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THE FORMATION FEATURES OF BASALTOIDS ELECTRICAL PROPERTIES IN THE TALYSH STRUCTURE OVER A WIDE TEMPERATURE RANGE

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Abstract

This study investigates the formation of the electrical properties of basaltoids and related igneous rocks from the Talysh structural zone over a wide temperature range (200–1000°C). Laboratory measurements of electrical resistivity were conducted on trachydolerites, trachybasalts, troctolites, and peridotite to determine the influence of mineral composition, structure, and temperature on electrical conductivity. The results show that resistivity is primarily controlled by the abundance and distribution of ore minerals (magnetite and titanomagnetite) and high-resistivity minerals such as olivine. Troctolites exhibit the lowest resistivity values due to their higher content of conductive ore minerals, whereas olivine-rich rocks display higher resistivity. Resistivity anomalies observed between 550 and 800°C are associated with the dehydration of micas, serpentine, and prehnite, causing significant changes in conductivity. Analysis of activation energy values indicates that extrinsic conductivity dominates below approximately 600°C, while intrinsic conductivity becomes predominant above 800°C. Comparison with continental basalts from other regions demonstrates that Talysh basalts are characterized by relatively high resistivity and a narrow resistivity range, attributed to their distinctive mineral composition and the isolated distribution of conductive ore minerals. These findings improve understanding of the electrical behavior of igneous rocks under high-temperature conditions and contribute to the interpretation of geophysical data related to the Earth's crust and upper mantle.

Keywords: *electrical properties, electrical resistance, basaltoids, high temperature, high pressure*

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INTRODUCTION

Laboratory studies of the electrical properties of rocks under high thermodynamic conditions, along with elastic, deformation, and other physical parameters, in conjunction with field geophysical data, help explain the nature of changes in geophysical fields with depth and play a significant role in determining the composition of the Earth's crust and upper mantle. Since rocks, even those of the same name, exhibit a wide variety of chemical and mineral compositions, it is necessary to have information on the electrical properties of rocks from different regions. Therefore, the goal of this study was to establish the role of individual mineral phases and their distribution patterns in the formation of the electrical properties of some igneous rocks of Talysh at temperatures up to 1000°C.

The studied rocks were collected from outcrops within the Talysh Anticlinorium, part of the Talysh-Vandam structural-formational zone. The collection consists of basaltoids with varying contents of olivine and ore minerals, as well as troctolites and peridotite.

According to the description of transparent thin sections, the trachydolerites and trachybasalts (Table 1) share a porphyritic structure. Phenocrysts are represented by basic plagioclase, olivine, and clinopyroxene. Iddingsite phenocrysts are present. The ore mineral is primarily titanomagnetite, which occurs as medium and small irregularly shaped grains. In trachydolerites No 2–4, an increase in atomic number corresponds to an increase in olivine content. In sample No 4, for example, the maximum content of the high-resistivity phase, olivine, is combined with a minor amount of ore. Trachybasalts No 5 and 7 have fairly similar mineral compositions. Variations in ore mineral and olivine contents are minor. The groundmass structure of sample No 7 is pilotoxite. Troctolites No 1 and 6, unlike the rocks discussed above, are characterized by a uniformly grained structure. They consist of basic plagioclase and orthorhombic and monoclinic pyroxene. They are distinguished by the highest ore mineral content. The olivine content is negligible. Peridotite consists of serpentinized olivine and clinopyroxene. Secondary minerals include magnetite, muscovite, and prehnite. The rock structure is porphyritic.

Based on the above description of the rocks and a comparison of their mineral composition and structure, it can be assumed that troctolites should have lower resistivity values due to the presence and relative positions of low-resistivity minerals.

Resistance measurements were performed using direct current in the temperature range of 200–1000°C using the method described in [2,4,5].

It is known that the temperature dependence of the electrical conductivity of a dielectric with one charge transfer mechanism is described by the following expression:

$$\sigma = \sigma_0 \exp\left(-\frac{E_0}{kT}\right) \qquad (1)$$

Where σ_0 is the pre-exponential constant, E_0 is the activation energy of the current carriers, T is the Kelvin temperature, and K is the Boltzmann constant.

According to equation (1), the graphic of lg σ = f (1/T) is linear, allowing the values of E_0 and σ_0 to be determined graphically.

Figure 1 shows a graph of the temperature dependence of resistivity (ρ) for the six studied rocks. Their order on the graph, in decreasing resistivity order, according to chemical analysis and petrographic description of thin sections, is directly related to the amount of ore mineral (magnetite, titanomagnetite) and inversely related to the content of high-resistivity minerals, particularly olivine. Troctolites, which have similar petrochemical characteristics, exhibit the lowest resistivity across the entire temperature range. These rocks differ from trachydolerite No 4 and peridotite, which occupy the extreme upper position on the graph (Fig. 1), by their higher titanomagnetite content and negligible olivine. In troctolites, olivine is present as isolated, relatively large grains; however, this distribution of the high-resistivity phase in rocks typically does not significantly affect their resistivity. The remaining rocks, including samples No 5 and 7, occupy an intermediate position (to avoid complicating the graph, data for samples No 5 and 7 are presented in the table).

Table 1.

Values of specific electrical resistance (ρ_o), activation energy (E_0) and pre-exponential term (ρ_o) of igneous rocks of Talysh at different temperatures.

№ Sample	Rock	ρ, Ом·м		E_0, eV	ρ_0, Om·m	Range temperature, t°C
		200°C	800°C			
1.	Troctolite	$4{,}0\cdot10^6$	$1{,}2\cdot10^3$	0,48 0,77 0,58	$2{,}5\cdot10^1$ $4{,}0\cdot10^1$ $5{,}6\cdot10^9$	200-450 450-1000 150-550
2.	Trachydolerite	$1{,}65\cdot10^7$	$3{,}3\cdot10^3$		anomaly	550-800
3.	Trachydolerite	$1{,}0\cdot10^7$	$5{,}0\cdot10^3$	1,6 0,44	$6{,}3\cdot10^{-5}$ $3{,}2\cdot10^1$ anomaly	800-1000 200-600 600-650
4.	Trachydolerite	$5{,}0\cdot10^7$	$1{,}7\cdot10^4$	1,12 0,51 0,76 1,06	$5{,}6\cdot10^{-2}$ $1{,}25\cdot10^2$ 4,0 $3{,}2\cdot10^{-1}$	650-1000 200-600 600-800
5.	Trachybasalt	$3{,}5\cdot10^7$	$5{,}5\cdot10^3$	0,46 0,83 1,26	$4{,}0\cdot10^2$ 1,25 $3{,}2\cdot10^{-3}$	800-1000 200-470 470-700
6.	Troctolite	$5{,}3\cdot10^6$	$2{,}8\cdot10^3$	0,61	2,5 anomaly	700-1000 550-750
7.	Trachybasalt	$6{,}0\cdot10^7$	$3{,}16\cdot10^3$	0,86 0,57 1,12	$1{,}0\cdot10^{-2}$ $8\cdot10^1$ $1{,}6\cdot10^1$	750-1000 200-500
8.	Peridotite	$3{,}15\cdot10^7$	$1{,}6\cdot10^4$	0,58 0,84 1 55	2,0 $3{,}0\cdot10^{-1}$ anomaly $3{,}2\cdot10^{-3}$	500-1000 200-470 700-850 850-1000

Samples No 2 and 8 exhibit a resistivity anomaly in the temperature range of 550–800°C, accompanied by a sharp decrease, while samples No. 3 and 6 exhibit a kink in the same region, followed by cooling of the curves. Additional studies have shown that this is associated with the dehydration of micas (muscovite, biotite), serpentine, and prehnite. The intensity of this process is directly dependent on the amount of constitutional water in the rocks [1,2,3]. According to cyclic analytical weighing, the weight loss of samples No 2, 8, 6, and 3 is 6.8; 5.1; 3.3, and 2.8%, respectively.

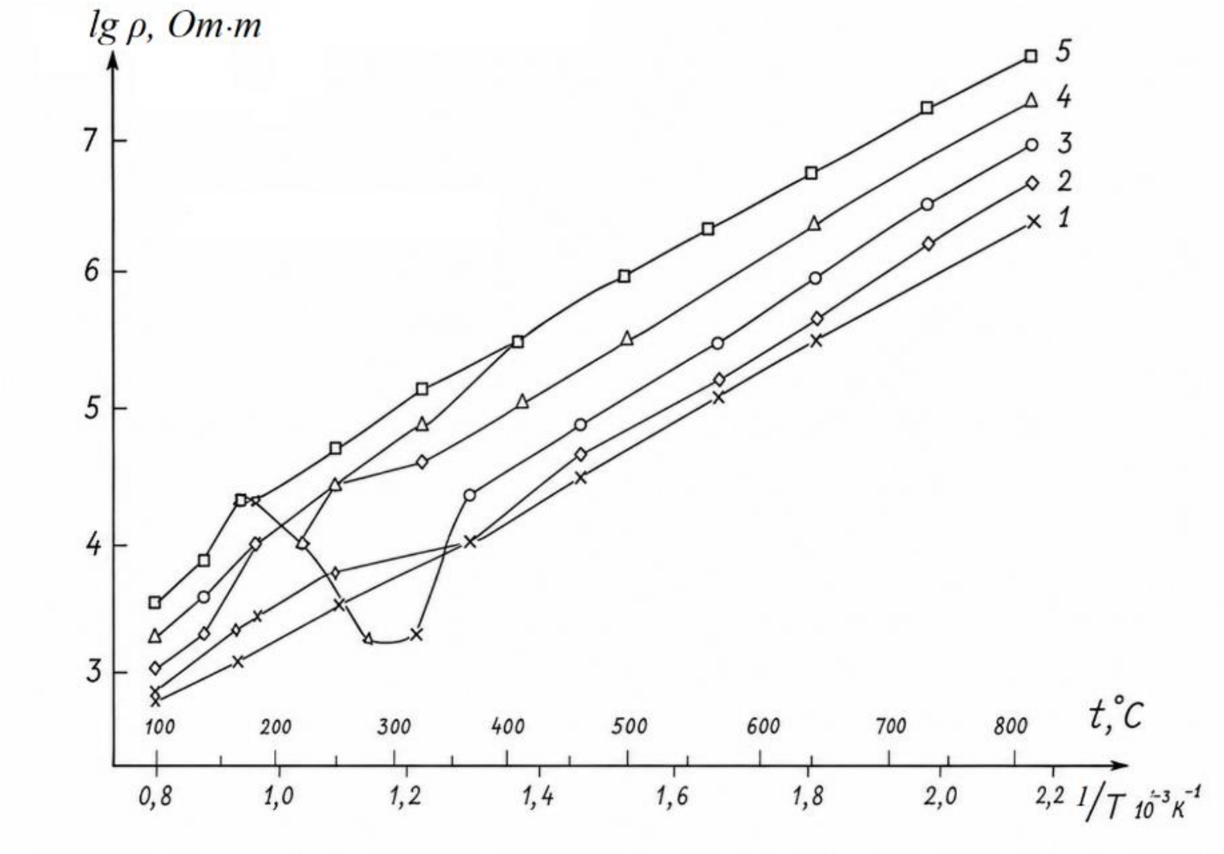

Figure 1. Dependence of electrical resistance of igneous rocks of Talysh on temperature

Figure 1 shows that the rocks studied exhibit different patterns of dependence.

$$lg\rho = f(\frac{1}{T})$$

The change in sample weight was calculated relative to their weight after holding for several hours at temperatures of 120–130°C. The sharp increase in resistivity after the dehydration process is complete is due to the removal of conductive OH^{-1}. A hysteresis loop, particularly pronounced at temperatures below 800°C during the cooling cycle, also indicates an irreversible phase transition in the aforementioned minerals. Furthermore, examination of some samples (No 4 and 7), preheated to 1000°C, revealed that they undergo some changes relative to the original minerals, macroscopically manifested as an increase in the number of volumetric pores and cracks, as well as a change in color (reddening). Microscopic examination revealed the presence of ilmenite precipitates due to the partial oxidation of titanomagnetite. Minor fine precipitates of the ore component, previously not observed, were also detected along newly formed cracks. This is apparently due to the partial oxidation of the main rock-forming minerals. Overall, despite the open oxygen supply during the experiments, the degree of rock alteration at high temperatures was lower than expected, due to the limited duration. However, the influence of the above-mentioned thermochemical transformations of iron on the electrical parameters and hysteresis loop cannot be ruled out.

Knowledge of the activation energy and pre-exponential term (ρ) plays an important role in studying the conductivity mechanism of rocks. Analysis of the experimental data presented in the table showed that values of E ≤ 1 eV correspond primarily to temperatures below ~800°C, while in the 800–1000°C range, E ≥ 1 eV. This temperature range is also characterized by lower ρ values.

One of the reasons for this behavior of E in the low-temperature region is the significant dependence of the electrical properties of rocks in this range on the presence of ore minerals. At high temperatures, the contribution of cations from rock-forming minerals with higher activation energies increases. Therefore, it can be assumed that for the studied group of rocks, the temperature range of 600–800°C is the boundary between the region of impurity and intrinsic conductivity.

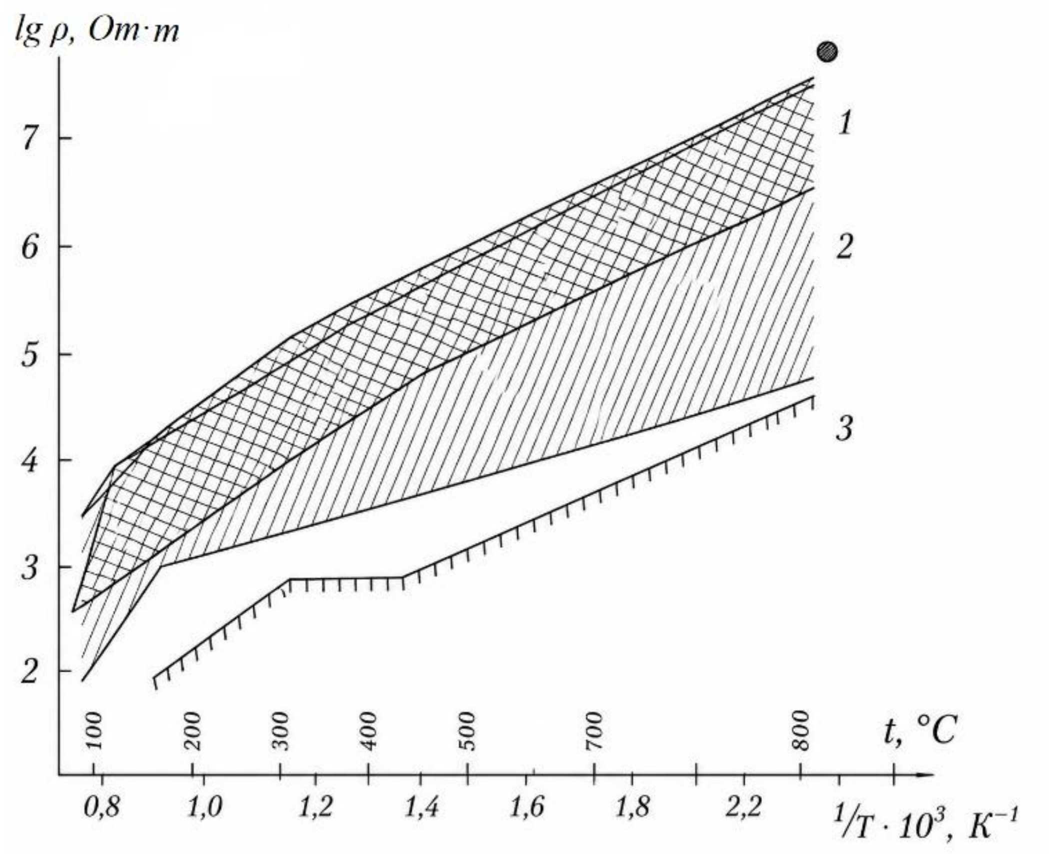

Figure 2. Resistivity range of continental basalts in the temperature range of 200–1000°C: 1 – Talysh; 2 – Lesser Caucasus (Geghama Highland); 3 – Czech Massif.

Figure 2 shows the resistivity ranges of continental basalts from various regions. It is evident that Talysh basalts have high resistivity and exhibit relatively weak ρ dispersion over the entire temperature range. The former, according to the above, is related to the chemical and mineral composition of the rocks. The authors believe the weak ρ dispersion is due to a structural factor: specifically, in the basalts of the Czech Massif and Lesser Caucasus, the ore mineral occurs as finely dispersed grains uniformly distributed throughout the volume. This distribution pattern typically stimulates electrical conductivity in rocks. At the same time, in the studied Talysh samples, magnetite and titanomagnetite occur as single, isolated grains. In this case, the resistivity of the rock is less sensitive to variations in the amount of highly conductive phases. These structural differences are one of the reasons for the weak resistivity dispersion of Talysh basalts over the entire temperature range and, along with the peculiarities of their chemical and mineral composition, can explain the higher ρ values. Furthermore, the presence of an amorphous phase has a decreasing effect on the resistivity of the rocks. The latter is more characteristic of basalts of the Czech Massif.

CONCLUSIONS

1. The chemical and mineral composition play a leading role in the formation of the electrical properties of Talysh igneous rocks, which determines the high resistivity of Talysh basalts relative to continental basalts of other regions (the Caucasus and the Czech Massif). 2. The narrow range of ρ values for the rocks in the region under study is explained by their structural features, i.e., the distribution pattern of ore and high-resistivity minerals, namely titanomagnetite and olivine, respectively.

3. The dehydration of micas and serpentine can cause a several-fold increase in conductivity at the corresponding geotherms (550–800°C) in the region under study under conditions of progressive epigenesis.

4. It has been established that the studied group of rocks is characterized by extrinsic conductivity at temperatures < 600°C. The temperature range above 800°C corresponds to the region of predominantly intrinsic conductivity.

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