MINERALOGICAL SOCIETY OF GEORGIA
G. TSULUKIDZE MINING INSTITUTE
GEORGIAN TECHNICAL UNIVERSITY
INSTITUTE OF HYDROGEOLOGY AND ENGINEERING GEOLOGY

THE DEVELOPMENT OF MINING AND GEOLOGY IS THE PRECONDITION FOR THE REVIVAL OF ECONOMY



BOOK OF ABSTRACTS

12 th International Scientific-Practical Conference on Up-to-date Problems of Mining and Geology

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Tbilisi

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PERTOGRAFIC AND MINERAGRAFIC STUDY OF THE GHARTA GOLD-POLIMETALIC ORE OCCURRENCE (ACHARA_TRIALETI< GEORGIA)

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The Gharta gold–polymetallic ore occurrence is located in the eastern part of the Achara–Trialeti Fold-and-Thrust Belt and forms part of the Tethyan–Eurasian Cu–Au metallogenic belt [1]. The host rocks of the Gharta ore occurrence are represented by the Upper Cretaceous Tetritskaro Formation (alternation of limestones and marls) and the terrigenous turbidites of Borjomi Flysch.

The ore-bearing sedimentary succession forms an arched anticline (the Kodmani Anticline), which is intruded by dioritic bodies. Skarn assemblages developed along the contacts between diorites and carbonate rocks. The geological complex is further complicated by pre-ore and post-ore fault structures, which played a key role in the evolution of the hydrothermal processes.

The aim of this study was to investigate the petrographic and mineragraphic characteristics of the Gharta ore occurrence and to evaluate their significance for the genetic interpretation of mineralization.

The petrographic study is based on 50 thin sections prepared from drill-core samples obtained from 20 exploration boreholes, together with 20 thin sections prepared from surface rock samples collected within the Gharta ore occurrence. The investigated material includes both fresh and hydrothermally altered rocks. Mineragraphic investigations were carried out on

61 polished sections prepared from ore-bearing drill-core samples obtained from 18 exploration boreholes.

Petrographic investigations show that ore mineralization is spatially associated with dioritic intrusions, skarn assemblages, hydrothermal breccias, vuggy silica, and hydrothermally altered zones. Endoskarns and exoskarns are characterized by garnet–epidote and garnet–pyroxene mineral assemblages, whereas the principal hydrothermal alteration types include quartz–sericite, chlorite, epidote, and carbonate alteration. Mineragraphic investigations indicate that ore mineralization is dominated by pyrite and chalcopyrite occurring as disseminated, veinlet, and locally massive mineralization. Magnetite, hematite, molybdenite, chalcocite, sphalerite, and stibnite were also identified. Brecciated pyrite, replacement of pyrite by chalcopyrite, sulfide veinlets, and the pyrite–chalcopyrite–molybdenite and stibnite–chalcopyrite paragenetic assemblages record several successive stages of sulfide mineralization.

The integrated interpretation of the petrographic and mineragraphic results indicates that the Gharta gold–polymetallic ore occurrence formed through multistage magmatic–hydrothermal evolution. The spatial association of mineralization with dioritic intrusions, skarn assemblages, and hydrothermally altered zones, together with the textural characteristics of the ore mineralization and the characteristic paragenetic assemblages, provides a basis for interpreting the Gharta ore occurrence as porphyry-related skarn-type mineralization formed through multistage magmatic–hydrothermal processes.

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IMPLICATION OF THE STRUCTURAL–KINEMATIC EVOLUTION OF MOLASSE BASINS AND ADJACENT PARTS OF THE FOLDED MOUNTAIN FRAME WITHIN GEORGIA

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The fold arc of the Lesser Caucasus is secondary in nature and was formed after the Cretaceous period. According to paleomagnetic data, during the Late Cretaceous it represented a weakly southwest-convex arc, while the Adjara–Trialeti fold zone, as the northernmost element of the Lesser Caucasus structural arc, generally exhibited northwestern strike directions of its folds. However, during the Paleogene, apparently in the early Pyrenean (Trialetian) phase of folding, a gradual change in the deformation pattern began, caused by the submeridional northward movement of the Arabian promontory and its "intrusion" into the body of the Mediterranean belt. It was precisely this change in the deformation pattern that led to the reorientation of the Subhercynian–Laramian folds of the Caucasian region. Naturally, these morphological features are observed mainly within the lower, pre-Paleogene structural level. In our opinion, this deformation phase was associated with the formation of the so-called Transcaucasian transverse uplift, within which the oldest rocks are exposed. The formation of this major structural element of the Caucasus caused a series of changes not only in post-Paleogene sedimentation, but primarily in the distribution and localization of subsequent deformation

throughout much of the Caucasian region. First of all, it is necessary to clarify the cause of the formation of the Transcaucasian transverse uplift in order to reveal its role in the development of the region's dynamic-kinematic regime and deformation, up to the formation of individual secondary tectonic structures. Beginning with the early Pyrenean (Trialetian) phase of folding, tectonic units located directly north of the Arabian promontory experienced overall submeridional compression. Subsequent deformation phases — the late Pyrenean (pre-Oligocene), Styrian (pre-Middle Miocene), Rhodanian (pre-Late Miocene), and younger Alpine tectogenic phases — contributed to the convergence of relatively rigid blocks (fragments) of the Transcaucasian median massif. Based on the general kinematic picture of the Late Alpine deformation of the Caucasian region, it is assumed that during the convergent movement of these blocks they also generally moved northward, but at different velocities. As a result, certain zones underwent maximum deformation, and along some suture zones various supra-fault and near-fault structures of differing morphology and genesis were formed. This complex movement of blocks and masses can figuratively be compared to the drift of fragmented ice floes. Under such an arrangement of vectors of general compressive stress, horizontal compression forces on one hand and already formed positive morphostructural elements on the other caused all major vertical faults to transform into thrusts, nappes, and strike-slip faults. Studies of the mechanical conditions of horizontal compression in its various aspects show that within the Earth's crust, uneven distribution of compressive forces over an area leads to the formation of combined disjunctive-plicative structures of compression and extension.

Exactly such special conditions developed in the zone adjacent to the Dzirula massif, which inherited its development during the Late Miocene–Quaternary period. During the overall northward advance of the Adjara–Trialeti zone, the massif acted as a rigid obstacle whose bypassing determined the different kinematic nature of movement along the Surami–Gokishuri fault system. On the southern periphery of the massif, a thrust with small horizontal displacement formed, while along the southwestern margin a strike-slip thrust and tectonic nappe developed. At the same time, the northward advance of this nappe, where the fault possessed a strike-slip thrust character, caused the formation of en echelon strike-slip-related folds within the Cenozoic cover of the foredeep basin. West of the Transcaucasian transverse uplift, nappe-thrust structures are in most cases characterized by northward vergence and movement of masses from south to north. Thus, in the vicinity of Kutaisi, a gently dipping South Okriba thrust is observed. This tendency of south-to-north thrusting is also preserved within the junction zone of the southern slope of the Greater Caucasus and the Georgian block, particularly within the Racha–Lechkhumi syncline. Despite the controversial nature of the question concerning the origin of the fault structures of the Racha–Lechkhumi syncline, we support the view that marginal thrusts formed there with movement of masses from south to north. As has been noted, “the impulse for northward movement could not have originated from the Caucasian fold zone, where tectonic movements are oriented southward. However, in the Anti-Caucasian zone we observe major displacements toward the north. The boundary of the influence of the north-vergent impulse originating from the Anti-Caucasus is represented by

the Racha syncline. It acts as a buffer zone in which tectonic movements originating from both north and south gradually diminish." Further east, the Racha syncline zone is overlain by a thrust of Caucasian flysch. Here the aforementioned buffer no longer exists, and structures of the southern slope of the Caucasus are able to penetrate southward. Thus, the role of the Transcaucasian transverse uplift is emphasized in separating oppositely directed tectonic movements expressed in oppositely vergent nappe-thrust structures of the Caucasus and Anti-Caucasus. Further west, the Racha–Lechkhumi belt of marginal dislocations, serving as the boundary between the Georgian block and the southern slope of the Greater Caucasus, is replaced by the Tsageri–Tkvarcheli–Gagra flexural uplift zone, which generally is not characterized by the development of significant fault structures. Only in some places (Inguri Gorge, Magana) horizontal flexural bends are observed, which are associated with meridional basement faults and probably also with strike-slip deformations caused by rotational movements of individual basement blocks. In our view, such movements caused the formation of supra-fault strike-slip-related folds in the Zugdidi region, reflecting the southwestward movement of the Odishi block and the formation of hemianticlines. Thus, analysis of tectonic structures within the junction zone of the Georgian block and the southern slope system of the Greater Caucasus in its western sector (between Gagra and Ambrolauri) reveals no evidence supporting southward-directed movement from north to south. On the contrary, all existing disjunctive structures indicate the possible influence of north-vergent mass movements. A major obstacle to the northward movement of masses within the Lesser Caucasus structural arc, represented by

the Adjara–Trialeti fold zone, was apparently posed by opposing movements generated under the influence of southward-directed tectonic nappes of the southern slope of the Greater Caucasus. The collision of northern and southern mass movements becomes particularly evident near the meridian of Gori, where clearly expressed southward-directed movements are mainly manifested by fault structures involving movement of masses from north to south. Specifically, in the vicinities of Gori, Kaspi, and Mtskheta, exploratory drilling has revealed subhorizontal tectonic detachments (gentle thrusts). The direct manifestation of the collision between northern and southern movements is especially clearly reflected in the structural character of the northern periphery of the Adjara–Trialeti fold zone between the meridians of Gori and Mtskheta. Here, in connection with this process, the extensive Dvessi reverse-right-lateral strike-slip fault formed, with a fault plane dipping southward at approximately 70°. Further east, near Dzegvi and Mtskheta, a junction occurs between south-vergent and north-vergent strike-slip systems, with predominance of south vergence. On the eastern plunge of the Adjara–Trialeti zone, as it approaches the nappes of the southern slope of the Greater Caucasus, horizontal flexures with a significant strike-slip component are formed. Further eastward, south-vergent gentle thrusts and nappes replace one another in an en echelon arrangement. These structures represent manifestations of the underthrusting process of the Transcaucasian plate beneath the southern slope of the Greater Caucasus. A characteristic example of this process is the development of the Tsiv-Gombori uplift (Kakheti Ridge) and the Alazani depression, whose formation is paragenetically related. The formation of these structures is

associated with a ramp thrust in the crystalline basement, as evidenced by both geological and geophysical data.

Thus, the kinematic pattern of the investigated region during the Late Alpine stage of development was determined, on the one hand, by the northward movement of the Afro-Arabian promontory and the formation of the Lesser Caucasus structural arc, and on the other hand by the gradual underthrusting of the truncated Transcaucasian massif beneath the fold system of the southern slope of the Greater Caucasus. This, in turn, caused the formation of asymmetric molasse basins in the South Caucasus. The underthrusting process along the entire Caucasus–Anti-Caucasus front is most strongly expressed in its eastern part (east of the Transcaucasian uplift).

PREDICTING CHEMICAL BOND TYPE IN BINARY CRYSTALS

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The role of chemistry in the study of geological processes on Earth is constantly growing. All systems tend to equilibrium and to a decrease in free energy – this is preached by the second law of thermodynamics. Atoms in a molecule interact and form chemical bonds, which leads to stability in molecular and crystal structures by minimizing the total energy of the system [1-3].

The bonding in a molecule arises when two atoms share pairs of valence electrons or through the electron transfer from one atom to another. Electronegativity (X) reflects the ability of an atom to attract bonding electrons towards itself [2, 3].

The absolute value of the difference in electronegativity of two elements (ΔX) provides insight into the bond type and degree of polarity in binary crystals (Fig. 1).

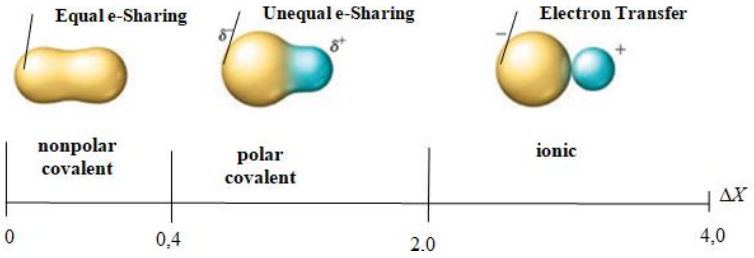

Fig. 1. Evaluating chemical bond type in a binary compound

We can now evaluate the nature of bonding in minerals using specific ΔX indicator. For example, for *Na* and *Cl* atoms in

halite crystal, also known as rock salt: $\Delta X = 2{,}23$ and two different atoms form a strong ionic bond. Sodium chloride is a typical 6:6 coordinated ionic crystal (Fig. 2).

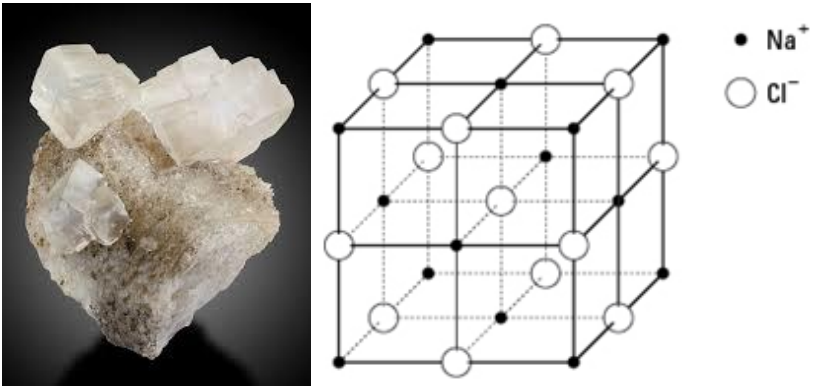

Fig. 2. Halite (Rock salt) and its crystal lattice

In case of rutile, brookite and anatase minerals (titanium dioxide) $\Delta X = 3{,}44 - 1{,}54 = 1{,}9$. Consequently, the bond is a polar covalent and the electron cloud is heavily shifted toward the oxygen atom. The electronegativity values on the Pauling scale are taken from [4].

Assessing the nature of interatomic bonding in minerals is crucial to understand their physical and chemical properties, since the bond type determines hardness, structural stability, melting point, conductivity, solubility and etc.

An equal e-sharing perfectly describes nonpolar bond. This type of bond is formed in molecules between atoms of the exact same nonmetal element. For instance, $Cl - Cl$ bond in a diatomic chlorine molecule: two identical atoms share electrons equally, resulting in $\Delta X = 3{,}2 - 3{,}2 = 0$ (Fig. 3).

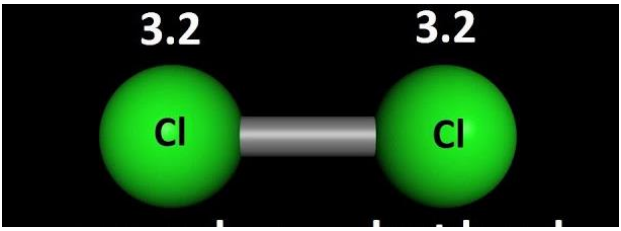

Fig. 3. Electronegativity and bonding in Cl_2 molecule

In binary crystals purely nonpolar bonds are rare and observed mainly in the molecular lattices of simple elements such as white phosphorus (P_4), iodine (I_2) and sulfur (S_8). They are nonmetals with $\Delta X = 0$, so the bonding is nonpolar covalent.

As can be seen, the calculated ΔX value for two elements gives a clear prediction about the type of interatomic bonding between them that dictates the arrangement of atoms, the stability and the overall crystalline structure of a material.

Thus, the electronegativity difference between two elements may be used as a guideline to assess the nature of the chemical bond in binary crystals and compounds, as well as to predict the outcome of interaction prior to actual synthesis.

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ROLE PLAYED BY SELECTED NATURAL FACTORS IN DEBRIS-FLOW VELOCITY FORMATION (TETRI ARAGVI RIVER RIGHT-BANK TRIBUTARIES AS EXAMPLES)

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Debris-flow activity periodically intensifies in the Chokheltkhevi and Naghvareviskhevi rivers, which are right-bank tributaries of the Tetri Aragvi River. These events create obstacles along the Natakhtari-Mleta section of the Georgian Military Highway.

Field studies conducted between 2023 and 2025 identified the main factors contributing to debris-flow formation. Climatic conditions are among the most important factors. Heavy rainfall and sharp increases in temperature during spring and summer cause rapid snowmelt and rising water levels in the valleys. Debris-flow formation and dynamics are also influenced by the geological and geomorphological structure of the area, ongoing geodynamic processes, steep channel gradients, and the morphological and hydrological characteristics of the rivers.

The obtained data can be regarded as relative characteristics of debris-flow-forming factors in the studied valleys. The proposed method cannot be used to calculate the direct impact force of debris flows or to design protective structures. However, it can be applied to the zoning of large geological and geomorphological units according to debris-flow

hazard. The obtained indicators may also be considered when addressing operational and construction issues along the Natakhtari-Mleta highway and assessing potential impacts on the natural and technogenic environment.

Determining debris-flow velocity is difficult because it depends on numerous natural factors. One such factor is river-channel roughness δ, which reduces flow velocity and is calculated using the formula $\delta=\delta_1/H$, where δ_1 is the absolute channel roughness and H is the flow depth. The average roughness values for the Chokheltkhevi and Naghvareviskhevi rivers were 2.02 and 1.88, respectively. Following recalculation using a new method, the values for the Chokheltkhevi River were 1.78 for a flow depth of 1.0 m and 1.64 for a flow depth of 2.0 m. The corresponding values for the Naghvareviskhevi River were 1.68 and 1.54.

Flow velocity is also affected by the sinuosity Z of the main river channel, or transit zone. It is calculated using the formula $Z=\ell/L$, where ℓ is the straight-line distance from the river source to its mouth and L is the length of the sinuous channel. The sinuosity coefficient is 0.88 for the Chokheltkhevi River and 0.92 for the Naghvareviskhevi River.

Drainage-basin asymmetry is another important factor. In an asymmetrical basin, runoff enters the river channel unevenly, preventing the debris-flow discharge from reaching its maximum value. This affects flow depth H, which is directly related to flow velocity. The ratio between the areas of the right and left sides of the basin is 0.91 for the Chokheltkhevi River and 0.88 for the Naghvareviskhevi River.

Considering these factors, the expected debris-flow velocity in the Chokheltkhevi River is 4.02 m/s for a flow depth

of 1.0 m and 8.81 m/s for a flow depth of 2.0 m. The corresponding values for the Naghvareviskhevi River are 4.49 m/s and 9.89 m/s.

The obtained data made it possible to determine the relationships among the hydrological, geological, and geomorphological characteristics of the studied valleys. Based on these relationships, relative characteristics of debris-flow formation and velocity were calculated. The nature, frequency, and velocity of debris-flow passage in the Chokheltkhevi and Naghvareviskhevi rivers were also assessed.

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MODERN ENGINEERING CONCEPTS AND EVALUATION CRITERIA FOR DESIGNING IMPACT-RESISTANT STRUCTURAL SYSTEMS UNDER DYNAMIC IMPACT LOADING CONDITIONS

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In the modern world, ensuring the safety of critical infrastructure, strategic facilities, transport systems, energy facilities, and special-purpose buildings is one of the most important engineering challenges. In light of the increase in military conflicts, terrorist threats, industrial accidents and man-made disasters, the development of shock-resistant structural systems has become particularly important.

Current engineering approaches mainly focus on assessing individual parameters, such as the structure's geometry, stress, deformation, displacement, and energy absorption resulting from the impact. However, there is no scientifically substantiated, universal, integral, quantitative criterion that combines impact energy transformation, the interaction of protective and protected structures, material properties, and maintenance of the structure's functional state into a single system.To address this issue, a modern engineering concept of impact resistance has been developed.Protective and protected structural systems are considered as a single dynamic system.To solve the above problems, the modern engineering concept of impact resistance was developed.

- The protective and protected structural systems were considered as a single dynamic system.

- An integral quantitative assessment criterion for impact resistance was created.
- Impact energy, material properties, and the structure's dynamic response was combined in a single mathematical model.
- A numerical model of the protective-protected structural system will be developed based on this model.

A numerical model of a protective-protected structural system was developed to determine the system's optimal geometric, physical-mechanical, and dynamic characteristics.

The optimization was carried out according to the following criteria: maximizing the absorption of impact kinetic energy, the absorption of incident energy on the protected object, and constructive efficiency.

Based on the theoretical and numerical results obtained within the framework of the study, engineering recommendations will be developed for selecting, calculating, and assessing the impact resistance of the protective-protected structural system, ensuring the application of the obtained results in practice.

ORE TYPES OF THE EAST TSITELISOPHELI LOW-SULFIDE GOLD AND GOLD-COPPER DEPOSIT AND THE CHARACTERISTICS OF THEIR MATERIAL COMPOSITION

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The deposit is located in the Bolnisi mining district and is localized within the Upper Cretaceous Mashavera suite. The following ore types are identified at the deposit: Gold-low-sulfide; Quartz-hematite-pyrite-sphalerite-gold-chalcopyrite; Hematite-gold-chalcopyrite-pyritic; Gold-pyrite chalcopyrite; Brecciated gold-pyrite-chalcopyrite ores of quartzitic composition.

It is noteworthy that the hematite-gold formation is unknown in ore geology; it has been identified by us, and its description is being presented for the first time.

Based on the current level of research, four stages of mineral association formation are established within the deposit: 1. Quartz-pyrite; 2. Quartz-hematite-sulfide; 3. Hematite-sulfide; 4. Gold-pyrite-chalcopyrite associated with brecciation. Within the deposit, we have identified hypogene, vein, and supergene mineral associations. The hypogene ore minerals are: pyrite, marcasite, galena, sphalerite, chalcopyrite, gold, hematite, magnetite and ilmenite.Vein minerals: Quartz, calcite, siderite, barite, adularia, sericite, montmorillonite, etc.

Supergene minerals are: Iron oxides, jarosite, bornite, malachite, cuprite, azurite, and tenorite.

Pyrite is represented by three modifications; galena and marcasite occur rarely, whereas sphalerite is quite widely distributed throughout the deposit.

Within the deposit, chalcopyrite occurs as xenomorphic, unusually shaped segregations, as well as in bead-like (moniliform), skeletal, revolver-like, vermicular (worm-like), colloform, and other forms.

Gold occurs in three varieties: Visible gold, which is easily seen with the naked eye and is represented by sharp-edged crystals forming localized clusters along a single straight line along fractures, associated with cuprite within hematitized secondary quartzites. Visible gold, which is clearly visible under a microscope and magnifying glass, represented by crystals of various shapes and sizes: rounded twins; scorpion-shaped; elongated with serrated/jagged edges; crescent-shaped; club-shaped; chain-like; tadpole-shaped; arrow-shaped, etc. Invisible, finely dispersed gold, which is detected only through chemical analyses. We have two types of hematite: in one case, it is red and associated with quartz; in another case, it has the color of iron oxide (rust-colored). This color variation appears to be caused by differing amounts of iron content. In both cases, it is characterized by colloform structures and acts as a carrier for gold-sphalerite-pyrite-chalcopyrite mineralization. Magnetite is represented by fine, black crystal disseminations (specks). Ilmenite is characterized by a fine-prismatic structure and is almost always observed together with hematite. It exhibits sheaf-like, broom-like, or radially-fibrous (radial-rayed) structures. Vein minerals are represented by: quartz, calcite,

siderite, barite, alunite, and adularia. The latter, together with quartz, forms 1–5 cm veinlets. Quartz-adularia quartzites are always characterized by elevated gold content, which serves as proof that this mineral can be used as a mineralogical prospecting criterion for gold mineralization. Among the supergene minerals noted at the deposit are: iron oxides, bornite, cuprite, and tenorite. The latter occurs as fibrous, sheaf-like, and radially-fibrous aggregates, which are often deformed due to lateral pressures. It sometimes contains fine disseminations (relicts) of chalcopyrite. Coatings, stains, and rounded segregations of azurite, jarosite, and malachite are common. Quartz-jarosite quartzites are always characterized by elevated gold content, which allows us to use this feature as a mineralogical prospecting criterion for gold, taking into account that the jarosite mineralization must be older relative to the gold mineralization. Cuprite is represented by reddish or rust-colored crystals.

THE IMPORTANCE OF COMPLEX ANALITICAL METHODS IN GUNPOWDER RESEARCH

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Gunpowder research is one of the important directions of chemical expertise, the purpose of which is to accurately identify the composition, physicochemical properties and residues of gunpowder. The use of a single analytical method is often not enough to obtain reliable and complete results, which is why special importance is attached to complex, multi-method research.

The paper discusses the main analytical methods used in gunpowder research, including the capabilities of chromatographic, spectroscopic and mass spectrometric analysis. We also mastered the determination of nitroethers and nitroamines in gunpowder by extraction and volumetric analysis methods. The advantages, limitations and their complementary role in the process of identifying the chemical composition of gunpowder and its residues are evaluated. Special attention is paid to the joint use of various analytical techniques, which significantly increases the accuracy of the research and the reliability of the results obtained.

The paper emphasizes that the use of complex analytical methods helps to increase the efficiency of the examination, reduces the probability of obtaining unreliable results and ensures the accuracy of the examination results. This issue is particularly relevant in the development of modern chemistry.

PROSPECTS FOR THE USE OF INNOVATIVE TECHNOLOGIES FOR THE PROCESSING OF MINERAL RESOURCES DEPOSITS IN INCREASING THE EFFICIENCY OF MINING AND GEOLOGICAL COMPANIES

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In the conditions of the modern global economy, the effective use of mineral resources is one of the main prerequisites for the sustainable development of the mining and geological sector. Technological progress, digital transformation, tightening environmental standards and the need for rational use of resources pose a need for the mining industry to introduce innovative approaches. In this context, the use of modern technologies for deposit processing acquires particular importance, which ensure increased production productivity, reduced costs, improved labor safety and minimized environmental risks [1]. The aim of the study is to analyze innovative technologies for deposit processing of mineral resources and assess the prospects for their use in increasing the efficiency of mining and geological companies. The study is based on a comparative analysis of modern scientific literature, international practice, technological trends and digital solutions implemented in the mining and geological industry. It has been established that the integration of Artificial Intelligence, Big Data, Geoinformation Systems (GIS), Automated Drilling and Transport Systems, Remote Monitoring, Robotization and „Smart Mining“ technologies is

characterized by particular effectiveness in the mining sector. These systems significantly increase the accuracy of geological modeling of deposits, reduce technological losses and improve operational management of production processes. Special attention is paid to environmentally friendly technologies, including energy-efficient equipment, waste recycling, circular use of water resources and low-emission production systems. These approaches comply with ESG standards and modern requirements of the „green economy", which increases the investment attractiveness and international competitiveness of companies [2, 3]. The introduction of innovative technologies for the processing of mineral resources is the strategic basis for increasing the economic efficiency of mining and geological companies, and accordingly, the Mining 4.0 and Mining 5.0 models create a new technological paradigm, where: productivity increases, operating costs decrease, safety improves, energy efficiency increases, and environmental sustainability strengthens (see Fig. 1) [4]. Modern technological transformation of mineral resource deposit processing and the main directions of development of the mining and geological industry with systematic and logical structures significantly and clearly demonstrate the integration of both technological and economic and ecological aspects in the mining and geological industry. Special emphasis is placed on digital technologies - artificial intelligence (AI), big data (Big Data), geoinformation systems (GIS/Geographic information systems), automated drilling and transport equipment, robotization and the concept of smart mining (Smart Mining). These elements express the transition of the mining and geological industry from the traditional model to high-tech and

data-based management systems. It is also worth noting the importance of sustainable development, ESG standards and the ,,green economy", which shows that the efficiency and success of the modern mining and geological industry is no longer measured solely by economic indicators, but also by the effective integration of digital technologies, artificial intelligence, ESG standards, human-centered intelligent systems and environmental responsibility (see Fig. 1).

Fig. 1. Inovative technologies for mineral processing



The impact of innovative technologies on the activities of companies is particularly important, as productivity increases, operating costs decrease, safety and the quality of resource management improve. The circular model symbolically reflects the interconnection of technological systems and the complex effect on production processes. Overall, it is noteworthy that innovation, digital transformation and environmental

responsibility are the main foundations for the competitiveness and sustainable development of the mining and geological sector. The results of the study show that the introduction of innovative technologies in mining and geological companies leads to an increase in labor productivity, optimization of operating costs, improvement of the resource utilization ratio and reduction of production risks [5]. In addition, the development of digital and automated systems helps to reduce the influence of the human factor and increase the level of industrial safety. In conclusion, it can be said that innovative technologies for the processing of mineral resources are an important factor in the technological modernization and sustainable development of the mining industry. Their large-scale implementation is especially relevant for developing economies, including Georgia, where the mining and geological sector is one of the strategic directions of the country's economic potential, and cooperation between the state, the scientific sector and private companies creates an essential prerequisite for the effective integration of innovative mining technologies.

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STUDY OF LOW-STRENGTH FACING STONES AND DETERMINATION OF OPTIMAL METHODS FOR THEIR EXTRACTION, PROCESSING, AND USE

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Low-strength stones differ in their physical-mechanical, mineralogical, and structural characteristics. These properties play an important role in their extraction and processing.

The principal composition of low-strength stones includes calcium, silicates, aluminum, and carbonates. The proportion of these minerals determines the stone's strength. For example, tuff contains a higher proportion of volcanic glassy material, which reduces its strength. Granite is characterized by higher strength because its high quartz content provides structural integrity.

Compressive strength: 10–80 MPa, depending on the type.

Flexural strength: 3–12 MPa.

Water absorption**:** Low-strength stones generally have relatively water absorption—approximately 1–5%—which increases their susceptibility to weathering and mechanical impact.

In the United States, low-strength tuff is used for decorative tiles because it can be easily cut using CNC machinery.

In Italy and Germany, basalt is used as a road-construction material because its strength enables it to withstand considerable loads.

Georgia has numerous low-strength deposits, the principal types being tuff, andesite, and basalt, with strength values ranging from approximately 10 to 40 MPa.

The territory of Georgia is distinguished by a diverse

geological structure, which provides a wide variety of low-strength facing stones. These stones occur in different regions and vary in mineralogical composition, strength, physical-mechanical properties, and extraction methods.

In Georgia, these stones have formed as a result of volcanic or metamorphic processes. Tuff is primarily of volcanic origin and contains a considerable amount of glassy volcanic material, which contributes to its low strength. Basalt is of volcanic origin and is distinguished by high strength and durability, making it suitable for road construction and structural projects.

In Europe and the United States, similar types of stone are used for decorative and construction purposes. In many cases, chemical consolidation agents and CNC processing are applied to improve product quality. Georgia's tuff and basalt deposits are technologically accessible for extraction; however, optimized processing methods are required to increase their durability.

The use and processing of low-strength stones largely depend on their physical-mechanical parameters, which determine their structural durability, machinability, and resistance to environmental impacts.

The extraction of low-strength facing stones requires specialized technological approaches that ensure high productivity, waste minimization, and operational safety. Extraction methods vary according to the type, strength, size, and geological characteristics of the deposit.

Modern quarries employ advanced technologies that enable extraction to achieve:

- ✓ High productivity—greater quantities extracted within a shorter period;

- ✓ Consistent quality—uniform stone dimensions and strength characteristics;
- ✓ Environmentally responsible operation—reduced waste and lower fuel consumption.

Quarry Extraction Process

- ✓ Exploration—geological surveys, sampling, and strength testing.
- ✓ Equipment selection—excavators, tracked machinery, and transport vehicles.
- ✓ Extraction—cutting the stone and sorting it according to size.
- ✓ Transportation—delivery to the storage facility.
- ✓ Storage and subsequent processing—quality control, grading, and preparation in accordance with export and construction requirements.

International practice includes the following examples:

- ✓ Germany: Basalt extraction is largely automated and involves CNC machinery and diamond-wire cutting.
- ✓ Italy: Tuff is mainly extracted for decorative tiles, and nearly 90% of the waste is recycled.
- ✓ United States: Technological monitoring, drones, and consolidation agents are used to stabilize product quality.

The efficient use of low-strength stones requires scientific, technological, and practical approaches that integrate deposit extraction, processing, quality control, environmental protection, and economic efficiency.

The study of low-strength facing stones and the determination of optimal methods for their extraction, processing, and use play an important role in construction, decorative applications, and infrastructure projects. The paper

examines all relevant stages, including the geological context of deposits, physical-mechanical characteristics, extraction technologies, optimal processing methods, and economic and environmental aspects.

Low-strength facing stones represent an important resource for Georgia's construction industry. Their efficient extraction, processing, and use require innovative, technologically advanced, and environmentally sustainable solutions. Compliance with the proposed recommendations will ensure product quality, economic efficiency, and environmental protection.

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INTEGRATED ASSESSMENT OF MODERN WATER TREATMENT TECHNOLOGIES SND THEIR IMPLEMENTATION PROSPECTS IN GEORGIA

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The objective of this study is to perform a comparative techno-economic assessment of modern water treatment technologies and to determine the most appropriate solutions for their implementation under Georgian conditions.

The research methodology is based on a comprehensive review of scientific literature, comparative analysis, techno-economic evaluation, and multi-criteria assessment. The principal evaluation criteria include treatment efficiency, energy consumption, capital investment (CAPEX), operational expenditure (OPEX), maintenance requirements, and the feasibility of integration into Georgia's existing water infrastructure.

Table 1.

Techno-economic comparative assessment of modern water treatment technologies

№	Technology	Core signifcance	Cleaning efficiency (%)	Energy consumption (kWh/m³)	CAPEX	OPEX	Technical service	Prospects for implementation in Georgia
1	Mechanical filtration	Suspended particles	60–85	0.02–0.05	Low	Low	Simple	Very high
2	Sand filtration	Turbidityve	70–90	0.03–0.08	Low	Low	Simple	Very high
3	Granular Activated Carbon (GAC)	Organic compounds, odor	75–95	0.05–0.15	Average	Average	Average	High
4	Ultrafiltratio n (UF)	Bacteria, colloids	90–99	0.10–0.30	Average	Average	Average	High
5	Nanofiltratio n (NF)	Fortress, heavy metalheads	90–98	0.30–0.80	High	Average	Average	High
6	Reverse Osmosis (RO)	Salts, heavy metals	95–99.8	0.50–1.50	High	High	Difficult	High

7	Electro-dialysis (ED)	Open Salt-B	80–95	0.40–1.20	High	Average	Difficult	Average
8	UV disinfection	Bacteria and viruses	99–99.99	0.02–0.10	Average	Low	Simple	Very high
9	Ozonation	Microbes and organic compounds	90–99	0.30–0.80	High	Average	Average	High
10	UV/H_2O_2 (AOP)	Micropollutants	95–99	1.0–2.5	High	High	Difficult	Average
11	Ozone + H_2O_2	Pharmaceutical waste	95–99	1.2–2.5	High	High	Difficult	Average
12	Photocatalysis (TiO_2)	Organic toxins	85–98	0.5–1.5	High	Average	Difficult	Promising
13	Nanosorbents	Heavy metals	90–99	0.10–0.30	High	Average	Average	Promising
14	Membrane Bioreactor (MBR)	Organic and biological pollution	95–99	0.60–1.20	High	Average	Difficult	High
15	Smart Water Monitoring (IoT/AI)	Water quality monito-ring	—	<0.05	Average	Low	Simple	Very high

The comparative analysis covers fifteen modern water treatment technologies, including mechanical filtration, sand filtration, granular activated carbon adsorption (GAC), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), electrodialysis (ED), ultraviolet (UV) disinfection, ozonation, advanced oxidation processes (UV/H_2O_2 and O_3/H_2O_2), photocatalysis (TiO_2), nanosorbents, membrane bioreactors (MBR), and Smart Water Monitoring systems based on the Internet of Things (IoT) and Artificial Intelligence (AI).

The results indicate that Reverse Osmosis (RO), Membrane Bioreactors (MBR), and UV disinfection provide the highest purification efficiency, although their implementation requires relatively high capital investments. Ultrafiltration (UF) and Nanofiltration (NF) demonstrate the best balance between treatment efficiency and economic performance, making them particularly suitable for municipal and industrial water treatment applications. Smart Water Monitoring systems do not directly remove contaminants; however, they significantly improve operational efficiency, reduce maintenance costs, and enable continuous real-time monitoring of water quality.

Considering the current state of infrastructure and economic conditions in Georgia, the most appropriate solution is the integrated application of Ultrafiltration (UF), UV disinfection, and Smart Water Monitoring systems. For the production of high-quality drinking water, the combination of Reverse Osmosis (RO) and UV disinfection is considered the most effective technological option.

The scientific novelty of this research lies in the development of an integrated evaluation model for modern water treatment technologies based on five major technical and economic

criteria. This approach enables the selection of optimal technological combinations for Georgia's specific environmental and infrastructural conditions. The findings demonstrate that integrating membrane filtration, UV disinfection, and intelligent monitoring technologies represents the most rational engineering solution for the modernization of Georgia's municipal water supply systems[1-5].

The outcomes of this research may serve as a scientific basis for the modernization of municipal water treatment infrastructure, environmental policy development, and sustainable water resource management in Georgia.

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DETERMINATION OF THE ELEMENTAL COMPOSITION OF SOIL SAMPLES COLLECTED FROM THE VALLEYS AND ADJACENT AREAS OF THE RIVERBEDS OF THE MTKVARI RIVER TRIBUTARIES - THE LOCHINI AND ORKHEVI RIVERS

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In order to comprehensively assess the anthropogenic pollution of the surface waters and bottom sediments of the Lochini and Orkhevi Rivers, soil samples collected from the valleys and adjacent areas of the riverbeds were investigated. The samples were collected during the winter season, under dry weather conditions, from both the surface (5 cm) and accumulation (20 cm) soil layers. The aim of the study was to determine the elemental composition of the soils, including the concentrations of heavy metals, and to compare the obtained results with the Clarke values of the Earth's crust and urban soils.The study areas are predominantly characterized by brown soils, which possess favorable physical properties and moderate fertility [1].

The physicochemical analysis of the air-dried samples was performed using an EDX 3600B energy-dispersive X-ray fluorescence (EDXRF) spectrometer. The concentrations of 22 chemical elements were determined. The obtained results were averaged and compared with the Clarke values of the Earth's crust [2] and urban soils [3] (Table 1).

Table 1

Comparison of the concentrations of chemical elements in the investigated soil samples with the Clarke values of the Earth's crust and urban soils (mg/kg)

№	Elements	Average (5 cm)	Average (20 cm)	Average (5 cm)	Average (20 cm)	Clarke Values in Urban Soils	Clarke Values for the Earth's Crust
		Lochini		Orkhevi			
1	Na	N/A	1 268	3 342	4 817	5 800	26 400
2	Mg	3 986	4 169	4 803	4 885	7 900	21 000
3	Al	33 64	33 16	35 13	34 24	38 200	88 000
4	Si	130 833	134 632	128120	129276	289 000	276 000
5	P	774	545	461	462	1 200	800
6	S	731	1 128	2 306	2 580	1 200	520
7	K	5819	6 625	6 769	6 543	13 400	26 000
8	Ca	74 56	70675	43822	31413	53 800	36 300
9	Ti	2 483	2 479	2 855	2 942	4 758	6 000
10	V	94	77	110	113	105	150
11	Cr	129	120	178	159	80	200
12	Mn	593	488	508	542	729	1 000
13	Fe	18 87	18550	28909	31065	22 300	51 000
14	Ni	89	63	105	60	33	100
15	Cu	196	189	222	246	39	100
16	Zn	160	165	203	258	158	50
17	As	9	10	12	13	16	5
18	Rb	40	44	44	41	58	300
19	Sr	362	340	307	273	458	400
20	Zr	181	148	143	125	256	200

21	Ba	611	465	348	888	853	500
22	Pb	15	20	20	24	55	16

The results of the analysis showed that the concentrations of 12 out of the 22 analyzed elements (Na, K, Al, Mg, Si, P, Mn, V, Ti, Rb, Sr, and Zr) generally correspond to or are lower than their respective Clarke values.Particular attention should be paid to the elevated concentrations of copper and zinc. The copper concentration in the soils adjacent to the Lochini River is approximately two times higher than the Clarke value for the Earth's crust, while in the Orkhevi River area it exceeds the corresponding Clarke value by 2.2-2.5 times. Compared with the Clarke values for urban soils, copper concentrations are 5–6 times higher. Similarly, zinc concentrations exceed the Clarke value for the Earth's crust by 3.2–3.3 times in the Lochini area and by 4-5 times in the Orkhevi area.Elevated concentrations were also detected for several other heavy metals. Compared with the Clarke values for urban soils, iron concentrations in the Orkhevi area are 1.3-1.4 times higher, chromium concentrations are 2.0-2.2 times higher, and nickel concentrations are 3.2 times higher. In the Lochini area, chromium concentrations exceed the background values by 1.5-1.6 times, while nickel concentrations are 2.0-2.7 times higher.The study also revealed approximately a twofold increase in calcium concentrations in the soils of the Lochini area and 4.5–5-fold higher sulfur concentrations in the Orkhevi area. At both study sites, arsenic concentrations exceed the correspondding Clarke values for the Earth's crust by 2.0–2.5 times, while lead concentrations are 1.25–1.50 times higher.The obtained results confirm that the soils within the investigated areas are characterized by elevated

concentrations of several heavy metals relative to their background levels. These findings indicate the presence of anthropogenic impacts on the ecosystems adjacent to the rivers and provide additional evidence of contamination of surface waters and bottom sediments.

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IMERETI MINERAL WATERS AND PROSPECTS FOR THEIR USE

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Imereti mineral waters, thanks to their special chemical composition, have various healing properties. Currently, some of these waters have been exploited, although some, due to insufficient research, are still unused. The clarification and presentation of their resources and chemical composition will give impetus to the creation and construction of new medical facilities in Georgia, balneo resorts, sanatoriums, baths and others.

According to the hydrogeological regions of Georgia, the study area includes: the waters of the Tskaltubo and Argveti artesian basins and the western subduction admass of the Adjara-Trialeti mountain-fold system[1].

In 2025, the project "Field and laboratory research of hydrogen sulfide and thermal mineral waters of the Imereti region" was carried out. Field and expeditionary work was carried out in the Samtredia, Tskaltubo, Tkibuli, Vani, Baghdati, Terjola and Kharagauli districts, 13 groundwater sources were investigated on site (Fig. 1).

Warm (from 20°C to 35°C) and thermal (from 35°C to 42°C) chloride-hydrocarbonate, hydrocarbonate-chloride, chloride-calcium-sodium waters with low (0.2 – 2.3 g/l) and medium (>5 g/l) mineralization and alkaline reaction (pH ranges from 7.8 to 10.2) are widespread here. Some geochemical indicators are given in Table 1.

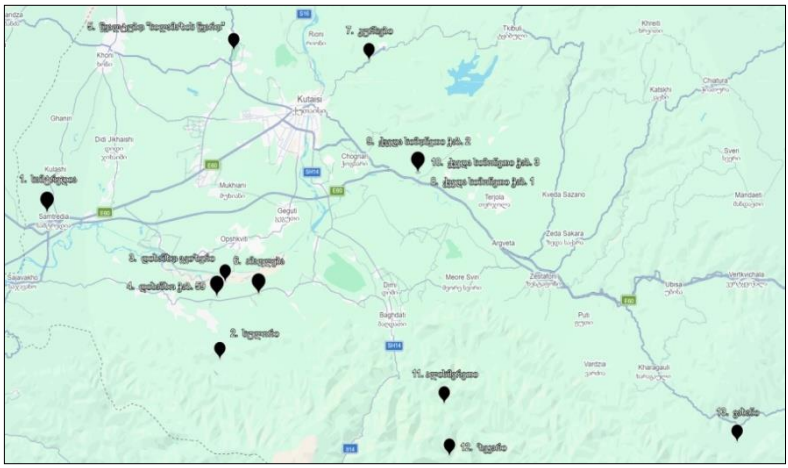

Fig. 1. Schematic map of the studied mineral waters location

According to the gas composition, the waters are mainly hydrogen sulfide (H2S from 13.1 to 14.7 mg/l), often with nitrogen content. Carbon dioxide gas is observed in small amounts almost everywhere.

As for microelements, most of them are within the limits accepted for balneological use. Bromine is present in small quantities in all studied samples. Its content ranges from 1 mg/l to 4 mg/l, only in the Dikhashkho well it is -14.9 mg/l.

In some cases, a trend of decreasing flow rates and decreasing mineralization (desalination) was observed. As a result of on-site chemical analyses, significant corrections were made to the chemical composition of some waters [2]. The decrease in flow rates or the cessation of self-flow from a well can be caused by both natural causes and irrational exploitation and unsatisfactory technical condition of the wells.

Table 1

Some results of the chemical composition of Imereti mineral waters

№	Location	M, g/l	T, °C	D m^3/day	ph	H_2S	As	Fe	Mn	Pb	Cu	Ni	Cr	I	Br
						mg/l									
1	Samtredia, Gormaghala	2.3	61.5	800	6.7	13,1	-	31.0	0.05	-	0.04	,,,	0.01	-	3.5
2	Soulori	0,6	39.5	60.5	10,9	14,6	,,,	12.8	0.02	-	0.05	-	-	-	0.4
3	Geyser Dikhashkho	9.4	38	90	6.6	32,1	-	170	0.07	-	0.03	0.01	-	6.4	2.1
4	WellDikhashkho	10.1	45	95	6.6	14,6	0.02	7.1	0.04	-	0.06	-	-	1.4	16.5
5	Tskaltubo	1.2	33	164.2	6.4	13.6	0.01	1.1	0.01	,,,	0.05	0.02	0.01	-	2.1
6	Amaghleba	8.5	35.2	400	7.1	14.1	,,,	28.4	0.06	-	0.01	0.01	-	2.1	14.9
7	Kursebi	0.7	16.7	14.7	7.1	13.9	-	11.1	,,,	-	0.03	-	,,,	-	1.5
8	Qv. Simoneti 1	0.9	40	60.5	6.7	13.9	-	8.8	0.06	-	0.07	,,,	-	,,,	1.8
9	Qv. Simoneti 2	1.8	30	43.2	7.0	13.9	-	13.3	0.01	-	0.04	-	-	-	2.1
10	Qv. Simoneti 3	0.8	30	34.6	7.9	13.8	-	4.2	0.03	-	0.02	,,,	-	-	1.9
11	Alismereti	0.15	16	-	10.1	13.8	-	0.05	0.05	-	0.01	-	-	-	1.0
12	Zekari	0.2	35	-	10.0	14.5	-	32.3	0.03	,,,	0.06	-	-	-	0.4
13	Vakhani	3.5	23.5	-	7.1	13.3	-	5.9	0.07	,,,	0.03	,,,	,,,	2.1	3.9

Studies have shown that many popular resorts need renovation, and in some cases, restoration. For example, resorts in the villages of Simoneti, Zekari, and baths in Amaghleba, Merilisi and Vakhani are completely destroyed. However, positive trends should also be noted: the resort "Chateau Kolkha" is being built in the Vani region on the Dikhashkho Well, and the resorts of Tskaltubo and Sulori have been restored and are operational.

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OIL AND GAS WELL CASING CARBON AND LOW ALLOY STEEL CASING PIPE PROTECTION FROM SOIL CORROSION

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The reliability and environmental safety of the operation of oil and gas wells, as complex engineering structures, are largely determined by the corrosion state of the casing pipes, which are the main element of the casing. Assessing the effectiveness of electrochemical protection and the condition of the metal of the well casing is a complex task that requires the use of various methods, simplifications, etc.

The main function of casing is to reinforce the walls of a costly well, prevent their collapse, and isolate different geological layers from each other. This is necessary to prevent the mixing of fluids from individual layers (layers), to protect the well from external influences, and to ensure safe and efficient drilling. Casing pipes vary in diameter, material, and design, which allows them to adapt to different operating conditions and well depths. In addition, they play an important role in preventing oil and gas blowouts and leaks, which makes the drilling process safer and more environmentally sustainable.

International experience shows that metal casings of wells are susceptible to both internal and soil corrosion. The greatest danger is posed by soil corrosion of the outer surface of metal casings of wells. The main indirect signs of casing failure caused by soil corrosion, in contrast to damage caused by other causes (burning, purely mechanical damage, abrasive wear, leakage of

threaded connections), are the statistical relationship of accidents with mining layers containing aggressive components (hydrogen sulfide, carbon dioxide, oxygen) and the increase in the number of annual accidents over time for a large number of wells of the same type of design [1, 2].

The cathodic protection system, which protects the outer wall of the metal casing of a well from electrochemical corrosion, consists of a constant current source, anode grounding and connecting cables. The protected structure is connected to the negative pole of the power source, and the anode grounding electrode is connected to its positive pole [3]. Anode grounding electrodes are made of low-alloy steel or cast iron (including coke-filled), iron-silicon alloys, graphite and graphite-plastic materials. A distinction is made between underground (the anode is installed below the freezing depth), trench (used in swampy areas) and deep anode grounding systems. A pit is dug for the anode grounding device, where the electrodes are placed. A control and measuring station is installed on the anode grounding device. Cathodic protection of well casing is implemented using cluster (Fig. 1) and individual well layouts.

The specific electrical resistance of the soil to the corrosive aggressiveness of the well casing made of carbon and low-alloy steel (low, medium and high) is, respectively: >50; >20≤50; <20, Ohm·m, the average cathodic current density is, respectively: >0.05; >0.05 ≤ 0.20; >0.20, A/m^2 [4].

The main reason for the increasing number of well production interruptions due to technical factors is the corrosion of metal casings, which sometimes even leads to the formation of through holes. The average external corrosion rate of metal casings is from 0.8 to 1.2 mm per year [5].

The main parameter of cathodic protection is the magnitude of the protective current. For casing structures, the

protective current is considered sufficient if the measurement results show that the electric current applied to the casing has eliminated all anodic areas.

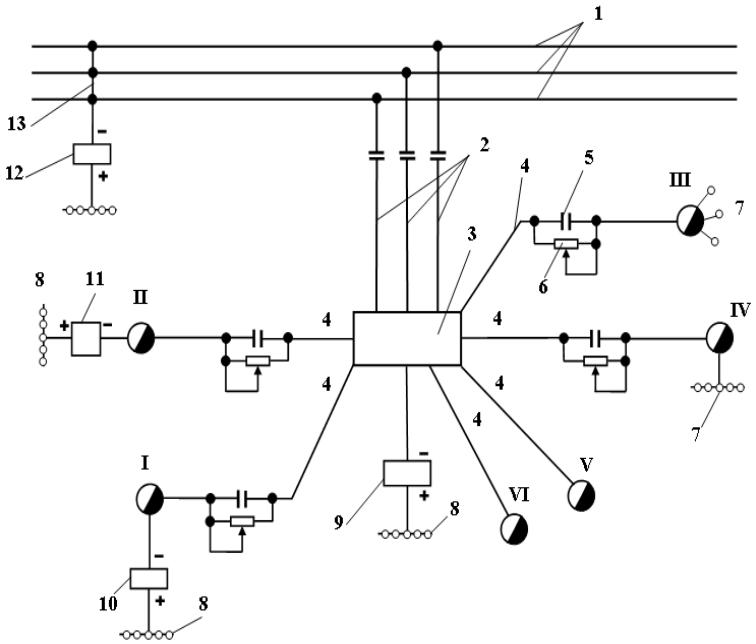

Fig. 1. Protection of industrial plume wells from electrochemical corrosion: I – IV - industrial wells; 1 - main pipelines; 2 - collection point pipelines; 3 - collection point; 4 - well plume; 5 - insulating flange; 6 - resistance; 7 - protectors; 8 - anode grounding; 9, 10, 11, 12 - cathode stations; 13 - electric fence

The criterion for the effectiveness of cathodic protection is the reduction of well casing accidents. Practice shows that the introduction of cathodic protection against electrochemical corrosion in various fields results in a reduction in the total number of accidents due to damage to the well casing ranging from 70-98 %.

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PROSPECTS FOR SHARING FOREIGN EXPERIENCE IN LOGIDTICS INFRASTRUCTURE IN GEORGIAN TRENDS

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The global energy system is rapidly transforming towards digital, ecological and integrated logistics models. Accordingly, the logistics infrastructure of the oil and gas industry is a key area of international cooperation and exchange of technological knowledge. In such conditions, Georgia, as a transit country, is particularly sensitive to the integration of foreign experience [1]. Georgia is a country with a deficit in energy resources and is heavily dependent on imports (mainly from Azerbaijan). Oil and gas production in Georgia is carried out on a small scale: the main directions are the exploitation of oil fields (mainly in Eastern Georgia), small-scale gas extraction and production sharing agreements (Production Sharing Agreements/PSA) with foreign companies. Meanwhile, the main participants are small international and local operators and state participation in certain projects. Among the main areas of experience and achievements of foreign developed countries in the field of research, it is worth noting the concentration in the following areas: digital logistics and Smart Pipeline Systems, automated terminals and SCADA management, LNG infrastructure development, environmental safety and zero emissions policy. Meanwhile, high-efficiency models are: Norwegian North Sea platforms, Dutch energy hubs and US multimodal oil logistics networks. Among the mechanisms for sharing achievements, it is worth noting: technology transfer from international energy

companies (British Petroleum/BP, Shell, TotalEnergies), regional energy cooperation (EU–Caspian Energy Corridor), joint infrastructure projects and investments, and the introduction of international standards (International Organization for Standardization/ISO; Health, Safety, and Environment/HSE, American Petroleum Institute/API), which will help the sector optimize processes, reduce risks, and enter international markets, while ensuring compliance with quality, safety, and environmental standards [2, 3]. From the point of view of integration into Georgian trends, the country is already using infrastructure based on foreign experience: the Baku-Tbilisi-Ceyhan (BTC) and South Caucasus Pipeline (SCP) pipelines and Black Sea terminals (Supsa, Kulevi); In addition, the following are underway: digitalization of infrastructure, optimization of transit operations, and strengthening of environmental standards [4]. In terms of development prospects, sharing foreign experience creates opportunities for: strengthening the role of Georgia as an energy hub, regional logistics integration, and increasing investments in energy infrastructure. Special perspectives include: AI-based logistics forecasting, LNG infrastructure development, integration with green energy systems, re-evaluation of remaining reserves based on modern 3D and 4D seismic surveys, the possibility of unconventional oil potential in deep layers, offshore exploration on the Black Sea shelf may become the most important direction,

deep geological drilling technologies, which increase the chance



of discovering natural gas (see Fig. 1) [5].

Fig. 1. Logistics Hub of the Georgian Oil and Gas Industry [AI]

Although large-scale discoveries are unlikely in the near future, the country will remain primarily a transit energy hub, with Georgia's energy future being more closely tied to transit, logistics, and regional energy integration than to the development of a large-scale oil and gas extraction industry. Therefore, sharing foreign experience is a key factor in the modernization of Georgia's oil and gas industry, so that the country can develop its significant potential into an energy and logistics hub of the South Caucasus, which will determine its future competitiveness in regional and global markets and ensure safe, efficient, and sustainable transportation of energy resources to regional and international markets.

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MAIN DIRECTIONS OF ECONOMIC EFFICIENCY OF INNOVATIVE TECHNOLOGIES FOR RATIONAL PROCESSING OF MINERAL RAW MATERIALS IN THE PROSPECTIVE DEVELOPMENT OF THE MINING-METALURGICAL INDUSTRY

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In the conditions of the global economy of the 21st century, mineral resources still remain one of the most important foundations of economic development, industrial production and technological progress. Against the background of energy transition, green economy, rapid development of digital technologies and growing demand for strategic minerals, the introduction of innovative technologies of mineral raw materials processing is gaining particular importance. These technologies not only increase the economic efficiency of enterprises, but also contribute to the rational use of resources, waste minimization, compliance with environmental standards and increased competitiveness [1, 2].

The aim of the paper is to determine the main directions of economic efficiency of innovative technologies for rational processing mineral raw materials, analyze international experience and assess the prospects for their use in the context of the development of the modern mining and metallurgical industry. The global mining and metallurgical industry is undergoing significant transformation. On the one hand, the demand for strategic minerals (lithium, cobalt, nickel, rare

earth elements) is increasing, and on the other hand, environmental requirements are tightening and the cost of energy resources is increasing. These circumstances force enterprises to introduce innovative technologies that ensure more complete utilization of raw materials and improve economic results. Of particular importance is the fact that in world practice, the issue of mineral raw materials extraction alone is no longer considered. The modern approach is based on the full development of the value chain - from extraction to deep processing and production of high value-added products [3].The global mining and metallurgical industry is actively introducing innovative technologies that are focused on the rational use of resources, reducing production costs, increasing energy efficiency and minimizing environmental impact. These processes are gaining particular importance against the background of mineral resource shortages, instability of raw material markets and increasing global competition. The main directions of economic efficiency of innovative technologies for processing mineral raw materials are: complex and full utilization of resources, introduction of energy-efficient technologies, use of digital technologies and artificial intelligence, waste recycling and circular economy, introduction of environmentally friendly technologies and production of high value-added products [3]. Particular importance is attached to the introduction of elements of Industry 4.0 and 5.0, including, if Industry 4.0 is focused on digital transformation of processes, automation and intelligent data management, the use of artificial intelligence, the Internet of Things (IoT), digital twins and big data analytical systems, Industry 5.0 complements these processes with the principles of human-centered, sustainable and environmentally responsible development, which overall significantly increases

the economic efficiency and international competitiveness of enterprises (see Fig. 1) [4].



Fig. 1. Main directions of economic efficiency of innovative technologies of mineral raw materials rational processing in the perspective development of the mining and metallurgical industry [AI]

The infographic in the first image clearly shows that the future of the mining and metallurgical industry is based on the synergistic development of digital transformation, hydrometallurgy, circular economy and green metallurgy. The presented model reflects modern world trends and confirms that the introduction of innovative technologies is the main prerequisite for economic efficiency, environmental sustainability and the creation of high added value.Georgia's mineral raw material base creates significant opportunities for the introduction of innovative technologies, where promising directions are: deep processing of copper and polymetallic ores, reuse of mining waste, introduction of digital mining technologies, development of green metallurgical

production, cooperation between scientific research centers and industry, and development of international technology transfer mechanisms.

Particular importance is attached to the cooperation of universities, scientific institutions, business and the state based on the ,,Quadruple and Quintuple Helix“ model, which will accelerate the process of commercialization of innovations and technological modernization [5]. The analysis confirms that innovative technologies for processing mineral raw materials are the main factor for the long-term development of the mining and metallurgical industry. Increased economic efficiency is achieved through the complex use of resources, increasing energy efficiency, integration of digital technologies, secondary recycling of waste and the development of green metallurgy.

Innovative technologies for processing mineral raw materials are the main factor for the competitiveness and sustainable development of the mining and metallurgical industry. International practice shows that the integrated use of digital transformation, energy efficiency, hydrometallurgy, green metallurgy and circular economy ensures a 20–40 % increase in production efficiency, a reduction in environmental risks and an expansion of the possibilities for the production of high-value-added products [6]. International experience shows that the introduction of innovative technologies increases production efficiency by an average of 15–30 %, reduces operating costs and strengthens global competitiveness [1, 7]. The above-mentioned directions are particularly relevant for Georgia, since the effective use of the country's mineral resource potential is possible only through the integrated use of modern technologies, scientific innovations and the principles of sustainable development. As a result, high-value-added products will be created, investment attractiveness will increase and the

country's positions in the international mining and metallurgical market will be strengthened.

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POSSIBILITIES FOR BENEFICIATION OF CARBONATE MANGANESE ORES BY A BIOTECHNOLOGICAL METHOD

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At the Chiatura manganese deposit, the proportion of oxidized ore and low-grade carbonate ores was almost equal in quantitative terms. However, as a result of the intensification of mining operations, the reserves of rich ores have been steadily decreasing, while the share of carbonate and oxidized ores has been increasing. Carbonate ores are characterized by granular (oolitic), massive and porous varieties, while transitional oxidized-carbonate ores are represented by granular (oolitic) forms, and hydrothermally altered ores by calcitized oxidized ores. The most widespread variety is the granular (oolitic) form. It consists of spherical grains. The oolitic structure is characterized by coated crystals and a fine-grained texture, while the cementing material is comparatively more crystallized. The center of oolitic grains contains quartz, glauconite, feldspar or other minerals. In oolitic ore, the grain size ranges from 1 to 8 mm. The grains are cemented by a clay-carbonate mass. Carbonate ores contain 30–35% manganese but almost no manganese dioxide. The principal minerals are calcium rhodochrosite (MnCO3) and manganocalcite[(MnCa)CO3].[1] The primary objective of manganese ore beneficiation is to increase the proportion of manganese in the ore mass. Therefore, considering the structural and textural characteristics of oolitic carbonate ores, the objective was to decompose the existing

oolitic cementing material using silicate microorganisms. Since this material has a composite composition, dissolving it into solution would increase the relative manganese content.It is known that silicate microorganisms (Bacillus mucilaginosus), during their life cycle, produce various organic acids and amino acids that act as active agents, causing the decomposition and dissolution of silicate minerals. This creates the preconditions for the destruction of the silicate cement of oolites. The efficiency of this process was tested under laboratory conditions. The chemical composition of the manganese ore used in the study is presented in Table 1.

Content	Mn	MnO	MnO_2	Al_2O_3	Fe_2O_3	SiO_2	P_2O_5	CaO
%	27.3	31.6	3.3	4.0	1.5	11.5	0.5	5.5

The ore fraction -1.0+0 mm was selected for testing. The bacterial substrate was prepared from the microorganism bank of the Department of Biotechnological Scientific Research. The solution titer was 10 million cells per milliliter. Leaching was carried out for four weeks, with weekly renewal of the solution. The experiment was conducted in three parallel tests. At the end of the experiment, the solid and liquid fractions were separated by filtration.The average chemical composition of the obtained solid fraction is presented in Table 2.

Element	Mn	MnO	MnO_2	Al_2O_3	Fe_2O_3	SiO_2	P_2O_5	CaO
%	40.6	44.6	4.0	1.5	1.3	2.5	0.2	4.5

The obtained results show that bacterial processing increases the proportion of Mn in the ore composition. This increase is caused by the destruction of SiO2 and its transfer into solution. The liquid biomass obtained after completion of the process is a silicate-containing liquid, considered a nutrient substrate for plants. It may be used either independently or in combination

with other nutrient elements as a fertilizer.

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THE ROLE OF CHAOTICALLY STRUCTURED ROCKS IN RECONSTRUCTING THE GEOLOGICAL PAST

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Chaotic-structure formations include a distinctive complex of rocks consisting of fragments of chaotically arranged rock of various sizes (ranging from centimeters to several thousand cubic meters), cemented by various materials (clays, limestones, lavas, tuffs, etc.). Their main part is represented by the following varieties of different genesis: conglomerates, breccias, olistostromes (block breccias), wildflysch, volcanic breccias, tectonic breccias (mélange), glacial breccias, horizons with inclusions, and others. The subject of our research is their sedimentary varieties, among which two groups can be distinguished by genetic characteristics — normal-sedimentary (conglomerates, breccias) and event deposits (olistostromes, wildflysch). Olistostromes and wildflysch contain the most information for reconstructing the geological past. Through them it is possible to determine the structure of the landmass that supplied terrigenous material to the sedimentation basins and to establish its probable location. In this respect, the Upper Eocene olistostromes distributed on the southern slope of the Caucasus Range stand out, whose analogous synchronous formations are widely distributed in certain regions of the Alpine fold belt [1]. Comprehensive study of these olistostromes within the southern slope of the Caucasus Range has shown that, along with clarifying many questions of Eocene paleogeography, a number of disputed issues have also arisen (the existence of Late Eocene volcanism, the location of

the landmass supplying terrigenous material to the olistostromes, and others). These questions arose from the fact that at certain sections of olistostrome distribution, exotic inclusions of various sizes are observed, the main outcrops of which do not exist south of the olistostrome distribution area (from the north, the olistostromes are covered throughout the entire southern slope by overthrust flysch). A good example of this is the Georgian Military Highway road-cut, where the olistostromes located between the Zhinvali reservoir and the Ananuri fortress section are built mainly of olistoliths and olistoplaques of Upper Jurassic reef limestones, as well as Bajocian volcanogenic rocks, and, rarely, blocks of crystalline basement. The main outcrops of the listed rocks do not exist south of the olistostromes; a similar picture is also observed in the Racha, Samachablo, and Kakheti regions. The search for the location of this disputed landmass has led us to hypothesize the existence of a hypothetical landmass — the "Racha-Vandami Cordillera" — which should have separated the Gagra-Java epicontinental and flysch basins, and which today is entirely covered by overthrust flysch deposits [2]. Upper Eocene olistostromes are also interesting because, along with reconstructing the paleogeographic picture, they allow us to conclude the tectonics of that time. Specifically, the formation of olistostromes in most of the Alpine fold zone, as in the South Caucasus, coincides in time with the peak of the Pyrenean orogenic phase, which points to their tectonic-gravitational origin.

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PURIFICATION OF EXPLOSIVE SUBSTANCES

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The purity of substances is one of the fundamental prerequisites for fully revealing their properties. It depends on many significant factors, such as synthesis conditions, storage technology, the presence of chemically aggressive environments, aging, and others.

In nature, absolutely pure substances do not exist. The following main criteria for the purity of chemical substances have been established: technically pure, pure for analysis, chemically pure, and ultrapure [1].

For the synthesis of energetic materials (explosives), priority is given to scientific research that ensures high yields of targeted explosives, maximum performance capability, safety, and purity.

The purification of explosives is a complex process and includes the following methods [2, 3]: Physical → filtration, sublimation; Physicochemical → recrystallization, distillation; Chemical→ neutralization, sulfitation; Technological → washing, stabilization.

In practice, the most effective approach is the correct combination of methods: Nitration→Washing → Neutralization → Recrystallization → Drying.The essence of these methods are discussed using the specific examples of two crucial explosives—nitrocellulose and TNT.

A. Nitrocellulose

Nitrocellulose is obtained by the nitration of cellulose [4]. After

nitration, nitrocellulose contains: residual acids (HNO_3, H_2SO_4), incompletely nitrated cellulose, decomposition products (NO, NO_2, N_2O_4, generally, NOx), and mechanical impurities. These factors increase the risk of explosion.

Purification of nitrocellulose involves several methods:

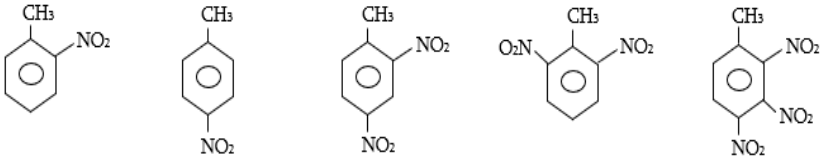
The main purpose of water washing is to remove acids, whereas long-term hot water washing is applied for the effective removal of remaining acids and NOx, Alkaline neutralization aims to fully neutralize the residual acids:

$$HNO_3 + NaHCO_3 \longrightarrow NaNO_3 + H_2CO_3$$
$$H_2SO_4 + Na_2CO_3 \longrightarrow Na_2SO_4 + H_2CO_3$$

For nitrocellulose, an effective combination of methods is: Washing →Long-term Boiling →Neutralization → Stabilization.

B. TNT (Trinitrotoluene)

TNT is produced by the nitration of toluene [4]. During this process, along with TNT, residual acids (HNO_3, H_2SO_4 resinous, colored, and incompletely nitrated products—isomeric mono-, di-, and trinitrotoluenes—are formed:



2-and-4-mononitro-toluenes **2,4 -and 2,6-dinitro-toluenes** **2,3,4-trinitro-toluenes**

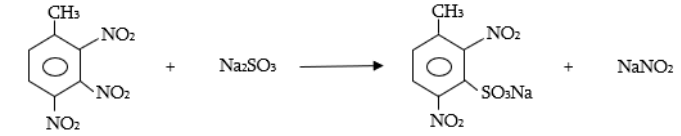
Impurities reduce the stability of TNT, increase its sensitivity to explosion, and impart an undesirable color (dark yellow or brown).

The purification of TNT relies on three processes:

Neutralization → Sulfitation → Recrystallization.

Neutralization aims to remove residual acids using sodium carbonate and sodium bicarbonate. Sulfitation is a specific and essential chemical stage in TNT purification: impure or expired TNT (conventionally designated as u-TNT) reacts with sodium sulfite. As a result, the products of incomplete nitration become soluble and are washed away.

Taking 2,3,4-trinitrotoluene as an example, this process is represented as follows:



2,3,4-trinitro-toluene **2,4-dinitro-3-sulfonate**

Removal of the soluble sulfonate salt yields high-purity TNT.

Recrystallization is based on the differing solubilities of substances, including TNT, at different temperatures: u-TNT dissolves in an organic solvent (toluene, alcohol) upon heating. Upon cooling, it crystallizes, resulting in pure, light-colored crystals from the brown u-TNT.

"Cold" Recrystallization of Expired TNT: In the innovative method developed by us for purifying expired TNT, the heating step is eliminated: u-TNT is dissolved in one solvent, and its crystallization is induced by adding a second solvent that dissolves the first solvent but does not dissolve the crystals. Impurities remain in the solution and are removed by filtration [5].

Here too, whitish crystals are obtained from the brownish u-TNT, which differ visually quite significantly from the initial crystals.

For primary verification, we detonated expired and purified TNT inside steel casings. The experiment shows that in the case of u-TNT ,the casing splits into only a few large pieces, whereas upon detonating the purified TNT, full fragmentation of the casing occurs. In other words, in the latter case, the explosive power is significantly increased.

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SYNTHESIS OF EXPLOSIVE CT COMPOUNDS FROM EXPIRED PICRIC ACID FOR OXYGEN BALANCE REGULATION

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LEPL Grigol Tsulukidze Mining Institute

The composition and structure of explosive molecules fully determine the characteristics and energy of an explosion, while significantly influencing both the environmental and economic aspects of the detonation.

Years ago, we improved the well-known methodology for synthesizing picric acid—one of the most powerful explosives—and increased its practical yield up to 86% [1]. Furthermore, the performance capability of one of the CT compounds synthesized from picric acid (TNP ● NH_4NO_3) exceeded the corresponding value of picric acid itself by 39%. We believe that one of the reasons for this is the partial regulation of the sharply negative oxygen balance (OB) of picric acid by ammonium nitrate.

Oxygen balance is one of the most critical parameters of explosion processes. Methods for its regulation have been discussed in our earlier publications [2, 3]. One such method involves ensuring a "tailored" ratio of the primary organogenic elements (C, H, O, N) in the molecule during the synthesis of the explosive substance itself. In addition, another equally important method proposed by us for the same purpose is the synthesis of so-called CT (Charge Transfer) compounds from well-known polynitroaromatic (PNA) compounds.

During the explosion of well-known explosives, the "fuel" elements (C, H) are oxidized by endogenous oxygen without the

involvement of atmospheric oxygen. If the ratio of atoms is stoichiometric, the explosion energy reaches its maximum, and the ecology of the blast area is preserved. Under these conditions, highest oxides (CO_2, H_2O) are formed from carbon and hydrogen, while nitrogen is released in its free form (N_2). None of these products are toxic.Oxygen balance is the ratio of the sufficient, excess, or deficient mass of endogenous oxygen relative to the initial mass of the explosive. For an explosive with the composition CcHhNnOo, it is expressed by the formula:

$$OB = \frac{\left\lfloor o - (2c + \frac{h}{2}) \right\rfloor \cdot 16}{12c + h + 14n + 16o} \cdot 100\%$$

(Note: c, h, o, n represent the number of corresponding atoms in the explosive, and denominator is its molecular mass).

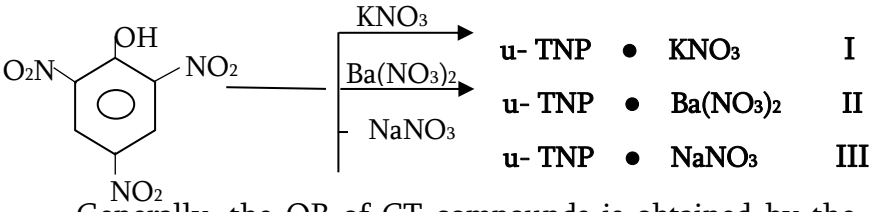
When the content of elements in the explosive molecule is stoichiometric, the difference in the numerator—and consequently the entire fraction—becomes zero (zero OB). In cases of oxygen excess (positive OB) or deficiency (negative OB), the explosion is accompanied by the release of toxic gases (CO, NO, NO_2, N_2O_4), which is undesirable.

The vast majority of explosives are produced via chemical synthesis. Well-known synthetic explosives often possess a sharply negative OB. To zero out this balance, composite (mixed) explosives are prepared. For example, to neutralize the negative OB of TNT (-74), ammonite is formulated by mixing it with ammonium nitrate (+20). One such formulation is: 79 %-NH_4NO_3, 21%-TNT.

The table below presents examples of well-known explosives with negative and positive OB values [4].

TNT	-74	Nitroglycerin	+3,52
Picric acid	-45,4	Ammonium nitrate	+20
Styphnic acid	-36	Potassium nitrate	+39,6
Trinitrobenzene	-56,3	Barium nitrate	+30,7
Tetryl	-47,4	Sodium nitrate	+47
PETN	-10	Potassium perchlorate	+46,2

Regarding explosives with zero OB, their explosive transformation results in the emission of environmentally safe gases.The picric acid synthesized by us underwent visual changes over the past 7–8 years—it darkened noticeably and lost its luster, effectively becoming expired (conventionally designated as u-TNP). To balance its OB, we synthesized three CT compounds with potassium, barium, and sodium nitrates:



Generally, the OB of CT compounds is obtained by the algebraic sum of the OB values of their components. Accordingly, the OB of Compound I will be -5.8, and Compound II will be -14.7 and Compound III will be +1.6.

A superior result—namely, the complete balancing of OB—can obviously be achieved by the synthesis of a CT compound of TNP with potassium perchlorate, yielding an OB of +0.8. As for the CT compound synthesized from tetryl and sodium nitrate, its OB is -0.4, meaning that in this case, the oxygen balance is nearly zeroed out. This indicates that the explosive transformation of this CT compound releases environmentally safe gases.

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RADIOFACES OF UNDERGROUND URBAN COMMUNICATIONS IN THE INTERPRETATION OF GEORADIOLOCATION ANOMALIES.

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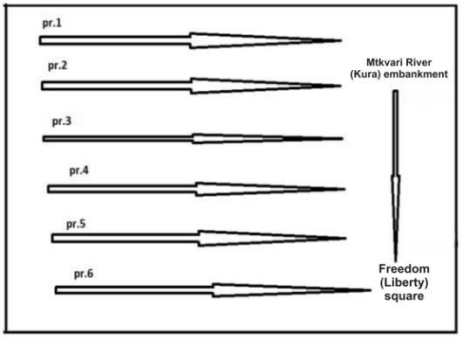
In the embankment area of Tbilisi, near Heroes Square (Photo 1), was discovered the location of underground communications for urban purposes. It was decided to carry out the work. using the georadiolocation method. For this purpose was selected a georadar with its standard antennas with central frequencies of 150MHz and 300MHz electromagnetic waves.

The collection of ground penetrating radar data and its computer processing to create a radargram were carried out using standard software Prizm 2.6.

There were conducted 6 geo-radiolocation profiles, below is a schematic drawing of the geo-radiolocation profiles (Scheme 1).



Photo 1. Fragment of the urban area under study.



Scheme 1. Schematic drawing of the conducted geo-radiolocation

GPR Profile 1 (Fig. 1). At the distances 15-19m a radio face was marked with a white line. A presumed urban structure with vertical sides and horizontal ridges was identified as a so-called "Bow-tie" type radio face. Also important is the possible location of a regularly placed urban object at the distances 3-7m and 10-15m. At the distances 16-18m and at a depth of 4m, a weak radio face may exist. The detection of clearly expressed synphasic axes on the radargram represents the superposition of electromagnetic waves, reflected from the objects.

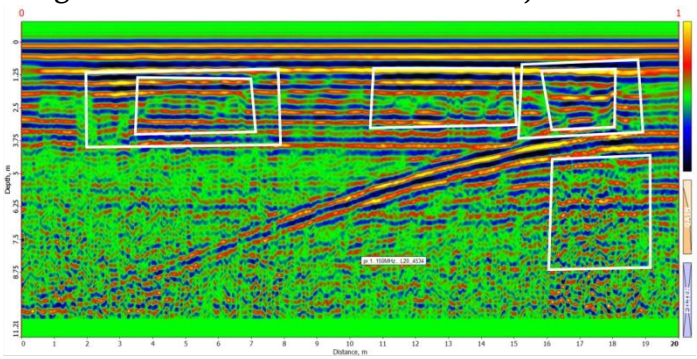


Fig. 1. Profile-1, the length of the profile made with a 150MHz antenna is 20m.

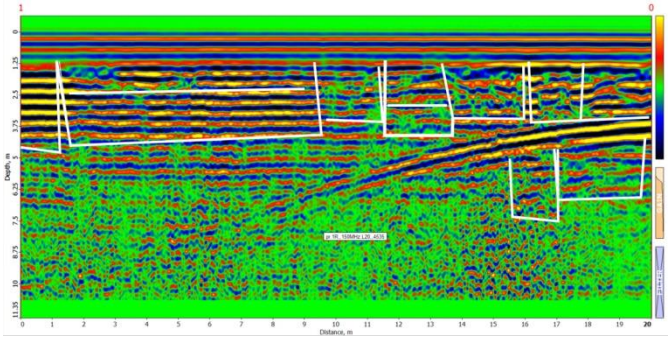


Fig. 2. Prof-1R (reverse). Length 20m, 150MHz, Parallel to Prof-1 and 3-4m away from it.

Prof. 1R (Fig. 2). At the distances 14-16m, 16-18m, 18-20m and at the depths up to 3.5m appeared radio objects, witch should

represent objects with parallel, single sided nests. They are probably of anthropogenic origin, as well as radio objects at the distances 16-18m and at the depths of 4-7m.

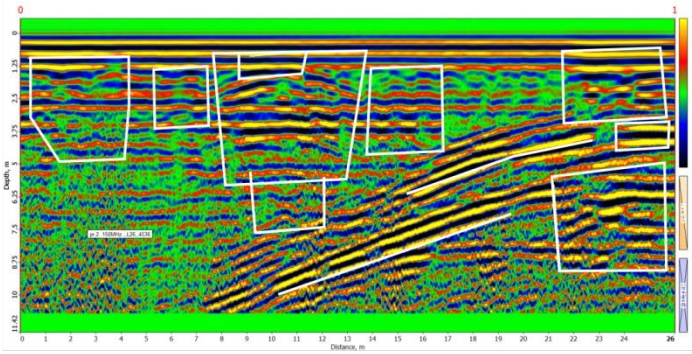


Fig. 3. Profile-2, the length of the profile made with a 150MHz antenna is 26m. It is approximately 40-45m away from Profile-1 and is parallel to it.

Prof. 2 (Fig. 3). The radargram clearly shows the radio face of a cylindrical object at the distances of 8-13m. It formed by characteristic diffracted electromagnetic waves, which were studied by the authors on a georadiolocation device using the physical modeling method for various types of cylindrical bodies [1-5]. At the distances of 22-25m, the location of the radio face of a rectangular object is again visible, as in the radargrams of Fig.1, 2. The location of the radio face of a collector-type object at a distance of 21-25m was clearly seen from the 4-4.5m depressions.

From the interpretation of the radar profiles, conducted and presented here, a complex set of radio features was identified, of which the target object's radio feature can be considered the radio feature of the collector at distances of 21-25m. The objects may have undergone repair, rehabilitation, possible parallelization, which led to their multifaceted complexity. The conducted cut confirmed the correspondence of the underground objects with their radio faces.

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THE ROLE OF MINERALS FOR THE HEALTH OF MODERN HUMANS (BASED ON THE MINERAL RESOURCE BASE OF GEORGIA)

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Introduction Minerals are inorganic substances that play a vital role in the normal functioning of the human body. In the modern era-under stressing conditions, consumption of processed food and environmental pollution-maintaining mineral balance has become a paramount priority. Classificationof Minerals -Minerals in the body are divided into two main groups: macroelements (the need for which is measured in grams) and microelements (which are needed in small doses, yet play a decisive role for human health). They are not synthesized in the body, and it is necessary to obtain them from external sources.

Key Macro- and MicroelementsMacronutrients agnesium (Mg): The "anti-stress" element for modern humans. Calcium (Ca) and Phosphorus (P): Responsible for the strength of the skeletal system and teeth, muscle contraction, and blood clotting.Potassium (K) and Sodium (Na): Maintain water-salt balance, regulate blood pressure, and heart rate. MicronutrientsIron (Fe): A component of hemoglobin that ensures oxygen transport to tissues and organs. Zinc (Zn), Iodine (I), and Selenium (Se): Powerful antioxidants that ensure immune resilience, thyroid function, and skin/hair health. Georgia's Mineral Potential -Georgia is distinguished by a rich and unique mineral resource base, giving the country the

potential to effectively utilize natural wealth to strengthen population health and balneological therapy. While the existing natural minerals in Georgia and their healing-health properties are substantial, individual mineral properties are constantly being reassessed experimentally in novel ways across medicine, balneology, and the pharmaceutical industry.

Mineral and Medicinal Waters of Georgia-Georgia is one of the world's leading countries in terms of the richness of its mineral and medicinal waters. Local mineral waters are distinguished by their unique chemical composition and are widely used both for prevention and balneological treatment. For example: Hydrocarbonate-Sodium Waters (Borjomi, Nabeghlavi, Likani): Restore the acid-base balance, regulate the function of the gastrointestinal tract, and normalize metabolism. Carbonate-Calcium-Magnesium Waters (Sairme): Effective for urolithiasis (kidney stone disease) and metabolic disorders. Waters Rich in Specific Elements (Utsera, Shovi): Contain iron and iodine, which are important for preventing anemia and supporting the endocrine system.

Study on Iodized Waters in Kaspi Region- The iodized waters studied by us in the Kaspi district are of great interest. In six selected springs, the chemical composition of the water was studied using ISO-standard compliant methods. According to the analysis results, the waters of the study region belong to practically neutral (pH=7.48–7.69) and normally mineralized waters (average content of main ions: 406 mg/L; total potassium and sodium content: 50–147 mg/L). Replenishing iodine deficiency in the human body using this iodized water proves to be significantly more effective.

Spirulina Experiment- An experiment conducted on the *Spirulina* alga using natural raw materials-in which I directly participated (M. Otarashvili)-is of particular interest. Its

cultivation and enrichment were carried out with iodine, along with the addition of calcium, potassium, and other elements necessary for the body, which was subsequently administered to the experiment participants in tablet form. The results were quite impressive.

Thermal Springs and Natural Resources- Alongside mineral waters, various natural thermal sources play a major role in replenishing the body's macro- and microelements, such as the thermal springs of Adjara and Guria, which are mostly located in high-mountain zones and valleys: Bogata (Boghata) Thermal Waters (Keda): Sulfur-bearing, thermal mineral water. Makhinjauri Thermal Springs: Chloride-sodium and sulfurous waters, used for the treatment of cardiovascular and musculoskeletal system disorders. Kokotauri Springs: Low-mineralized thermal waters that benefit the digestive system and metabolism. Thermal and Hydrogen Sulfide Waters (Tbilisi, Menji): Improve peripheral blood circulation and are used in treating dermatological and joint pathologies. Radon Waters (Tskaltubo): Stimulate tissue regeneration and the recovery processes of the central and peripheral nervous systems.

Peloids (Medicinal Muds)-Equally important are the so-called peloids-natural formations consisting of organic and mineral substances (mud, silt, peat) that possess high therapeutic properties. These include medicinal muds (Akhtala, Kumisi, Aketa) rich in mineral salts, which provide strong anti-inflammatory and analgesic effects. Microelements (iodine, bromine, sulfur) penetrate the body through skin pores. Zeolites-Zeolites (especially their activated form-clinoptilolite) are used as natural enterosorbents. Their action is based on the principle of ion exchange. Through ion exchange, they can attract and absorb heavy metals (lead, mercury, cadmium) into their structure and release beneficial ions (potassium, calcium,

magnesium) in return. Georgia's mineral resources represent a strategic asset for the country's healthcare and balneology (resortology). It is essential to achieve a targeted, scientifically grounded integration of natural minerals into modern medicine and rehabilitation.

COPPER IN ROADSIDE SOILS OF EASTERN GEORGIA

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Concentrations of copper in the roadside soils of eastern Georgia have been determined. It has been shown that levels vary significantly by region. The exceedance of permissible metal levels was assessed. The need for periodic monitoring in regions where metal levels are significantly above maximum permissible concentrations has been argued. Unfortunately, due to the format of the conference theses, the results of the study are presented in a condensed form and only for copper concentrations. The soil usually contains a number of naturally occurring heavy metals. However, human-induced heavy metal concentrations may reach levels that increase the risk of exposure. Modern soil-cleaning techniques are therefore needed.Copper usually primarily accumulates in the top soil layers (0-20 cm), where it gets adsorbed and ties up with organic matter, carbonates, manganese, and iron to create compounds. The estimated permissible concentration of total copper in soils depends on the soil type and ranges from 33 to 132 mg/kg. Soil contamination with copper compounds has been the subject of extensive research over several years [1], [2], [3]. Copper in roadside soils primarily accumulates as a result of intense vehicle emissions. The main sources are brake pad and tire wear, motor oil leaks, and road surface wear products. Metal concentrations decrease rapidly with distance from the road surface and into the roadside. Copper in soils becomes more mobile under roadside

conditions. This increases the risk of its easy migration into groundwater and active absorption by plants growing on the roadsides. Copper contamination of soils suppresses soil microflora and impairs soil respiration and nitrogen fixation. During highway operation, especially in new sections, contamina-tion typically spreads within 5–20 meters from the roadway edge. The occurrence of copper migration is contingent upon the environmental acidity and the particle size distribution in the soil.In addition, copper-based pesticides such as chloride, sulfate and hydrogen oxide play an important role in the complex system of plant protection in agriculture.Significantly elevated copper levels are observed in roadside soils near copper mines. In Georgia, heavily copper-contaminated soils are found in agricultural areas around Kazreti, where the Madneuli mine is being developed.This circumstance has led to the accumulation of copper and various metals in recent years, both in agricultural soils and especially in soils along highways. Soils in the villages of Ratevani and Nakhiduri have very high heavy metal content. The results showed that copper levels are elevated in the Abulmulk area, as well as in Kazreti and Balichi, reaching concentrations close to those found in ore-bearing soils. Roadside soil contamination in these villages is primarily the result of industrial dust particles being absorbed by the soil. Copper contamination is also observed in the vicinity of Rustavi, particularly in Gardabani, which can be explained by the presence of various large industrial enterprises (metallurgical, chemical, and others) in the region. High concentrations of Cu are also observed along urban roads, particularly on the outskirts of Tbilisi.

Figure 1 shows copper concentrations (mg/kg) in roadside soils in several regions of eastern Georgia. As can be seen from

the diagram, gross copper concentrations exceeding the permissible limits are observed near many populated areas.

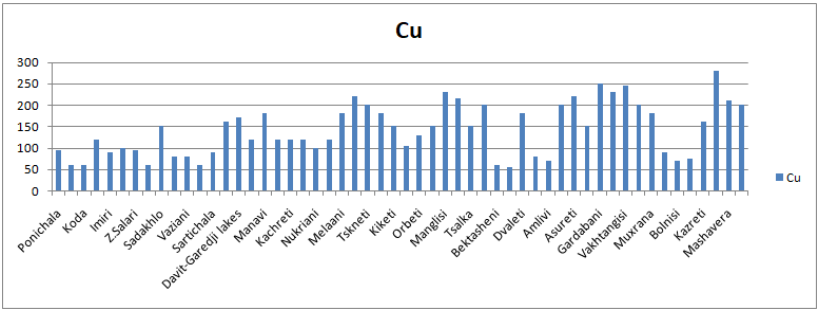

Fig. 1. Copper content (mg/kg) of roadside soils (The estimated permissible concentration of total copper in soils varies from 33 to 132 mg/kg)

The scale of pollution described in this article is not unique. It is a global problem. Such studies are particularly relevant for transit countries. According to the World Bank, cargo traffic through Georgia's Middle Corridor will increase by 52% by 2030 (World Bank Report, 2023).We believe that comprehensive studies of existing geoecological and geochemical potential should be conducted at least once every two years. This will help find timely solutions to improve environmental conditions and prevent the growing contamination of soils and plants with heavy metals and toxic chemicals in areas adjacent to international roads.Furthermore, the results of such studies should be taken into account when designing and constructing new roads with minimal environmental impact. This will help in selecting optimal routes and profiles for new highways, in assessing environmental impact; in determining the economic potential of road transport, etc.

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THE PROSPECTIVE ROLE OF GEOLOGY IN THE TRANSFORMSTION AND TRENDS OF SUSTAINABLE DEVELOPMENT OF THE MINING INDUSTRY

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Geology is one of the most important and creative knowledge-oriented sectors of the economy, where high demands are placed on innovative technologies, taking into account the needs of both specific and related industries and the country's development strategies. Accordingly, achievements in geology, the discovery and further development of new deposits become the driving force for the economic development of individual regions and the relevant countries [1].

In the modern era and conditions, the rational use of mineral resources, management and development of geology and the mining industry taking into account sustainable principles create a significant impetus for the economic strength of individual states, where the globalization of commodity markets, the introduction of geospatial innovative technological achievements in prospecting, the intensive development of the information technology industry, the effective implementation of research achievements and remote sensing methods require new progressive approaches to long-term strategic planning of the entire industry, because the mining and geological industry itself and the sectors synergistically connected with it are strategically important for Georgia, the development of which is directly related to the protection of state interests.

In the modern mining industry, geology is no longer limited to resource exploration. It has transformed into a strategic science that determines: resource management, technological planning, environmental safety and economic efficiency. Accordingly, the model of a sustainable mining industry is based on the integration of geology and technology, where the first picture presents an integrated model that combines geology, digital technologies, ESG standards, the economics of critical minerals and the concept of sustainable development. The infographic shows that the modern mining sector is based on: geological modeling, data analysis, environmental management and resource optimization. The main thesis here is that the traditional mining system is transformed into a digital and sustainable industrial model (See Fig. 1) [2].

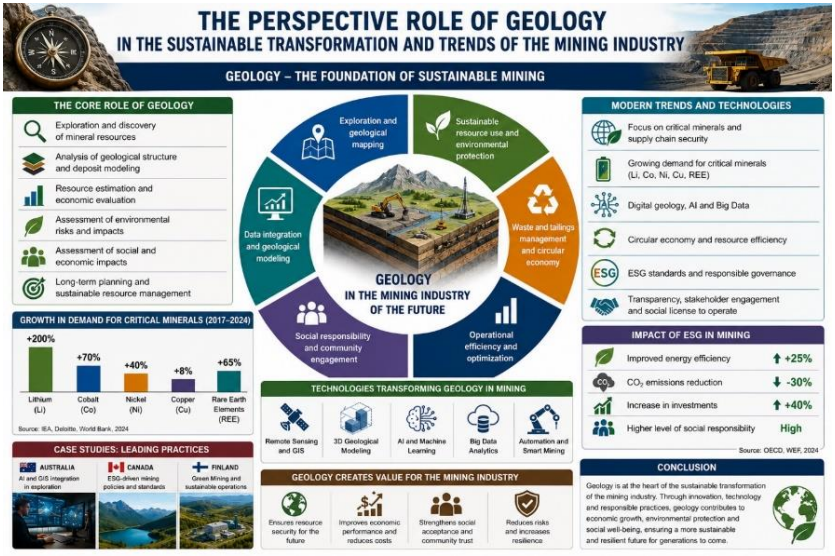

Fig. 1. The perspective role of geology [AI]

In the modern mining industry, geology is no longer limited to resource extraction. It has transformed into a strategic science that determines: resource management, technological planning,

environmental safety and economic efficiency. Accordingly, the model of a sustainable mining industry is based on the integration of geology and technology, where the first picture presents an integrated model that combines geology, digital technologies, ESG standards, the economics of critical minerals and the concept of sustainable development. The infographic shows that the modern mining sector is based on: geological modeling, data analysis, environmental management and resource optimization. The main thesis here is that the traditional mining system is transformed into a digital and sustainable industrial model.

The aim of the study is to assess the functional role of geology in the process of resource discovery, evaluation and optimization, as well as to determine its impact on the economic, environmental and social sustainability of the mining industry. Methods of system analysis, comparative assessment and statistical data interpretation are used.

The analysis shows that the demand for critical minerals (lithium, cobalt, nickel, copper and rare earth elements) has significantly increased under the conditions of energy transition, which directly increases the strategic importance of geological surveys. At the same time, artificial intelligence/AI, geoinformation systems/GIS, big data/Big Data, integration of remote sensing/Remote Sensing technologies and geometallurgy improve the accuracy of deposit evaluation and reduce operating costs [3].

The results of the study indicate that the implementation of ESG standards contributes to the reduction of CO_2 emissions, the increase of energy efficiency and the improvement of investment attractiveness. In addition, the examples of Australia, Canada and Finland confirm that digital and green mining models have already been practically implemented in developed countries [4].

Mineral resources play a vital role in the economic growth

and development of individual countries and represent long-term national wealth, which requires reasonable study and rational utilization taking into account sustainable principles, where environmental protection, economic development, national defense, security and climate change adaptation strategies are important in accordance with the needs of the pursuit of carbon neutrality in order to meet the requirements of the state's short-term, medium-term and long-term socio-economic development.

It is important to harmonize the conservation of mineral resource deposits and the sustainable development of the mining and geological industry through synergistic and coordinated engagement in order to protect the environment, landscape, historical and cultural relics, adapt to climate change, ensure social justice, national defense, security and sovereignty, transparent management of mineral resources and take into account market principles in mining and geological activities, in order to promote the use of advanced and modern scientific and technological achievements in the field, synergy of interests between the state, people and companies, taking into account the circular economy model and the principles of the green economy, international obligations and agreements.

In the development of mineral resources, it is especially significant and important to issue project licenses to companies that have the capabilities and experience in the areas of rational development of mineral resources and effective use of mineral raw materials, taking into account the involvement of interconnected advanced, effective and modern technologies, reconstruction, expansion and modernization of mineral resource extraction and processing facilities, responsible development of primary and secondary mineral resources, consideration of the principles of ecology and environmental

protection in accordance with the green economy model [4, 5].

11. In modern conditions, geology is transformed not only into a science of deposit discovery, but also into a strategic tool for sustainable industrial transformation, green economy and global energy security.

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STUDY OF KAOLINIZED CLAYS FROM GEORGIA FOR THE PURPOSE OF OBTAINING REFRACTORY CERAMIC MATERIALS

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The modern construction industry worldwide relies on cement/concrete, the production of which is associated with high energy and material costs and, most importantly, high CO_2 emissions [1].

One solution to this problem could be the wider use of ceramic building materials, the production of which requires less energy and is less associated with high CO_2 emissions than Portland cement.

The production of ceramic materials requires firing at temperatures of 900-1200°C, while the synthesis of cement clinker requires firing at 1450-1500°C [2, 3].

Conventional construction ceramic materials (bricks, blocks, tiles) are made from low-melting clays (deposits of Metekhi, Sagarejo, Miriani, Gardabani) with an Al_20_3 content of 10-15%. These materials do not withstand high temperatures: 1350°C and above begin to melt and deform. The use of such materials in thermal units or aggressive environments is not allowed. To obtain refractory ceramic materials, it is necessary to use clays with high Al_20_3 content (30-45%), which allows kaolinized clays. Kaolin clays belong to refractory clays. Their melting point is in the range of 1350-1580°C, and they can be used to produce materials such as linings for thermal units, chemically resistant tiles, etc. [3, 4].

There are no deposits of kaolin clays in Georgia, but there are kaolinized clays containing 20-25% Al_2O_3.

The purpose of this work is to study kaolinized clays of Georgia and develop a technology for producing refractory ceramic materials based on them.

Clays from the following deposits were selected for the study: Qobuleti, Makhinjauri, Brili, and Makvaneti. The chemical composition of the clays is presented in Table 1.

Table 1

Chemical composition of kaolinized clays of Georgia, wt.%

Loc.	LOI	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	SO_3	Na_2O	K_2O
Q.	9.65	49.5	15.5	5.2	1.23	8.6	4.01	1.63	2.5	1.6
Makh.	9.85	51.7	22.2	7.55	0.63	2.85	2.02	0.22	1.61	1.1
B.	4.59	62.33	20.2	8.51	-	1.43	0.57	0.32	0.51	1.2
M.	7.14	57.2	27.8	1.14	-	0.5	0.97	0.7	2.0	2.0

Q – Qobuleti, Makh. – Makhinjauri, B – Brili, M - Makvaneti

Properties such as plasticity, softening point, optimal firing temperature, and air and fire shrinkage were studied.

Water absorption is a significant performance parameter for ceramic materials, determining their range of applications. As expected, water absorption decreases with increasing firing temperature.

To determine mechanical strength, 25 mm diameter cylinders and 40 x 40 x 40 mm cubes were formed from clay paste of normal consistency. The samples were fired at 1150°C using the optimal firing mode and tested in a hydraulic press.

Experiments showed that 1150°C can be considered the optimal firing temperature, at which the water absorption of all ceramic samples remains within the specified range (≤10%).

Table 2 presents the results of physical and mechanical tests of

ceramic materials fired at the optimum temperature.

Table 2

Mechanical strength indicators

Location	Compressive strength (MPa)
Qobuleti	98
Makhinjauri	94
Brili	134
Makvaneti	444

The ceramic materials obtained from the clays we studied fully passed the tests and can be considered heat-resistant.

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GEODYNAMICS AND MAGMATIC EVOLUTION OF THE ACHARA-TRIALETI FOLD-AND-TRUST BELT

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Within the Transcaucasian Massive (TCM, island-arc) In the Late Cretaceous–Paleocene–Eocene, the Achara–Trialeti rift was formed, which divided the TCM into the Georgian and Artvin–Bolnisi Blocks [1].

The Achara–Trialeti tectonic unit, extending from the Black Sea coast towards Tbilisi, submerges east of Tbilisi under Oligocene–Neogene molasses [2], while westward it is geophysically extends within the Eastern Black Sea Basin.

Bajocian, Neocomian, Aptian and Albian volcanogenic–sedimentary formations are the oldest units of the Achara–Trialeti fold–and-thrust mountain belt. The Bajocian several hundred-meter-thick volcaniclastics of the calc-alkaline andesibasaltic composition crop out in the r. Chkherimela gorge.

The pre-collisional tectono-stratigraphic unit is represented in the Jurassic and Cretaceous–Paleogene structural stage (Fig.1). The Aptian-Albian stage is represented mainly by carbonate–volcanogenic strata conformably followed by Albian sub-alkaline basaltic lavas and volcanoclastic rocks [3,4].

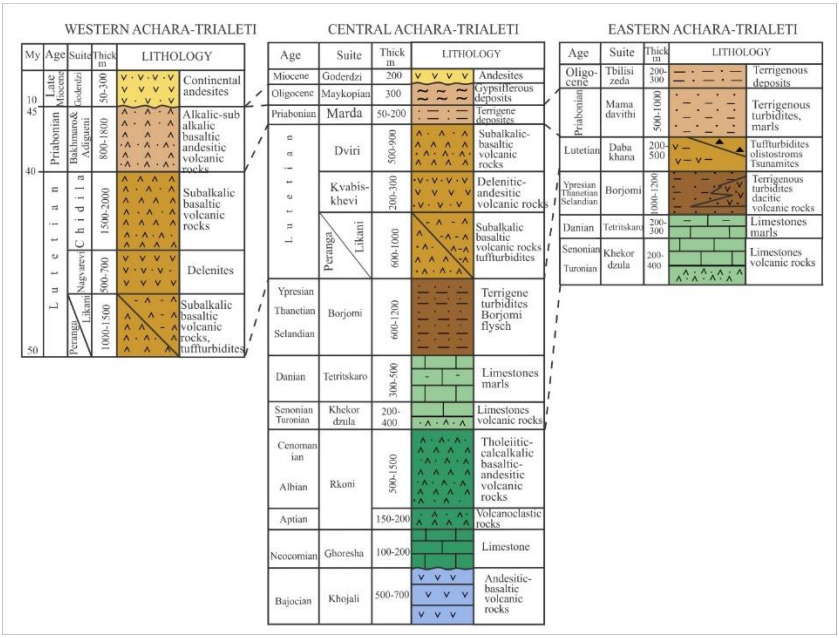

Figure 1. Generalized and simplified lithostratigraphic columns of the pre-collisional units of Achara-Trialeti: west, central and east [5].

Cenomanian, Turonian and all Senonian stages are represented by alternations of volcanogenic and carbonatic rocks. The Thanetian and Ypresian stages are mainly represented by terrigenous turbidites ('Borjomi Flysch') and olistostromes.The Paleocene–Lower Eocene terrigenous clastic deposits host dacitic lavas and volcanoclastic rocks. Volcanic activity attained its climax in the Middle Eocene. The Middle Eocene (Lutetian) thick volcanogenic–sedimentary series reaches its maximum thickness in Achara (c. 5.0 km). There are two distinct, upper and lower, basaltic levels separated from each other by a differentiated basalt–trachyandesite–dellenite horizon. Intensity of rifting and volcanic activity progressively increased from east to west, towards the Black Sea and caused formation of the oceanic crust presently existent in the central

part of the basin. Within the circum-Black Sea area of Achara Trialeti, there locate a narrow strip (2.5-3 km) fully built up of Middle Eocene massive subvolcanic hornblende basalts composing fractured dyke complex, which includes huge blocks of Upper Cretaceous bedded limestone brought out from the undelaying basement by basaltic magma. Samples from limestone blocks were investigated for calcareous nannofossils by T. Gavtadze. Despite high recrystallization of these samples, it was possible to identify several typical Late Campanian-Lower Maastrichtian species (*Uniplanarius trifidus, U. sissinghii, U. gothicus, Lucianorhabdus cayeuxii, L. maleformis, Micula decussate, Ceratolithoides aculeus and etc.*). The identified assemblage lacks specimens of the extinct before the Upper Campanian boundary taxons (apparently induced by extreme scarceness of this assemblage), therefore the mentioned samples could be ascribed to the Lower Maastrichtian CC 23b subzone.

The Upper Eocene (Priabonian) Oligocene(?) at the western and central segments of the Achara-Trialeti is also represented by volcanogenic–sedimentary formations. Volcanic rocks here correspond to the shoshonitic and calk-alkaline series [4].The Achara-Trialeti basalts have a strong subduction zone signature [4]. Post-Paleogene volcanic formations in the central part of the Achara–Trialeti belt are represented mainly by subaerial lava flows and volcaniclastics. Quaternary volcanic rocks directly occur in the central part of the Achara-Trialeti belt, within the Borjomi district (the Kura gorge). Here, the plateau built up of young andesite lava flows rises between the gorges of the r.r. Gujaretistskali and Borjomula.

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MAIN CLAY TYPES IN THE SAMEGRELO REGION AND THEIR TECHNOLOGICAL CHARACTERISTICS

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The Samegrelo Region, as an administrative unit, is the territory between the Rioni, Tskhenistkali, and Enguri rivers and the Black Sea and includes the following municipalities: Zugdidi, Tsalenjikha, Chkhorotsku, Senaki, Martvili, Abasha, Poti, and Khobi.

Geologically, the territory is part of the Rioni foothill basin (mountain depression), which, in turn, is part of the Georgian belt. The Rioni Intermontane Depression is a distinct morphostructural unit in the Caucasus, bounded to the north by the southern slope zone of the Caucasus and to the south by the Mesozoic ophiolite suture zone of the Lesser Caucasus. To the west, the depression gradually descends, widens, and subsides beneath the Black Sea. It should be noted that the Samegrelo administrative district includes part of the mountainous structure of the southern slope of the Caucasus, while to the east it does not extend beyond the Tskhenistkali River valley.

The exploration area is characterized by the presence of typical superimposed folds—asymmetrical brachyanticlines separated by wide, flat synclines. The zone is composed predominantly of Quaternary and Neogene sediments, underlain by Paleogene, Cretaceous, and Jurassic effusive, volcanosedimentary, carbonate, and terrigenous formations.

The Urti, Ekin, Nokalakev, and Abedat anticline massifs in the area are composed of Paleogene-Cretaceous (in the axial part) terrigenous and carbonate sediments. Rocks of the same age are exposed in the eastern part of the region in the deep valleys of the Tekhuri and Abasha rivers. The Askhi complex in the north of the region and the peripheral southernmost part of the Samegrelo Ridge are composed of Cretaceous limestones.

The region as a whole is composed of rocks of late Eocene-Miocene age. The central part is mainly filled with Miocene, Pliocene, Pleistocene, and Quaternary sediments, which are widespread. A continuous section of Eocene-Miocene formations is clearly visible, within which all stratigraphic units have been dated faunally.

The geological development of this region occurred during the Oligocene-Early Miocene, when it formed a basin located in front of the young Caucasus folded mountain system. It finally formed in the Middle Miocene-Pleistocene amid complex tectonic movements. In past eras, terrigenous material accumulated here (mainly clay, interspersed with numerous sandstone alternations over several kilometers), supplied by the denudation of young mountains.

Of the above-mentioned thickness, more than half is clay, although a layer of uniform mineral composition extending several tens of meters vertically is rare. The grain size distribution and percentage content of constituent minerals vary.

This is even more evident in the case of Quaternary or modern river terraces, where clay and clay deposits generally occupy a large proportion of alluvial deposits. This region represents the middle reaches of most rivers. Frequent changes in the erosional base do not provide a stable environment for the formation and accumulation of homogeneous clays (especially

those of monomineralic composition).

Within the region, numerous clay deposits, ore occurrences, and outcrops of varying composition have been discovered among Oligocene-Pliocene and Quaternary deposits, including modern alluvial deposits. The vast majority of these are polymineralic in composition; kaolin clays are virtually absent, and bentonites are less widespread, occurring in small outcrops and thin layers of non-industrial significance. The composition of polymineral clays is also unstable; they do not exhibit a uniform mineral composition in the vertical and horizontal directions, although in some areas they form deposits with moderate reserves.

Polymineral clays are found in sediments of both deep and shallow basins of the Black Sea, primarily in alluvial deposits. Their presence and reserves are primarily local. Such clays were used for decades as raw material for bricks in the last century (remains of old quarries have been found in all regions). Under current conditions, this issue is apparently irrelevant.

Within the exploration zone, we explored and studied the following deposits: Khibula (several sites), Sarakoni, Shua Khorsha (two sites), Lesichine, Odishi, Mikava, Nodzhikhevi, Tsaishi, Narazeni, and Didi Chkoni. According to X-ray phase analysis, the clay minerals in the samples are primarily montmorillonite, halloysite, chlorite, and, less commonly, kaolinite, while the silt material consists of quartz, feldspar, calcite, and micas. According to silicate analysis, the Al2O3 content in samples from different locations varies from 13 to 27%, while the content of the coloring oxide Fe2O3 ranges from 4 to 12%. CaO content is high in the Tsaishi, Sarakoni, and Shua Khorsha clays—10-11%. Depending on the location, surface clay samples were combined into process samples and their ceramic properties were studied. Without additives, the process parameters of these clays do not meet the

requirements of the standard for ceramic tiles. Obsidian was used as an additive. Tiles were pressed from a composite (clay + obsidian) at a pressure of 400 kgf/cm². The optimal firing temperature for the pressed tiles and the key ceramic properties of the fired tiles were determined: water absorption, total shrinkage, average density, porosity, and frost resistance. The optimal process parameters are listed in Table 1.

Table 1

Optimal technological characteristics of ceramic tiles made from a composite (clay + obsidian)

Sample name	Firing temperature, °C	Water absorption, %	Average density, kgs/m³	Porosity, %	Frost resistance, cycle	General shrinkage, %
Khibula 1	1150	0,03	2272	0,1	15	6,9
Khibula 2	1150	0,02	2302	0,1	15	7.2
Khibula 3	1200	0,6	2477	1,4	15	10,8
Lesichine	1150	0,5	2547	1,3	15	7,2
Odisha	1150	1,0	2427	2,4	15	8,8
Mikawa	1150	0,06	2374	0,1	15	8,9
Nojikhevi	1150	0,02	2413	0,1	15	7,7
Narazeni	1150	0,7	2413	1,7	15	9,1
Didi Chkoni	1200	0,7	2476	1,8	15	12,5
Saraconi	1150	0	2326	0	15	7,7
Shua Horsha Plot 1	1150	0,06	2332	0,1	15	7,1
Shua Horsha Plot 2	1150	0,01	2327	0,03	15	7,9
Caishy	1150	0,7	2315	1,6	15	7,4

A clay sample from the village of Lesičine in the Chkhorotsku municipality differs from other samples in the Samegrelo region both in its external characteristics and in key indicators characteristic of bentonite clays, such as montmorillonite content, dispersion, clay content, swelling after modification, and others.

The clay landscape of the Samegrelo region is examined from

a geological perspective. The age of the region's parent rocks and their role in the clay formation process are presented. The material composition of these clays and their technological parameters are studied. It has been established that these clays cannot meet standard requirements without additives, while high-quality ceramic tiles can be produced by adding composite obsidian. The sample from the village of Lesičine is bentonite clay and can presumably be used for the preparation of clay mortars.

STUDY OF THE POTENTIAL USE OF ACIDIC MINE WATER IN THE BENEFICIATION OF FLOTATION TAILINGS FROM GOLD-BEARING COPPER ORE

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Minerals are finite and non-renewable natural resources, and increasing demand for them directly affects their market value. As high-grade deposits are gradually depleted, the processing of low-grade ores and accumulated flotation tailings has become increasingly important. Tailings storage facilities are often sources of secondary environmental contamination. Under the influence of atmospheric precipitation, water-soluble heavy metals can enter groundwater and surface waters, posing a significant environmental hazard. Therefore, the processing of tailings, as waste products of mineral beneficiation, is economically and environmentally justified. To determine the material composition of the investigated sample, chemical, silicate, granulometric, and mineralogical analyses were performed.

As part of the study, the potential use of acidic mine water in the hydrometallurgical beneficiation of flotation tailings from gold-bearing copper sulfide ore was evaluated.

A combined technological flowsheet for beneficiation was developed, consisting of gravity concentration at the initial stage, thermal treatment of the resulting gravity concentrate, followed

by hydrometallurgical processing.

The results of the study established that the use of acidic mine water is effective in the hydrometallurgical processing of flotation tailings from gold-bearing copper sulfide ore. According to the results obtained, 78% of the copper and 80% of the gold were transferred into solution, indicating the potential of acidic mine water for tailings processing and recovery of valuable components.

PRODUCTION OF ENVIRONMENTALLY FRIENDLY BUILDING MATERIALS USING INDUSTRIAL WASTE

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Ordinary Portland cement (OPC) and concrete made from it are the most common building material. Approximately 4 billion tons of cement are produced globally annually, causing enormous CO_2 emissions. Currently, it emits approximately 2.4–2.8 billion tons of carbon dioxide annually, accounting for approximately 7–8% of all global anthropogenic CO_2 emissions [1]. This has a significant impact on the ecological balance and accelerates global warming. Furthermore, cement production is one of the most material- and energy-intensive industries in the world, further contributing to ecological imbalances.

One approach to preventing the environmental crisis is the development of new technologies for the production of clinker-free binders, one of which is geopolymer materials (GPM), which are considered an alternative to Portland cement.

Geopolymers are inorganic materials with a polymer structure formed by the alkaline or acidic activation of thermally treated aluminosilicates (kaolin, clay, ashe, and slags). Another advantage of geopolymer materials over Portland cement is that their production process primarily recycles various production wastes.

Geopolymer materials unlike Portland cement, are environmentally friendly, durable, and have low CO_2 emissions. Each ton of geopolymer produced emits only 0.18 tons of CO_2, which is five times less than Portland cement production. When

using metakaolin, CO_2 emissions are 0.5–0.7 tons [2].

Fly ash is a byproduct of coal combustion in coal-fired power plants. It consists of fine particles emitted from the boiler flue gases. Fly ash, along with metakaolin and granulated blast furnace slag, is a precursor for the production of geopolymer materials [3, 4].

Georgia has large deposits of fly ash, which pollute the environment and remains virtually unused.

This paper examines the potential use of Georgian fly ash for producing geopolymer materials, using fly ash from the Kutaisi Thermal Power Plant [5] as an example.

The chemical composition of the materials used is presented in Table 1

Table 1

The chemical composition of fly ash (% wt)

№	LOI	SiO_2	Al_2O_3	TiO_2	P_2O_5	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
1	6.1	52.1	31.6	1.3	-	5.2	0.7	0.7	0.5	0.9	0.3
2	-	1.4	0.2	-	-	-	97.3	-	-	-	-
3	-	33.3	12.1	1.1	-	0.8	43.4	5.6	1.1	0.3	0.9

1 – fly ash, 2 – CaO, 3 - granulated blast-furnace slag

The CaO content of the Kutaisi fly ash is less than 1%, which is insufficient to ensure the formation of calcium silicate hydroxides in the required quantities. Therefore, the addition of granulated blast-furnace slag is recommended.

To improve the quality of fly ash, it was activated thermally (heated to 1000°C), mechanically (milled to a specific surface area of 8000-10000 cm^2/g), and chemically (by adding CaO).

Geopolymer binders with mechanical strengths ranging from 50 to 80 MPa were obtained under laboratory conditions (Table 2).

Table 2

Compositions of geopolymer binders and the results of their physical and mechanical testing

No.	Components, % wt.			Alkaline component, % wt.		Compressive strength, MPa	
	FA	GBFS	CaO	NaOH	$Na_2O(SiO_2)n$	After 14 days	After 28 days
1	80	15	5	5	25	39.2	52.6
2	80	10	10	5	25	36.7	50.5
3	70	25	5	5	25	43.5	69.8
4	70	20	10	5	25	41.7	66.3
5	60	35	5	5	25	48.1	75.7
6	60	30	10	5	25	44.2	74.8
7	50	45	5	5	25	59.3	82.1
8	50	40	10	5	25	54.1	80.6
□U	75	20	5	5	25	14.5	32.8

□ Compositions 1–8 were prepared with FA heat treated at 1000°C. Composition U used untreated FA.

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STUDY OF THE TECHNOLOGICAL PROCESS OF GRAVITY CONCENTRATION OF MANGANESE OXIDE ORE

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With the depletion of mineral reserves, the processing of poor (low-grade) ores and tailings from beneficiation products is becoming increasingly important. The rational use of natural resources allows for increased extraction of useful components while reducing the negative environmental impact. Accordingly, the development of effective beneficiation technology for low-grade ores is of significant scientific and practical importance.

The object of the study was manganese oxide ore. To study the material composition of the ore, chemical, silicate, sieve, and mineralogical analyses were carried out. The manganese content of the initial ore is 18.16%. According to the mineralogical analysis, the ore minerals present in the ore are pyrolusite, psilomelane, manganite, and braunite, while the non-ore components are quartz and clay minerals. It was established that the disintegration of manganese minerals begins in the –5 mm size fraction.

Experimental studies were conducted on a diaphragm jig to investigate the possibility of gravity concentration of manganese oxide ore. During the study, the influence of operating parameters on the technological indicators of concentration process was investigated, and the following conditions were established for the jig: bed layer height — 40 mm, bed particle size — 15 mm, water flow rate — 3 L/min, diaphragm amplitude

— 8 mm, and the particle size of the ore to be enriched — 5–0, 5 mm. As a result, a manganese concentrate was obtained with the following technological indicators: γ %=32.7 %, β %=46.5 %, ε %=85.9%.

The research was carried out with the support of the LEPL Shota Rustaveli Georgian National Science Foundation "#FR-25-1564".

MAGMATIC EVOLUTION OF THE JURASSIC JORKVALI INTRUSION (CAUCASUS): PETROGRAPHIC, GEOCHEMICAL, AND GEODYNAMIC DATA

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Within the fold system of the Southern Slope of the Greater Caucasus, Jurassic magmatism is represented by volcanogenic successions and intrusive bodies of varying sizes and compositions. One such body is the Jorkvali Intrusion, located within the Chkhalta–Laila Zone of the of the Southern Slope of the Greater Caucasus. It is exposed in Upper Svaneti, in the Enguri River Valley, between the villages of Lakhani and Jorkvali. It intrudes Middle Jurassic (Aalenian) sandstones and clay slates and consists predominantly of pyroxenites and gabbros, cut by thin diabase dikes and diorite-porphyrite veins. At the regional scale, the Jorkvali Intrusion shows similarities to other Jurassic intrusive bodies of the fold system of the Southern Slope of the Greater Caucasus. These intrusions display similar petrographic characteristics and petrogenetic features, suggesting a possible genetic relationship between them and the existence of a common Jurassic magmatic system. At the regional scale, the Jorkvali Intrusion shows similarities to other Jurassic intrusive bodies of the fold system of the Southern Slope of the Greater Caucasus. These intrusions display similar petrographic characteristics and petrogenetic features, suggesting a possible genetic relationship among them and the existence of a common

Jurassic magmatic system.

Information on the Jorkvali Intrusion remains rather limited. The earliest references to the intrusion date back to the 1940s. Subsequent geological investigations [1-4] refined knowledge of its distribution and thickness, which has been estimated by different authors to range from 20-25 m to 150-200 m, while its lateral extent reaches several kilometres. Later studies provided petrographic descriptions of the rock types of the Jorkvali intrusion and diorite porphyrite veins; however, no comprehensive study based on modern geochemical methods has been carried out to date. One of the main objectives of the present study was therefore to address this gap by constraining the composition of the intrusive rocks, their genetic relationships, and the geodynamic conditions of formation.

Fieldwork was conducted in the Enguri River basin, along the Zugdidi–Mestia highway, and in the valley of a right-bank tributary of the Enguri River. The boundaries of the intrusion were refined through GPS-based mapping, and rock samples were collected from all rock varieties constituting the intrusion. At the Complex Laboratory of Geological Research of the A. Janelidze Institute of Geology the samples were subjected to petrographic examination, and the concentrations of major, trace, and rare earth elements were determined by X-ray fluorescence (XRF) analysis.

Petrographic investigation indicates that the Jorkvali Intrusion is composed of medium- to coarse-grained clinopyroxene-bearing rocks, including pyroxenites, plagioclase-bearing pyroxenites, and pyroxene gabbros. These rock types gradually transition into one another and do not form separate domains. Pyroxene is represented by clinopyroxene, whose equant crystals are variably replaced by secondary fibrous amphibole (uralite). Plagioclase is of bytownite composition

(An_{70-80}), is generally finer-grained, and forms short-prismatic crystals. It is partly saussuritized. The plagioclase-rich gabbros locally display elements of an ophitic texture, as well as zones of plagioclase accumulation.

Diabase dykes of small thickness are widespread throughout the intrusion. They are medium-grained, dark-grey rocks with predominantly ophitic textures and are strongly altered. They consist mainly of plagioclase, hornblende, and quartz. Diorite porphyrites are light-grey, medium-grained rocks containing phenocrysts of plagioclase, hornblende, and biotite. Intergrowths and mutual inclusions of these minerals are commonly observed.

The geochemical data show systematic distributions and compositional trends of the Jorkvali intrusive rocks across a range of classification and discrimination diagrams. The Zr/TiO_2 vs. Nb/Y classification diagram based on immobile elements, was used together with the Th–Co, $MnO/TiO_2/P_2O_5$, and Nb–Zr–Y discrimination diagrams.

The integrated interpretation of the geochemical data indicates that the apparently subalkaline and within-plate geochemical signatures of the Jorkvali intrusive rocks should not necessarily be interpreted as primary magma characteristics. Mineral accumulation in the cumulate pyroxenites and gabbros, particularly the concentration of Ti-bearing phases, together with HFSE fractionation, may have significantly modified elemental ratios and produced a geochemical signature distinct from that of the parental magma. At the same time, the results obtained from the Th–Co and $MnO–TiO_2–P_2O_5$ discrimination diagrams indicate a subduction-related setting (Fig. 1.). The shift of the pyroxenites and gabbros toward the boninite field may reflect extensive mantle depletion and a significant influx of subduction-related fluids. Such processes are characteristic of

the early stages of island-arc development and of subduction and fore-arc initiation.

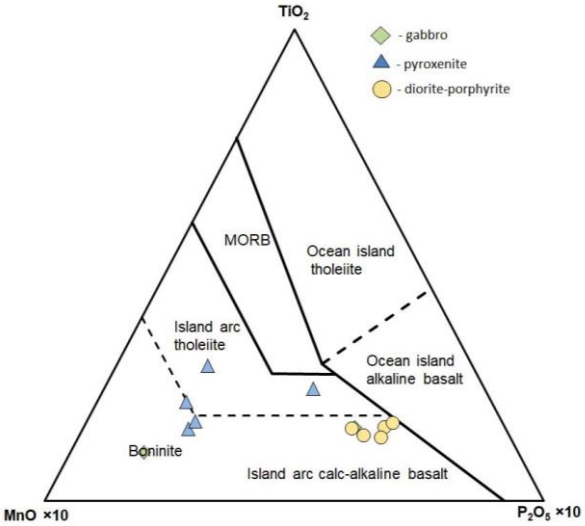

Fig. 1. $MnO/TiO_2/P_2O_5$: a minor element discriminant for basaltic rocks of oceanic environments and its implications for petrogenesis (Mullen, 1983).

The petrographic data are consistent with this geochemical interpretation and indicate intensive interaction with hydrothermal and/or magmatic fluids during crystallization and cooling. They also point to complex fractional crystallization and magma–magma interaction, as well as subsequent interaction between early mafic–ultramafic cumulates and more evolved calc-alkaline magma.

Thus, the results of the study of the Jorkvali Intrusion indicate the existence of a coherent, progressively differentiated magmatic series whose evolution was associated with subduction-zone processes. The magmatic system presumably evolved from early mantle-derived, depleted and fluid-enriched mafic–ultramafic magmas to later, more evolved calc-alkaline

and high-K magmas.

The geochemical and petrographic data indicate that the evolution of the Jorkvali Intrusion bears certain similarities to that of the adjacent Kirari–Abakuri Massif, suggesting that both intrusive complexes belong to a unified Middle Jurassic suprasubduction system in the Greater Caucasus region.

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LOW-CAPACITY SELF-PROPELLED ROPEWAY WITH STATIONARY POWER SUPPLY AND TRAILING POWER CABLE

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At the Ropeway Systems Laboratory of the G. Tsulukidze Mining Institute, a low-capacity self-propelled ropeway equipped with a stationary power source and a rope-guided trailing power cable has been developed. This new structural design enables high-power operation, significantly increasing the load capacity and overall efficiency of the ropeway system.

The system features a lightweight construction, allowing for easy transportation to various operational sites. Its line structures are installed using ground anchors.

The application of this ropeway system is particularly effective and operational in single-span line configurations, with span lengths not exceeding 150 meters.

The developed system can be applied in mountainous and hilly regions to provide multi-purpose agricultural and commercial transport operations.

Notably, this type of transport will also prove effective for logistical support during emergency situations or specialized defense operations, where the use of other modes of transport is impossible or severely restricted.

STUDY OF LOCAL NATURAL RESOURES FOR THE PRODUCTION OF LIGHTWEIGHT POROUS MATERIALS

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Among artificially produced inorganic porous materials, Lightweight Expanded Clay Aggregate (LECA)and foam glass are the two types most widely used in practice. Their technical and performance characteristics are regulated by the relevant standards [1, 2].These materials are produced by high-temperature processing (900–1250 °C) of charge with a specific composition (for foam glass) or clayey rocks (forLightweight Expanded Clay Aggregate (LECA)) [3].Therefore, the raw material base for LECA production is either limited (expanded clay) or characterized by high material consumption (foam glass).

The aim of the present study was to expand the raw material base suitable for the production of inorganic porous materials (LECA) based on the traditional high-temperature expansion method.For this purpose, nine types of raw materials of different origins and chemical compositions were selected as research objects (Table 1). The chemical compositions of all investigated raw materials are presented in our previous work [4]. All nine selected raw materials were subjected to thermal and X-ray phase analyses.

Table1

Evaluation of the Chemical Composition and Expansion Characteristics of the Raw Materials Studied for LECA Production

Gr. N	Raw Material Type	$SiO_2+Al_2O_3$ / $R_2O+R'O+R''O$[1]	Expansion at 1200°C[2] by Thermal Treatment	Note
I	Obsidian	2,53	++++	Fragment expanded
	Volcanic ash	5,05	+	Granule fragmented
II	Argillite	2,24	++	Granule expanded
	Clay shale	4,65	+++	Fragment expanded
III	Trachyte	3,89	-	Granule fragmentedF
	Zeolitic tuff	7,04	-	ragment did not expand
IV	Cement production dust	0,30	+	Granule fragmented
		0,91	++	Granule melted
	Gypsum	1,91	+	Granule fragmented
	manganese carbonate ore.			

[1]R'O -content of alkaline earth metal oxides; R''O — content

of alkaline earth metal oxides and FeO(Mn).

(2)Expansion intensity (g/cm³): (++++) — very good (<0.5); (+++) — good (0.5–1.0); (++) — average (1.0–1.5); (+) — poor (1.5–1.8); (-) — the material did not expand (>1.8).

Their expansion tendency was determined by thermal treatment in the temperature range of 900–1200 °C (with a temperature step of 100 °C).The expansion behavior was evaluated for both bulk samples and granules obtained by processing powdered materials (Table 1). The mass of both types of experimental samples was 10 ± 0.5 g.To evaluate the expansion tendency of the investigated materials and the effect of thermal treatment conditions on their properties, their bulk density (g/cm³) was determined.The expansion tendency was evaluated using a five-point scale. To determine the influence of composition on expansion behavior, a conditional coefficient was calculated to assess the material's potential for transition into a pyroplastic state:$(SiO_2+Al_2O_3)/(R_2O + RO)$.

The results obtained from the conducted research are presented in Table 1, based on which the following general conclusions can be drawn:The amorphous obsidian presented in Group I, characterized by a lower value of the coefficient indicating the potential for transition into a pyroplastic state, undergoes intensive expansion during thermal treatment and forms foam glass with a low bulk density (<0.5 g/cm³);Argillite and clay shale with a layered structure (Group II) exhibit an expansion tendency; however, clay shale expands more effectively than argillite. Expanded clay shale (with a bulk density <1.0 g/cm³) can be considered a potential raw material for the production of Lightweight Expanded Clay Aggregate (LECA); The other investigated materials (volcanic ash, trachyte, zeolitic tuff, cement plant dust, gypsum, and manganese carbonate ore) do

not exhibit a tendency toward transition into a pyroplastic state or expansion.

It was established that obsidian and clay shale can be considered suitable raw materials for the production of Lightweight Expanded Clay Aggregate (LECA). Thermal treatment of their individual batches at 1200 °C provides the production of foam glass and expanded clay aggregate, respectively.

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INFLUENCE OF GASIFICATION AGENTS ON COAL EXTRACTION BY UNDERGROUND COAL GASIFICATION

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In recent years, research on improving Underground Coal Gasification (UCG) technologies has been particularly active in coal-producing countries worldwide. In this regard, the scientific, technical, and industrial achievements of the USA, China, the European Union, South Africa, Australia, and other coal-mining nations are noteworthy [1-3]. The feasibility of utilizing UCG technology for the development of the Tkibuli-Shaori deposit has been repeatedly emphasized by the Georgian scientific and engineering community, and it is considered a promising direction alongside traditional mining technologies for the sustainable operation and safe exploitation of the deposit [4-5].

This paper presents the results of experimental research on the extraction of coal from the Tkibuli-Shaori deposit using the underground coal gasification method, currently being conducted at the G. Tsulukidze Mining Institute. By using atmospheric air and various oxygen-enriched mixtures as gasification agents, the composition of the main product—raw synthesis gas (syngas)—obtained during underground gasification was investigated. A series of experiments has established that varying the oxygen (O_2) concentration in the gasification agent from 21% to 95% substantially affects the quality of the raw synthesis gas: the carbon monoxide (CO)

content increases from 15% to 41%, the carbon dioxide (CO_2) content decreases from 37% to 13%, while the methane (CH_4) share varies from 1.8% to 5.2%. A high oxygen concentration (50–95%) ensures the maximum CO yield and high energy efficiency of the process.

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1:50000 SCALE MAP OF THE DISTRIBUTION OF NATURAL BACKGROUND RADIATION IN THE KHRAMI CRYSTALLINE MASSIF (LESSER CAUCASUS)

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The Khrami Crystalline Massif is one of the most important structural units of the Artvin-Bolnisi Belt and represents an exposure of the Precambrian-Early Paleozoic crystalline basement. It is composed of a Neoproterozoic gneiss-migmatite complex, Middle-Upper Paleozoic granitoid and volcanogenic-sedimentary formations, and Upper Paleozoic quartz porphyries and granite porphyries, all of which underwent multiple stages of metamorphic, magmatic, and tectonic transformation.

This geological setting was favourable for the formation of accessory minerals containing uranium, thorium, and rare-earth elements; consequently, the Khrami Crystalline Massif is regarded as one of the most prospective regions of Georgia in terms of strategic mineral resources. Mineralogical, geochemical, and radiochemical investigations conducted during different periods have confirmed the occurrence of zircon, cyrtolite, monazite, allanite, xenotime, thorite, and bastnäsite, as well as uranium- and thorium-bearing mineralization. Nevertheless, a substantial part of the massif has remained insufficiently investigated [1,2,3].

The present study aimed to conduct a detailed assessment of natural background radiation within the Khrami Massif, identify radioactive anomalies, establish their relationship with the host rocks, and compile a 1:50000 scale map of natural background radiation. The study is based on the integrated application of field radiometric measurements, remote sensing, geospatial analysis, and spectral data,

enabling a comprehensive assessment of the spatial distribution of the identified anomalies.

During the fieldwork, natural background radiation was measured using modern spectrometric instruments, including the MEASALL Radiation Analyzer Gamma Spectrometer KC761CN and the Radiacode 103G gamma spectrometer. Measurements were carried out over an area of approximately 300 km² along the Khrami River valley and its tributaries, as well as in the vicinity of the villages of Didi Gomareti, Mamulo, Bediani, Didi Kharebi, Kokhti, Chrdilisubani, Ivanovka, Didi Kldeisi, and Patara Kldeisi, including watershed areas and artificial exposures in quarries. In total, approximately 150 km of survey tracks were recorded, and more than 5000 measurements were obtained.

The acquired data were integrated into a geospatial database and processed in the ArcGIS environment. Spatial distribution modelling was performed using the Spline with Barriers and Kriging interpolation methods available in the Spatial Analyst module.

In addition to the radiometric data, multispectral ASTER satellite imagery was used and processed in the ENVI Classic 5.3 software environment. Atmospheric correction was performed using the FLAASH module, while noise reduction was achieved through Minimum Noise Fraction (MNF) transformation and inverse MNF reconstruction [4]. The Constrained Energy Minimization (CEM) algorithm was applied to identify spectral anomalies associated with monazite, allanite, and zircon [5]. Reference spectra from the USGS Spectral Library were used, allowing the distribution of the target minerals to be predicted and their spatial correspondence with the field radiometric data to be evaluated.

Based on the obtained data, five levels of natural background radiation were distinguished (Table 1)

Table 1

Natural Radiation Levels of the Khrami Crystalline Massif

№	Colour scale	Radiation level	Rock types
1	Green	(0-10 μR/h)	Gabbros, gabbro-diabases
2	Yellow	(10-15 μR/h)	Tuffites
3	Orange	(15-25 μR/h)	Gneiss-migmatites, granites
4	Red	(25-35 μR/h)	Quartz porphyries; rarely, granites
5	Dark red	(>35 μR/h)	Quartz porphyries

The lowest natural background radiation levels were recorded in mafic rocks and lower tuffite units, whereas intermediate values were observed in the gneiss-migmatite complex and granitoids. The highest natural background radiation levels were associated with the quartz porphyry-granite porphyry complexes. In addition, local high-intensity radiometric anomalies were identified within the granitoids and the gneiss-migmatite complex; these anomalies are presumably related to concentrations of uranium- and thorium-bearing accessory minerals. The study also demonstrated that no correlation exists between natural background radiation levels and the hypsometric elevation of the area.

Spectral analysis of the ASTER data revealed anomalous zones corresponding to the reference spectra of monazite, allanite, and zircon. Most of these zones spatially coincide with areas of elevated natural background radiation identified by field radiometric measurements. These results confirm that remote-sensing methods significantly enhance the potential for predicting uranium- and thorium-bearing mineralization.

The principal outcome of the study is the compilation of the first integrated 1:50000scale natural background radiation map of the Khrami Crystalline Massif. The map illustrates the spatial distribution of natural background radiation, the localization of radioactive anomalies, and their relationship with the geological setting. The presented results broaden current understanding of the metallogenic potential of the Khrami Crystalline Massif and provide a reliable basis

for further geological, geochemical, and radiometric investigations of prospective uranium- and thorium-bearing areas, as well as for the assessment and rational development of Georgia's strategic mineral resources.

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