

PHYSICAL PROPERTIES OF ROCKS OF THE KULZHUKTAU MOUNTAINS ACCORDING TO BOREHOLE AND GEOPHYSICAL DATA

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ABSTRACT

This study examines the physical properties of rocks in the Kulzhuktau Mountains area, using field samples from geological traverses and, to a limited extent, samples from drill cores and underground workings from selected deposits (Taskazgan Graphite and Taushan Gold). Density and magnetic susceptibility were measured most extensively, while electrical resistivity and chargeability, as well as remanent magnetization, were investigated to a lesser degree. Results show strong lithological and process-related variability: Paleozoic and Meso-Cenozoic units form distinct density groups, sedimentary rocks are generally non-magnetic, and igneous rocks - especially sulfide-enriched and ultrabasic varieties - exhibit markedly higher magnetic responses. Electrical properties vary widely with lithology, hydration state, silicification, fracturing, and especially carbonization/graphitization and sulfide mineralization, which substantially affect chargeability and SP behavior. The integrated dataset supports the use of geophysical fields for identifying lithological-tectonic framework elements that control gold and related mineralization.

Keywords: *Geophysics, Density, Magnetism, Resistivity, Sediments*

INTRODUCTION

Physical properties of rocks provide key constraints for interpreting geophysical observations and for delineating subsurface lithological and tectonic structures associated with mineralization. In the Kulzhuktau Mountains area, the representativeness of samples varies from single specimens to large sets, which can influence parameter reliability. A further limitation noted in prior studies is the incomplete mineralogical-petrographic and chemical (spectral) characterization of many samples, restricting the ability to directly quantify alteration history (e.g., metamorphism and hypergenesis). Consequently, the physical parameters are treated primarily as indicators of rock type and of the cumulative effects of geological processes, including graphitization, carbonization, silicification, fracturing, and sulfide enrichment. (fig.1) (Khamrabaev, 1975).

The geological structure of the region comprises compositionally diverse, highly dislocated Paleozoic formations and less dislocated Mesozoic and Cenozoic deposits. The region is characterized by a variety of folded and faulted structures, significantly complicated by intrusive activity and fault deformations. The Paleozoic basement is composed of Ordovician volcanogenic-terrigenous, partially carbonate formations; thick carbonate formations of the Silurian, Devonian, and Lower Carboniferous; and volcanogenic-terrigenous and molasse strata of the Middle and Upper Carboniferous, intruded by granitoid and gabbro-ultramafic intrusions. Much of the area is overlain by loose Mesozoic-Cenozoic formations 50-800 m thick (Khamrabaev, 1975).

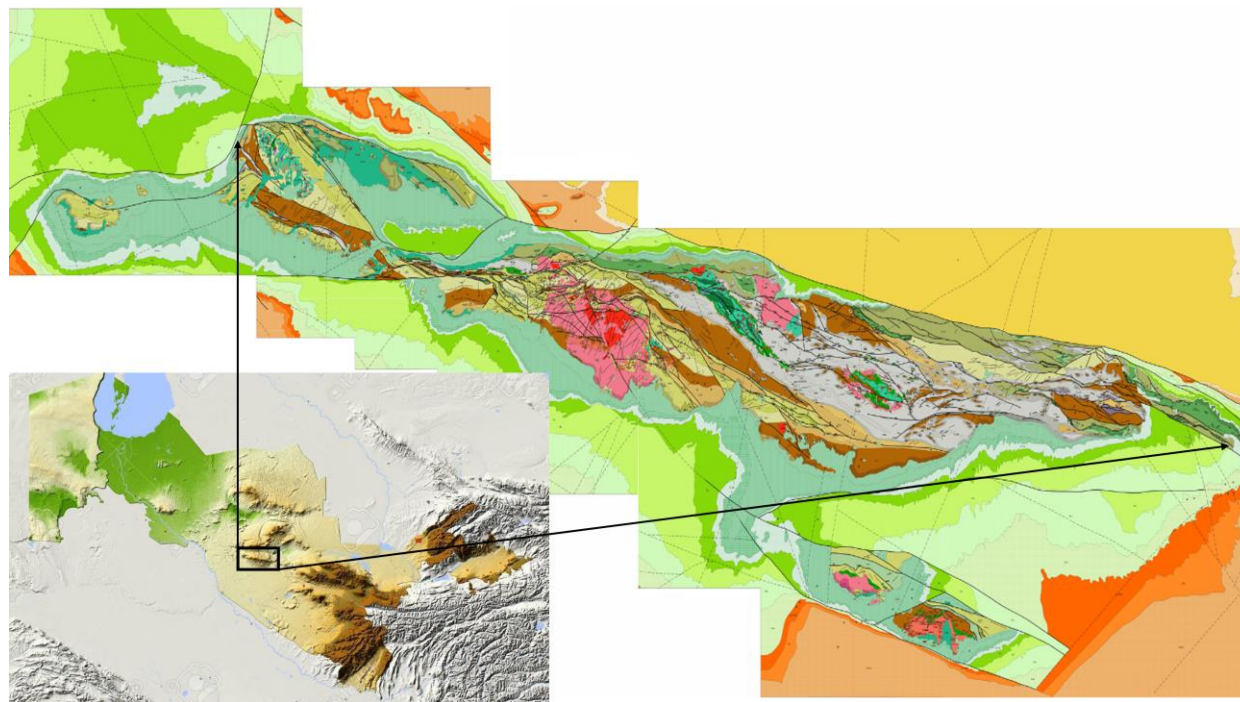


Figure 1. Location and schematic geological map of the Kulzhuktau mountains (*modified from Aysanov, 1984*).

METHODS

The physical properties of the rocks were studied mainly using samples collected from the surface during geological traverses and, only to a limited extent - primarily within the Taskazgan Graphite Deposit and the Taushan Gold Deposit - using samples from drill cores and underground workings. Of the physical parameters, density and magnetic susceptibility were determined most extensively, while electrical properties (electrical resistivity and chargeability) and remanent magnetization were investigated to a lesser extent. It should be noted that the representativeness of the samples for different rock types is highly variable, ranging from individual specimens to several tens or even hundreds of samples. This undoubtedly affects the reliability of the determined parameters.

According to *Eisfeld et al, 2010*, a significant shortcoming in the study of the physical properties of the rocks in the area is the lack, in most cases, of mineralogical-petrographic determinations and spectral (chemical) analyses of the collected samples, which would make it possible to establish the degree of alteration of a given rock under the influence of various geological processes (metamorphism, hypergenesis, etc.). In this regard, the physical properties should be regarded as parameters characterizing particular rock types and varying depending on the manifestation of diverse geological processes.

The dataset was compiled from:

- Surface geological traverses, using collected rock samples as the main source for most measurements.
- Targeted subsurface sampling, primarily within the Taskazgan Graphite Deposit and the Taushan Gold Deposit, using drill-core and underground samples.

Measured or analyzed physical parameters included:

- Density, determined using available data from geological-geophysical mapping and supplemented by petrophysical information from drill holes in adjacent covered districts.

- Magnetic susceptibility (most extensive among magnetic measurements), along with vector remanent magnetization in selected detailed studies of igneous units (notably the Beltau Intrusion), supported by mineralogical work to determine mineral composition.
- Electrical resistivity via parametric vertical electrical soundings (VES) and, secondarily, well logging, and to a lesser extent IP (induced polarization) field VES.
- Chargeability, measured on rock samples, with surface data especially tied to IP anomaly investigations in the Taushansky and Taskazgan areas (*Kerimov et al., 2010*).

RESULTS

Density Characteristics. Determinations of the density of the Meso-Cenozoic deposits in the area are relatively few and were carried out mainly along the eastern margin of the Kulzhuktau Mountains during geological-geophysical mapping by the Ayak Party (*Kerimov et al., 2010*). To obtain a more complete characterization, we also used petrophysical data from drill holes in the covered area of the adjacent Auminza-Beltau district.

Rock density varies widely from 1.50 to 3.40 g/cm³. Two distinct groups can be identified by density: Meso-Cenozoic deposits, with densities of 1.5-2.62 g/cm³, and Paleozoic rocks, with densities of 2.36-3.10 g/cm³. The average density of the Cretaceous deposits is 2.12 g/cm³; the Cenozoic deposits have a density of approximately 1.98 g/cm³, while the average density of the Meso-Cenozoic formations is 2.02 g/cm³.

The density range of the Paleozoic formations is broad; however, density values show systematic grouping according to lithological type. Distinct groups with different density characteristics are represented by carbonate, terrigenous, and igneous rocks.

Carbonate formations, represented predominantly by limestones and dolomites, are characterized by relatively high average densities of 2.70-2.75 g/cm³, whereas terrigenous formations (shales, sandstones, and gravelites) have relatively low densities of 2.64-2.67 g/cm³.

Basic rocks have lower densities than ultrabasic rocks and form a distinct group with characteristic values of 2.82-2.86 g/cm³, with deviations of ± 0.10 g/cm³ in either direction.

The presence of disseminated sulfides in gabbro significantly increases its density, with the increase becoming greater as the sulfide content rises. Thus, gabbro composing the Beltau Intrusion has a density of 2.88 g/cm³; with up to 1% disseminated sulfides, the density increases to 2.94 g/cm³, and at 5% it reaches 2.96 g/cm³. The type of mineralization also plays an important role. A change in sulfide mineralization from pyrite to pyrite-pyrrhotite and pentlandite-pyrrhotite increases the density from 2.68 to 2.99 g/cm³.

With decreasing basicity of the rocks and their transition toward more felsic varieties, density values also decrease accordingly. Thus, the density of diorites and granodiorites ranges from 2.60 to 2.86 g/cm³, whereas in granites it decreases sharply to an average of 2.58-2.68 g/cm³. The contrast between rocks in terms of density makes the gravity-survey method effective for deep geological mapping (*Eisfeld et al., 2010*).

Magnetic Properties of Rocks. In terms of magnetic properties, all sedimentary and sedimentary-metamorphic rocks occurring in the area are essentially non-magnetic. Their magnetic susceptibility generally ranges from 0 to 10, locally reaching $30-40 \times 10^{-6}$ CGS. Much stronger differentiation of magnetic properties is observed among the igneous rocks widely developed in the Kulzhuktau Mountains, with magnetic susceptibility increasing slightly with increasing basicity. Thus, felsic and intermediate igneous rocks - granites, granodiorites, and diorites - show magnetic susceptibility values ranging from units to $10-20$, and in some cases up to 40×10^{-6} CGS. At the same time, significant magnetic anomalies are sometimes observed in the contact zones of granitoids owing to enrichment of these zones in ferromagnetic minerals during assimilation. This process also affects, to some extent, the enclosing sandstone-shale sequence. (*Eisfeld et al., 2010*) however, disagrees with this interpretation. In his view, attributing magnetic anomalies in the contact parts, particularly of the Tozbulak Intrusion, to "enrichment in ferromagnetic minerals during assimilation" is unjustified. He considers that magnetic anomalies in the study area may indicate only the

presence of basic and ultrabasic intrusive rocks, while the degree of alteration of these rocks can be inferred from magnetic-field intensity.

Basic rocks exhibit a broader range of magnetic properties. Most varieties, represented by different types of gabbro (hornblende gabbro, titan-augite gabbro, etc.), are weakly magnetic ($\chi = 20-100 \times 10^{-6}$ CGS), whereas only some varieties, such as olivine gabbro, have elevated magnetic susceptibility values ($\chi=50-884 \times 10^{-6}$ CGS). This is particularly characteristic of the Beltau Intrusion, where the physical properties and the causes of their variation were studied most comprehensively and in detail by the “Ultrabasic Massifs of Uzbekistan” field party (Kerimov *et al*, 2010). In addition to magnetic susceptibility, the vector of remanent magnetization was determined and the necessary mineralogical studies were carried out to establish the mineral composition of the samples.

Unaltered petrographic varieties of gabbro with similar composition (biotite gabbro, hornblende gabbro, titan-augite gabbro, leucocratic gabbro, gabbro-norite, and gabbro-diorite), differing in grain size (fine-, medium-, and coarse-grained), do not differ significantly in their physical properties. These rocks are characterized by low remanent magnetization ranging from 2 to 25×10^{-6} CGS.

All varieties of sulfide-enriched gabbro, in which pyrrhotite predominates, are characterized by elevated magnetic susceptibility ($50-884 \times 10^{-6}$ CGS) and remanent magnetization ($30-10,080 \times 10^{-6}$ CGS), with the two constants being similar in magnitude.

Based on their magnetic properties, graphitized gabbro in the vertical section is distinctly subdivided into four zones, which, according to mineralogical studies (Kerimov *et al*, 2010), correspond to specific typomorphic assemblages of rock-forming and, most importantly, sulfide minerals.

The zone down to a depth of 120 m is characterized by the lowest values of magnetic susceptibility and remanent magnetization. It is characterized by an association of clay minerals with graphite, weathering of the rocks, and a complete absence of sulfides.

The deeper intervals of the graphitized gabbro – 120-160 m, 160-260 m, and 260-700 m -are characterized by a change in sulfide mineralization from pyritic to pyrite-violarite-pyrrhotite and pentlandite-pyrrhotite assemblages. Among non-metallic minerals, chlorite, prehnite, biotite, hornblende, and pyroxenes are predominant, respectively. A substantial increase in magnetic susceptibility, remanent magnetization, and rock density is observed.

In graphitized gabbro with pyrite-violarite-pyrrhotite sulfide mineralization, magnetic susceptibility is approximately five times higher; remanent magnetization is equal to or greater than magnetic susceptibility. The increase in magnetic susceptibility and remanent magnetization is directly related to the presence and amount of pyrrhotite in the graphitized rock. Samples consisting almost entirely of pyrrhotite exhibit extremely high values of these constants.

Ultrabasic rock varieties (pyroxenites, peridotites, lherzolites, and wehrlites) are distinctly expressed and are characterized by very high magnetic susceptibility values ($1,044-4,900 \times 10^{-6}$ CGS) and remanent magnetization ($197-960 \times 10^{-6}$ CGS).

Electrical Properties of Rocks. Among the electrical properties, rock resistivity was determined most extensively, while chargeability was investigated on a limited scale. Resistivity was determined from data obtained by parametric vertical electrical soundings (VES) and well electrical logging, and to a lesser extent from field VES-induced polarization (IP) measurements; chargeability was determined on rock samples. The resistivities of both Meso-Cenozoic and Paleozoic deposits are in some cases comparable and vary over a very wide range, from units to tens, hundreds, and even thousands of ohm-m, depending on lithological composition. In salt-marsh areas, the resistivity of the upper horizons decreases to fractions of an ohm-m. The resistivity of the upper horizons is strongly affected by their saturation with waters of varying degrees of mineralization.

Paleozoic igneous rocks, limestones, and siliceous shales are characterized by high electrical resistivity values (100 to $15,000 \Omega \cdot \text{m}$). Clayey, carbonaceous-clayey, and graphitized Paleozoic shales and siltstones are low-resistivity rocks ($6-8 \Omega \cdot \text{m}$). Intense silicification of Paleozoic rocks significantly increases their

resistivity, to 1,000 $\Omega \cdot m$ or more. In contrast, zones of crushing and intense fracturing are characterized by reduced electrical resistivity.

Rock chargeability was studied mainly on surface samples collected during traverses conducted to investigate IP anomalies (the “Taushansky” and “Taskazgan” areas) and, less frequently, on drill-core samples (the “Taskazgan” area and the Taushan Deposit). Chargeability values determined from surface samples are characteristic of the upper oxidized part of the section, the so-called “weathering crust,” which is widespread throughout the Central Kyzylkum. Chargeability varies within a relatively narrow range, averaging 1-2%, but locally reaching 5-6% and even 34%. An increase in chargeability to 5-6% or more is caused by the development of graphitization. Graphite ore and graphitized rocks are characterized by high chargeability, reaching 30-83%.

The widespread processes of carbonization and graphitization occurring in the area exert a particularly strong influence on changes in the electrical properties of any rock variety. Fine-dispersed carbonaceous matter distributed throughout the entire mass of any initial lithological variety determines a high chargeability background and the occurrence of broad, intense negative SP anomalies, accompanied by only a slight decrease in the electrical resistivity of the given rock variety (Kerimov *et al*, 2010).

On the other hand, disseminated (finely disseminated) sulfide mineralization in any rock variety produces higher and more stable chargeability than graphitization. Increased sulfide mineralization in the terrigenous-sedimentary rocks of the area is expressed by persistently high rock chargeability without significant changes in electrical resistivity (Yin *et al*, 2025).

Graphitization of varying intensity is observed, among other settings, within zones of tectonic reworking of rocks and along major faults. During rock crushing and hydrothermal alteration, carbonaceous matter is redistributed into tension fractures, along which sinuous, polished slickensides subsequently develop. Under the microscope, these slickensides contain black graphitic-carbonaceous matter, fine-flaky sericite, and a significant amount (3-10%) of fine sulfide inclusions.

Other researchers (Kerimov *et al*, 2010), in addition to graphitization along faults, have noted a sharp increase in the concentrations of iron-group elements (titanium, vanadium, nickel, and chromium) within these structures.

Most likely, such redistribution of carbonaceous matter and sulfides within tectonic zones, together with rock crushing, is the principal factor responsible for the development of intense localized SP anomalies, high chargeability, and low electrical resistivity above these zones (Yin *et al*, 2025).

As a result of the synthesis and analysis of the physical properties of the rocks in the Kulzhuktau Mountains area, R.Kh. Faizulin determined the physical parameters of the principal lithological rock types.

Carbonate formations, represented predominantly by limestones and dolomites, are characterized by relatively high average densities of 2.65-2.75 g/cm³, non-magnetic behavior, high electrical resistivity, and low chargeability.

Terrigenous formations (shales, sandstones, and gravelites) have relatively low densities of 2.6-2.65 g/cm³, are essentially non-magnetic, exhibit reduced electrical resistivity, and have elevated chargeability.

Intrusive rocks ranging from felsic (granites) to ultrabasic (peridotites and pyroxenites) are differentiated by physical parameters such as density and magnetic susceptibility, whereas, in terms of chargeability and electrical resistivity, all unaltered varieties of these rocks are broadly comparable.

Granites have the lowest densities, ranging from 2.56 to 2.66 g/cm³, and are non-magnetic.

Gabbro has elevated densities of 2.7-2.9 g/cm³, depending on composition and the abundance of disseminated sulfides. The magnetic character of these rocks is likewise attributable to sulfide mineralization. Ultrabasic rocks are magnetic and have high densities of 2.9-3.0 g/cm³ and higher.

Thus, the principal rock complexes should be expressed in the geophysical fields, and these fields, in turn, will make it possible to identify the main elements of the lithological-tectonic framework of the Kulzhuktau Mountains area, which are known to play a leading role in the localization of gold and other mineralization (Yin *et al*, 2025).

CONCLUSION

Rock physical properties in the study area display systematic, lithology-dependent patterns, but also strong modification by geological processes. Density differentiates major sedimentary and igneous groups: Meso-Cenozoic deposits show lower densities than Paleozoic rocks, with additional lithological grouping among carbonates, terrigenous units, and igneous rocks. Magnetically, most sedimentary and sedimentary-metamorphic rocks are essentially non-magnetic, whereas igneous rocks - particularly sulfide-enriched gabbro and ultrabasic lithologies - exhibit substantially higher magnetic susceptibility and remanent magnetization, with graphitized gabbro showing depth-controlled transitions linked to sulfide assemblage changes. Electrically, resistivity varies over orders of magnitude depending on lithology, degree of mineralization of pore waters, silicification, and fracturing. Chargeability is strongly influenced by carbonization/graphitization (producing high background values and broad SP-negative anomalies) and, even more persistently, by disseminated sulfide mineralization (yielding higher and more stable chargeability). Overall, the integrated interpretation of density, magnetic, and electrical parameters demonstrates that geophysical expressions can be used to identify the main lithological-tectonic elements of the Kulzhuktau Mountains area, which are fundamental to understanding the localization of gold and related mineralization.

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