көмірсутектердің сүзілуінің екі түрі жалпы алғанда ерекшеленеді: макросүзілу және микросүзілу. Мұнайдың макросүзілуі көзге көрінеді және Жер бетінде салыстырмалы түрде көп мөлшерде пайда болады. Экологиялық және экономикалық тұрғыдан мұндай сүзілулер әдетте қалпына келтіру және жою шараларын қажет етеді. Көп жағдайда макросүзілулер тек негізгі мұнайлы аймақтардың шекарасында ғана байқалады. Микросүзілу, керісінше, көмірсутектердің миграциясының әлдеқайда төмен қарқындылығымен сипатталады. Деген-

мен, бұл процестер тудыратын ауытқуларды талдау олар пайда болатын аймақтардың көмірсутек әлеуетін болжау үшін құнды ақпарат бере алады. *Мақсаты.* Бұл зерттеу көмірсутектердің микросүзілуімен байланысты жылулық ауытқуларды зерттейді және мұндай көріністерді анықтауға және алдын ала бағалауға бағытталған зерттеу әдістерінің қолданылуын көрсетеді. *Әдістер.* Зерттеу Landsat 9 жүйесінен алынған спутниктік суреттерге негізделген, ал кескіндерді өңдеу ERDAS IMAGINE және ENVI бағдарламалық пакеттерін пайдалану арқылы жүзеге асырылды. Зерттеу аймағы Әзірбайжанның Гобустан аймағын қамтыды. *Нәтижелер.* Зерттеу спутниктік деректерден алынған сейсмикалық сызықтар мен жердегі деректерден алынған сызықтар арасында сәйкестік бар екенін анықтады. Сейсмикалық сызықтарды талдау көмірсутек әлеуетін болжауда шамамен 65% сенімді болды, ал жарық аймақтарының қиылысуы маңыздырақ болды. Термиялық инфрақызыл өлшеулер микроағып кетуден зардап шеккен аудандарда температура айырмашылығын 1,5-3,0°C көрсетті. *Қорытынды.* Бұл зерттеу жұмысы көмірсутек микроағып кетуімен байланысты жылулық ауытқуларды анықтау және бастапқы бағалау үшін қашықтықтан зондау әдістерін қолдана отырып, зерттеу аймағының көмірсутек әлеуетін бағалау үшін пайдалы ақпарат береді.

Түйін сөздер: көмірсутектерді барлау, жылу сәулеленуі, микроағындылық, көп спектрлі кескіндер, сұйықтықтың ағындылық көріністері, кескіндерді өңдеу бағдарламалық жасақтамасы

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НЕКОТОРЫЕ АСПЕКТЫ ПРОГНОЗИРОВАНИЯ ЗАПАСОВ ПОДЗЕМНЫХ УГЛЕВОДОРОДОВ НА ОСНОВЕ МУЛЬТИСПЕКТРАЛЬНЫХ СПУТНИКОВЫХ СНИМКОВ

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Аннотация. *Актуальность.* В настоящее время значительное внимание уделяется разработке и совершенствованию методов прогнозирования углеводородного потенциала территорий с использованием мультиспектральных спутниковых снимков. Особое значение в данном направлении имеет изучение процессов просачивания углеводородов на земную поверхность, позволяющих выявлять косвенные признаки нали-

чия подземных нефтегазовых залежей. Выделяют два основных типа просачивания углеводородов: макропросачивание и микропросачивание. Макропросачивание характеризуется поступлением относительно значительных объемов углеводородов на земную поверхность, вследствие чего его проявления могут быть обнаружены визуально. Такие процессы способны вызывать экологические последствия и в отдельных случаях требуют проведения природоохранных и рекультивационных мероприятий. Микропросачивание, напротив, характеризуется низкой интенсивностью миграции углеводородов и отсутствием отчетливых визуальных проявлений. Вместе с тем анализ связанных с ним поверхностных и температурных аномалий может служить дополнительным источником информации при оценке углеводородного потенциала исследуемых территорий. *Цель.* Выявить и проанализировать тепловые аномалии, связанные с микропросачиванием углеводородов, а также оценить возможности применения методов дистанционного зондирования Земли для их обнаружения и предварительной оценки углеводородного потенциала территории. *Методы.* Исследование выполнено на основе мультиспектральных спутниковых снимков Landsat 9. Обработка и анализ спутниковых изображений проводились с использованием программных комплексов ERDAS IMAGINE и ENVI. В качестве объекта исследования выбран Гобустанский регион Азербайджана. Методический подход включал выявление и сопоставление линеаментов, интерпретированных по спутниковым изображениям и наземным данным, а также анализ температурных аномалий в тепловом инфракрасном диапазоне. *Результаты.* Установлено пространственное соответствие линеаментов, выявленных по спутниковым изображениям, с линеаментами, определенными на основе наземных данных. Анализ показал, что надежность прогнозирования углеводородного потенциала на основе выявленных линеаментов составила приблизительно 65 %. При этом наибольшую информативность имели участки пересечения разломных зон. Анализ данных теплового инфракрасного диапазона позволил выявить температурные различия в пределах 1,5–3,0 °C на участках, предположительно подверженных микропросачиванию углеводородов. *Выводы.* Полученные результаты свидетельствуют о перспективности применения методов дистанционного зондирования Земли для выявления тепловых аномалий, потенциально связанных с микропросачиванием углеводородов. Совместный анализ пространственного распределения линеаментов и температурных аномалий может использоваться в качестве дополнительного инструмента предварительной оценки углеводородного потенциала исследуемых территорий. Вместе с тем установленные закономерности требуют дальнейшей проверки с привлечением геологических, геофизических и наземных измерений.

Ключевые слова: разведка углеводородов, тепловое излучение, микропросачивание углеводородов, мультиспектральные спутниковые снимки, тепловые аномалии, дистанционное зондирование Земли.

Introduction. At present, specialists working in various research fields, including the exploration and prediction of hydrocarbon deposits, regard remote sensing (RS) methods as highly useful and, in many cases, indispensable. Various measuring instruments installed on satellite platforms are considered important sources of information and represent a promising approach for identifying potential oil and gas accumulations.

Among the principal applications of optical remote sensing methods are the identification of geophysical fault directions (lineaments) on the Earth's surface, the detection of oil seep manifestations, and the determination of their probable locations associated with hydrocarbon-bearing structures. In addition, these methods may also be applied to the assessment of anomalous methane concentration levels in petroleum-bearing regions (Yusifov and Rakhmanov, 2008).

In recent years, several major oil companies, including PetroChina, Shell, and ExxonMobil, have achieved significant results in this area. Owing to their efficiency and economic advantages compared with conventional exploration approaches, these methods have gradually gained wider practical application.

One of the indicators characterizing oil and gas deposits is the emergence of fluids on the Earth's surface as a result of geophysical processes and the seepage of certain hydrocarbon components from deep geological layers (Narimanov, 2017). Depending on the characteristics and structural features of the deposit, both macroseepage and microseepage processes may occur.

In the first case, the process develops due to the relatively large volume of oil reaching the surface, where it accumulates and becomes visible to the naked eye. This phenomenon generally depends on the depth of the reservoir, its productivity, and the properties of the soil cover (Yusifov and Rabinowitz, 2004; Berman et al., 2010).

In the second case, seepage is associated with the comparatively weak migration of hydrocarbons contained within subsurface petroleum accumulations. According to numerous studies, prolonged hydrocarbon seepage to the surface eventually causes local alterations in the near-surface layer compared with the surrounding background environment. These changes are mainly produced by a combination of geophysical and geochemical processes (Ragimov and Azizov, 2011; Uno et al., 2013). As a result, secondary geochemical formations, commonly referred to as fluids, are formed.

Until recently, optical methods were used primarily for detecting macroseepage (Mekhtiev et al., 2009). The detection of microseepage using optical techniques has been introduced comparatively recently due to the more complex nature of these processes. Geochemical changes associated with microseepage are linked to variations in the permeability and concentration of migrating hydrocarbons, which in turn alter the characteristics of clay minerals used as principal indicators detectable by optical methods. Studies have shown that oxidation of hydrocarbons by microorganisms on mineral surfaces may lead to the formation of carbon dioxide (CO₂) and hydrogen sulfide (H₂S) (Azizov et al., 2011), transforming clay minerals into kaolinite.

Following their detection and qualitative as well as quantitative assessment in different spectral regions of the optical range, these changes can be mapped within the investigated territory of a prospective hydrocarbon-bearing area using appropriate technical equipment (Merv and Brown, 2018).

The present study examines the formation of fluids generated by hydrocarbon microseepage to the surface, together with their detection and assessment using a geothermal approach. The main objective of the research is based on the assumption that zones where hydrocarbon fluids emerge at the Earth's surface exhibit anomalous thermal contrasts compared with surrounding territories. The detection and analysis of these contrasts may therefore provide a basis for the qualitative prediction of oil and gas deposits within the investigated region.

Study Area and Geological Structure. The Gobustan geographical region occupies the southeastern extremity of the Greater Caucasus mountain system. Owing to its geographical characteristics, the territory of Gobustan is divided into several distinct zones that differ considerably from one another.

The first zone, referred to as Northern Gobustan, covers mainly the southern and, to a lesser extent, the eastern parts of the Caucasus Mountains. The second zone, representing the foothill area, is known as Central Gobustan. The third zone is a coastal, hilly, and lowland area extending toward the shores of the Caspian Sea and is referred to as Southern Gobustan (Fig. 1).

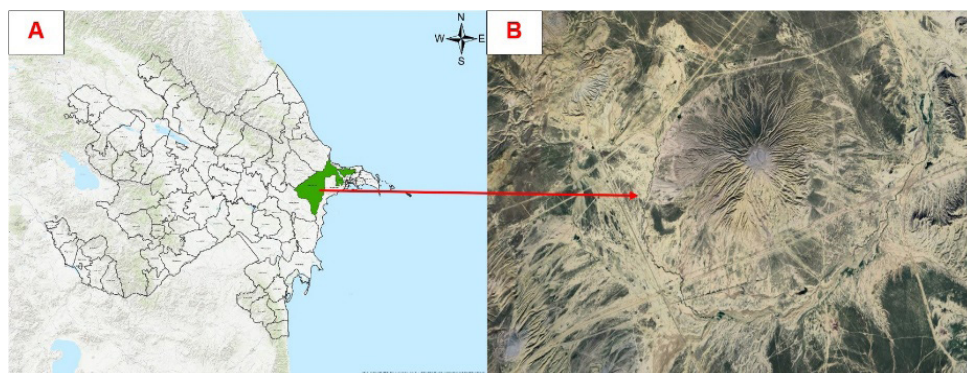


Figure 1. Geographical location of the Gobustan region (a) and its satellite image obtained from Google Earth Pro.

Ground-based geophysical investigations have shown that the southern zone covers more than half of the Gobustan oil and gas province. This territory is bounded by the central zone to the north, the Kura lowland plain to the west and southwest, and the coast of the Caspian Sea to the east.

The geomorphological structure of the third zone is less complex than that of the two zones described above and consists mainly of low hills, small mountain ridges, and various depressions. Its geological structure is predominantly composed of Neogene deposits. In turn, the zone is subdivided into three distinct subzones: the

southeastern subzone (the Jeyrankechmez depression), the southwestern subzone, and the Alyat subzone.

The southeastern subzone, or the Jeyrankechmez depression, is characterized by relatively simple topography. Nevertheless, within this area there are several orographic formations with elevations ranging from 15 to 400 m, including Mount Turogay, Develidag, Utelgi-Akhtarma, Shykhgaya, Garidag, Chapylmysh, and Chukhuroglubozu, among others.

Most of these elevations are associated with the mud volcanoes widely distributed throughout Southern Gobustan. Their cones are formed by materials periodically and continuously expelled onto the Earth's surface during volcanic activity. These volcanoes generally resemble truncated cones and are dissected by numerous ravines and gullies of various sizes (Yusifov and, Rabinowitz, 2004; Berman et al., 2010).

The study area considered in the present research represents a territory extending for approximately 50 km and forming the southwestern part of Gobustan. The southwestern slope of this territory, stretching in the northwestern and southeastern directions, is relatively steep, whereas the northeastern slope is more gentle. Both slopes are strongly dissected by deep gorges and ravines.

Mud volcanoes are also present within the investigated territory. The principal orographic formations include the cones of the Dashmardan (514 m), Solakhay (230 m), Garakure (195 m), Ayrantoken (193.1 m), Goturdag (205 m), Gyrdag (210 m), Delyaniz (163 m), and Dashgil (87.4 m) mud volcanoes (Narimanov et al, 2017; Mekhtiev et al., 2009).

Theoretical Background. The migration of fluids toward the Earth's surface, or their direct discharge onto the surface, gives rise to anomalous thermal contrasts. As is well known, the nature of a thermal contrast is primarily determined by the temperature, physical characteristics, and specific properties of the source object itself. In the present case, the role of such a source is played by gas-bearing fluids originating from subsurface geological formations.

These fluids, characterized by specific thermal and physical properties, enter into direct heat exchange with the surrounding atmosphere upon reaching the ground surface. This exchange is mainly governed by the thermal radiation emitted by the fluids penetrating to the Earth's surface.

On the other hand, under normal temperature conditions (300 K), there is practically no difference between the thermal emissivity of the atmosphere and that of the Earth's surface. Therefore, their emissivity coefficients may be assumed to be equal (Merv and Brown, 2018). Since the temperature of the fluids exceeds the background surface temperature, thereby forming an anomalous thermal indicator, such anomalies can be detected and evaluated using modern satellite observation systems.

The spatial distribution of surface temperature under specified boundary conditions may be determined by solving the steady-state heat transfer equation.

$$\frac{d^2T}{dx^2} = -\frac{q}{\delta} \quad (1)$$

where:

q — heat source power;

δ — surface heat transfer coefficient.

The following boundary conditions are assumed:

$$1. \quad \delta \frac{dT}{dx} \Big|_{x=0} = \delta^* (T_{surf}^4 - T_a^4) \quad (2)$$

Here, T_{surf} — denotes the surface temperature, while T_a — denotes the atmospheric temperature.

In this case,

$$\sigma^* = \sigma \cdot \varepsilon';$$

where σ — is the Stefan–Boltzmann constant, and, ε' - is the effective emissivity coefficient, defined as follows:

$$\varepsilon' = \frac{1}{\left(\frac{1}{\varepsilon_s} + \frac{1}{\varepsilon_0}\right) - 1}$$

$$2. \quad T_{(x)} \Big|_{x=0} = T_2 = \text{const} \quad (3)$$

By integrating Equation (1), the following expression for the temperature T can be obtained:

$$\frac{dT}{dx} = \frac{q}{\delta} x + c \quad (4)$$

$$T = -\frac{q}{2\delta} \lambda^2 + c_1 x + c_2 \quad (5)$$

Taking boundary condition (2) into account, expression (4) yields: (4)

$$\frac{q}{\delta} (T_{surf}^4 - T_a^4) = c_1 \quad (6)$$

Substituting Equations (3) and (2) into Equation (5), we obtain:

$$T = \frac{q\sigma^*}{2\delta} + \frac{\delta}{\lambda} (T_{surf}^4 - T_a^4) + c_2$$

$$c_2 = \frac{q\sigma^*}{2\delta} - \frac{\delta}{\lambda} (T_{surf}^4 - T_a^4) + T_2$$

In this case, when $x=0$, the following expression is obtained:

$$T_{surf} = \frac{q\sigma^*}{2\delta} - \frac{\sigma^*}{\delta} (T_{surf}^4 - T_a^4) \quad (7)$$

the surface temperature can be estimated by solving Equation (7).

On the other hand, in order to determine the boundaries of thermal anomalies, i.e., the zones associated with fluid seepage, it is necessary to evaluate the difference between the background and anomalous temperatures (12) for the quantitative assessment of the radiation contrast (11).

As is known, in order to increase the measurement accuracy of the temperature of the object under investigation, it is necessary to distinguish between the object's temperature and the background temperature. For this purpose, an n -th degree approximation of the differential law obtained in the study was used:

$$C_{rad} \approx A \cdot T^n \quad (8)$$

where:

- A — characterizes the absorption property of the real object based on thermal radiation theory, and is directly applied in evaluating the contrast between the object and the background;
- T — is the absolute temperature;
- n — is the degree of approximation.

It should be noted that the value of n is approximately 11 in the 3–5 μm (MWIR) range, and approximately 4.5 in the 8–14 μm (LWIR) range.

Since the level of ΔT temperature signals arising from fluctuations is low, the following mathematical expression, which characterizes the integral radiation contrast, is used:

$$\Delta C_{py} = \left(\int_{\lambda_1}^{\lambda_2} \frac{\partial c_{\lambda}}{\partial T} \cdot d\lambda \right) \cdot \Delta T \quad (9)$$

The calculations performed and the graphs constructed on their basis demonstrate that the contrast values reach 1.7% within the 10.6–11.9 μm spectral range and 3.7% within the 11.5–12.5 μm range (Figs. 2 and 3).

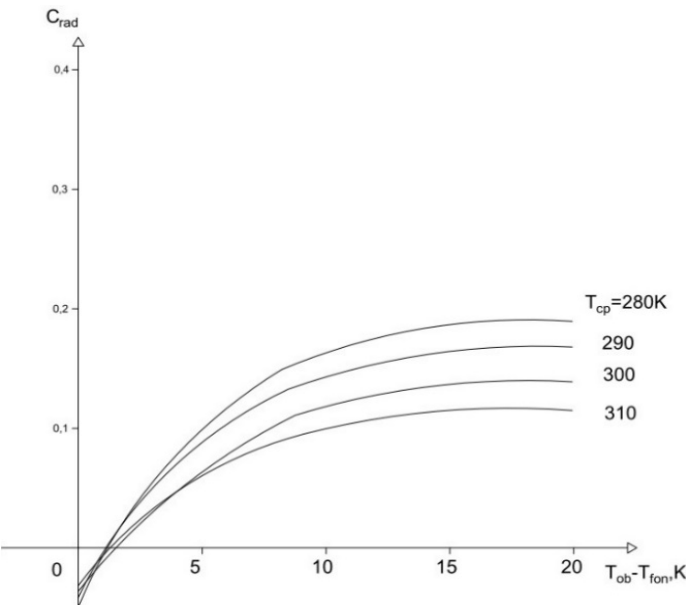


Figure 2. Radiation contrast between fluids and the background under different temperature conditions within the 10.6–11.9 μm spectral range.

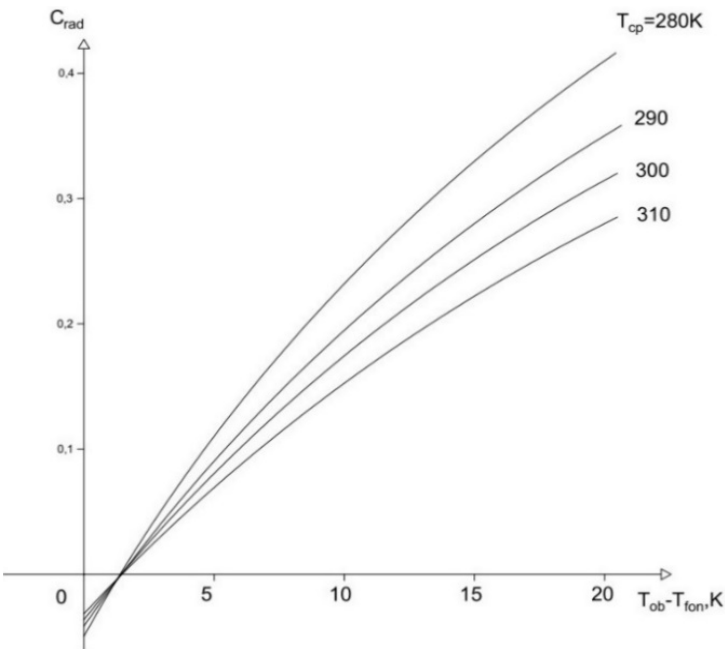


Figure 3. Radiation contrast between fluids and the background under different temperature conditions within the 11.5–12.5 μm spectral range.

Materials and Methods. The present study was based on satellite imagery acquired from the Landsat 9 platform, while the primary sources of initial data were the OLI-2 and TIRS-2 scanning radiometers. In general, the Landsat system provides data from 11 spectral bands, including one panchromatic band ($\lambda=0.50\text{--}0.68\ \mu\text{m}$), eight visible and near-infrared bands ($0.43\text{--}0.45$; $0.45\text{--}0.51$; $0.53\text{--}0.59$; $0.64\text{--}0.67$; $0.85\text{--}0.88$; $1.57\text{--}1.65$; $2.1\text{--}2.3$; $1.36\text{--}1.38\ \mu\text{m}$), and two thermal infrared bands ($10.6\text{--}11.9$ and $11.5\text{--}12.5\ \mu\text{m}$).

The spatial resolution of the system is 15 m in the panchromatic band, 30 m in the multispectral bands, and 100 m in the thermal infrared bands.

For the comparative interpretation of the satellite-derived data from geological and geophysical perspectives, topographic maps together with geological and geomorphological maps provided by SOCAR were used.

Discussions. Based on the conducted research, two principal directions of investigation were undertaken:

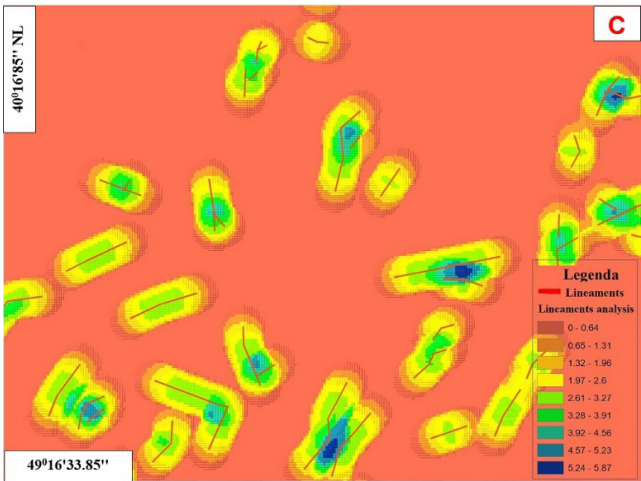
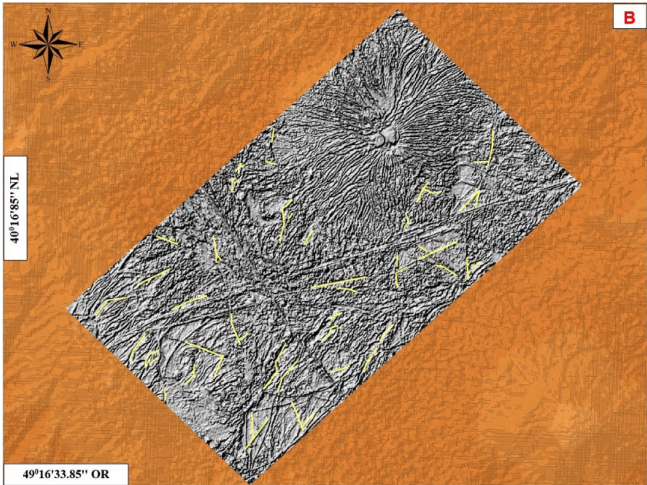
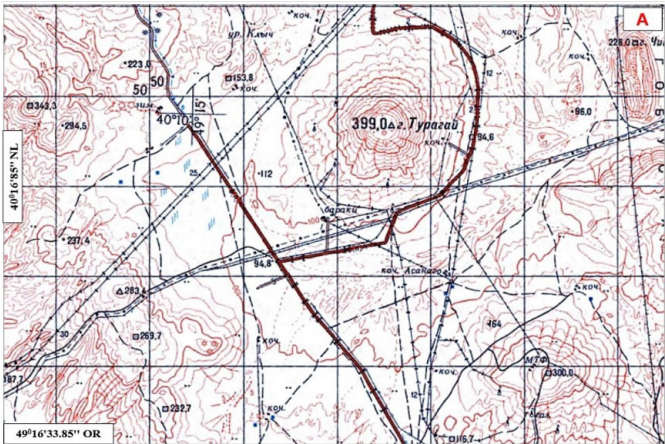
1. Identification of lineaments within the study area and assessment of their spatial density distribution;
2. Detection of fluids reaching the Earth's surface and analysis of their relationship with lineament density.

For the identification of lineaments using satellite imagery and digital elevation models (DEMs), the LESSA module of the ERDAS IMAGINE software package was applied. LESSA (Lineament Extraction and Stripe Statistical Analysis) is a modern method designed for the automated detection of linear features and the determination of their orientation and spatial distribution. The software implementing the LESSA approach makes it possible to identify linear elements within images and describe their characteristics for geological investigations.

Using this method, it is possible to determine distribution patterns, evaluate the density of linear features, and analyze the characteristics of extended lineaments. By providing a comprehensive description of imagery, LESSA enables the processing of various data types, including grayscale imagery, binary images, and digital elevation models (Kumpula et al., 2010), Mekhtiev et al., 2009).

Thus, LESSA provides objective information on the investigated area and supports further analytical interpretation. The obtained information may be applied both for interactive analysis (schematic representations, rose diagrams, and pseudocolor maps) and for automated analysis within GIS environments.

Of particular importance for the present study was the capability of LESSA to compare and integrate data obtained from different sources, including various spectral bands and imagery acquired at different observation periods. Figure 4 presents the distribution scheme of lineaments derived from satellite image processing using the above-mentioned software packages.



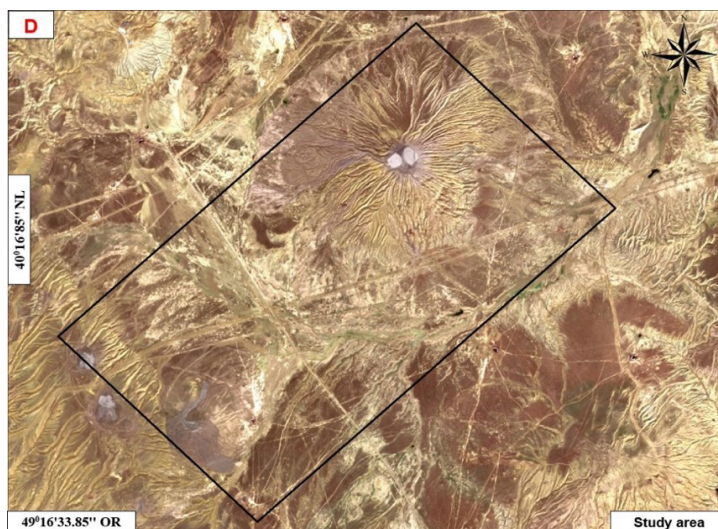


Figure 4. Distribution characteristics of lineaments within the investigated area based on geophysical methods and satellite data, together with the results obtained from integrated data analysis.

- A) Fragments of lineaments identified on a 1:200,000 scale topographic map;
- B) Diagram showing the cumulative density distribution of lineaments of different orientations;
- C) Predictive potential map of the investigated territory;
- D) Satellite image of the study area (Landsat 8–9).

The lineament density distribution derived from satellite imagery demonstrates a gradual variation in density across the investigated area. Lineament density is determined by the number of linear features per unit area. Analysis of the spatial distribution patterns of total lineament density, derived from lineaments of different orientations, indicates that hydrocarbon prospecting may be improved through the assessment and interpretation of the distribution characteristics of the identified fracture systems.

The application of lineament analysis for hydrocarbon prospecting, particularly on the basis of lineament density, has been used for a considerable period of time. However, it should be noted that the reliability of predicting oil and gas reserves solely on the basis of lineament indicators generally does not exceed 50–60%. In order to improve predictive accuracy, it is necessary to incorporate additional methods directly associated with lineament structures.

One of the approaches that has recently gained widespread application is the identification of fluid seepage locations. It should be emphasized that one of the principal techniques for detecting fluids is the detection and assessment of thermal anomalies within the investigated territory. It has long been established that the temperature of fluids exceeds that of the surrounding environment.

Temperature assessment using satellite systems is carried out primarily within the thermal infrared spectral range. Remote sensing is regarded as a passive method for the detection and evaluation of thermal radiation because it records naturally emitted radiation. Measurements of the temperature of surface objects are mainly performed within the 3–5 μm and 8–14 μm wavelength ranges (Moses et al., 2017; Tekenov et al., 2017; Maya et al., 2008).

In the present study, measurements were conducted using the above-mentioned TIRS (Thermal Infrared Sensor) radiometer installed onboard the Landsat 9 system. Initial image processing was performed using the absolute blackbody algorithm, taking into account the characteristics of the measurement range.

In order to improve the accuracy of the obtained results, not only radiometric correction but also relative radiometric correction was applied to images acquired at different observation times. Such correction procedures can be performed using the ENVI software package (Khutorskoy et. al., 2005; Kislukhin and Kislukhin, 2012; Neprimerov et al., 1983).

Atmospheric correction was based on the determination of temperature enhancement caused by absorption processes, taking into account the reflectance characteristics of the investigated object. Atmospheric correction represents one of the principal stages of preliminary image processing and is considered one of the major factors affecting the accuracy of the final processing results.

Based on the information obtained from the processing of the above-mentioned imagery, a schematic map of fluid distribution across the investigated territory was developed and prepared (Mark et al., 2018; John et al., 1993).

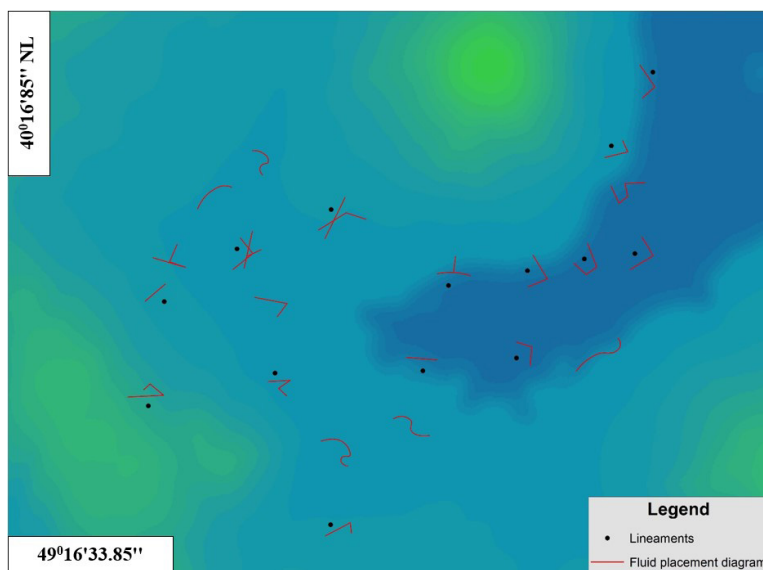


Figure 5. Schematic prediction map of the hydrocarbon potential of the territory within the Gobustan region based on satellite image processing.

Results. The principal findings of the present study may be summarized as follows:

1. The conducted investigations demonstrated a substantial correspondence between the lineaments identified from satellite-derived information and those obtained through ground-based seismological studies. At the same time, several significant distinguishing features were additionally identified, including lineaments that could not be detected through seismic investigations as well as lineaments characterized by differing orientations. Based on the analysis of the lineament maps developed from satellite data, the locations of major faults within the investigated hydrocarbon-bearing area were identified, and the characteristics of their formation were examined according to their spatial scale.

2. The results of hydrocarbon potential prediction based on lineament analysis indicate that the reliability of the obtained information does not exceed approximately 65%. This indirectly suggests that the formation of lineaments is not always unambiguously associated with the presence of oil and gas deposits. The conducted investigations also demonstrated that lineament intersection zones may possess a higher predictive significance. One confirmation of this assumption is the observed correspondence between previously discovered hydrocarbon deposits and the locations identified during the present study through the analysis of lineament intersection points. In order to improve the reliability of predictions based on satellite-derived lineaments, it is necessary to integrate additional methods capable of providing a more comprehensive and accurate assessment during remote investigations of hydrocarbon-bearing territories.

3. The widespread occurrence of mud volcanoes within the investigated region, together with other geological factors, may contribute to improving the accuracy of hydrocarbon potential prediction. In this context, the presence of fluids is regarded as one of the principal indicators. The underlying mechanism is associated with the extrusion of oil and gas toward the Earth's surface as a result of subsurface tectonic compression processes, leading to the formation of anomalous indicators on the surface. These anomalies, combined with elevated thermodynamic temperatures in the investigated areas, make it possible to obtain more reliable results based on the reflectance and signal penetration characteristics observed within different spectral ranges.

4. The conducted investigations established that, according to measurements performed in the thermal infrared range, temperatures within areas affected by microseepage vary between 1.5 and 3.0°C relative to the surrounding background environment. Consequently, variations in reflectance characteristics within the investigated territories directly influence radiometric resolution parameters. Such investigations should precede and serve as one of the principal criteria for identifying the most promising areas for comprehensive exploration aimed at discovering new subsurface hydrocarbon resources.

In order to improve the accuracy of parameters derived from satellite imagery,

data acquisition should be carried out under appropriate observation conditions, while the detection of thermal anomalies should be performed during periods of thermodynamic equilibrium within the investigated area. To ensure the proper consideration of reflectance characteristics, image acquisition should be conducted when the solar elevation angle is not lower than 60°.

Conclusion. The study showed that the analysis of lineaments and thermal anomalies obtained from the processing of Landsat 9 satellite data can be used as an effective approach in the initial assessment of hydrocarbon potential. The correspondence between the lineaments determined from satellite and ground data, as well as the higher prognostic significance of the intersection areas of the fault zones, confirm the applicability of this method. The identification of temperature differences of 1.5–3.0°C associated with microseepage indicates the importance of thermal infrared data in the detection of hydrocarbon leaks and the initial selection of prospective areas.

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