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MINERALS-INDICATORS OF SPECIAL CHANGES IN THE PROPERTIES OF IGNEOUS ROCKS

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Abstract. The analysis of mineralogical associations in rocks provides insight into their genesis, prevailing conditions at the time of formation, post-formation history, and transformation pathways, which ultimately lead to changes in physical properties. Variations in pressure, temperature, geochemical instability, and tectonic processes contribute to the formation of new minerals that are stable under specific physicochemical conditions.

These mineral associations reflect the physical and mechanical state of the rock.

This study aims to evaluate the current state of research the physical properties of minerals in igneous rocks, using selected regions of Ukraine as case studies. Changes in parageneses result from reactions between early-formed minerals and residual melt. Minerals that crystallize during the cooling of magma, or form after the completion of melt crystallization, are classified as postmagmatic. The formation of new minerals may occur through several mechanisms:
a) within a single primary mineral (or glass) without a change in chemical composition;
b) through significant mass transfer without alteration of the host rock's overall composition;
c) via mineral formation involving both removal and addition of material.

Processes in the first category include polymorphic transformations, exsolution of solid solutions, recrystallization of volcanic glass, among others. All three mechanisms are reflected in the resulting mineralogical associations. Typical indicators of mineral transformations include serpentine replacing olivine, amphibole replacing pyroxene, and sericite replacing feldspar.

Albitization of igneous rocks – whether of mafic or felsic composition – leads to an increase in porosity. The highest porosity values have been observed in volcanic tuffs and tuff-lavas, including both basaltic series and felsic varieties such as rhyolites, dacites, and trachy-dacites. The formation of secondary mineral phases has a direct impact on the physical and mechanical properties of the rocks.

The integration of compositional and physical data on changes in the mineralogical associations of igneous rocks is essential for an objective evaluation of their quality and for optimizing extraction processes. Porosity, which is closely linked to the degree of mineral replacement, serves as a key indicator across all rock types.

Keywords: mineralogical associations, rocks, transformations, mineral changes, properties.

1. Introduction

According to the definition by academician V.I. Vernadsky, mineralogy is fundamentally based on the concept of a mineral as a physically or chemically individualized molecular product of natural chemical reactions [1]. In his work "The History of Minerals of the Earth's Crust," he identified key directions in mineral research: morphology (form), paragenesis (i.e., mineral associations), and genesis—the chemical process responsible for the information. A mineral is a constituent element of a mineral body, while mineral bodies form rocks. Modern reference books [2, 3; 4, etc.] define a mineral association as a set of all minerals present within a particular section of the Earth's crust. This concept is broader than mineral paragenesis, encompassing minerals that share common conditions of formation in nature. The physical properties of minerals are a function of their internal constitution and are intrinsically linked to their chemical composition and crystal structure. The most significant characteristics of minerals include density, optical, mechanical, magnetic, electrical, luminescent, and microstructural properties.

The relationships between individual minerals (texture), the conditions of their manifest in crystallographic order and its defects, are reflected in the microstructural

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disturbances of minerals. The combined effect of such minerals facilitates tectonic disintegration of the rock mass (schistosity, cleavage, micro- and macrofracturing).

A review and critical analysis of current studies on the physical parameters of minerals from igneous rocks across various regions of Ukraine reveals a diverse and varied dataset.

The aim of this study is to assess the state of research into the physical properties of igneous rocks in selected regions of Ukraine, identify minerals that serve as indicators of such changes, and determine research priorities.

2. Methods

The author utilized original data supplemented by previous researches (generalized data from open sources). Examination of thin sections was conducted by the author and colleagues from the Institute of Geotechnical Mechanics (IGTM), using a POLAM R-111 microscope and DSM-200 camera, along with various analytical techniques.

3. Results and discussion

In igneous complexes, the mineral composition, structure, and texture are the primary observable characteristics that reflect formation conditions and determine the physical properties of a rock. Researchers of the last century [5, 6, 7, 8, 9, 10, and many others] classified igneous rocks by their chemical composition, emphasizing oxides of silicon, aluminum, magnesium, iron, and alkalis. These oxides vary in proportion, but the SiO_2 content never falls below 24%. As a result, silicates dominate among igneous minerals, a view supported by both domestic [2, 11, 12] and international scientists [7, 13, 14].

Each classification scheme had its rationale, but all authors linked mineral properties to rock genesis. Igneous rocks are classified by cooling conditions into intrusive and extrusive types, and by chemical composition into silica-saturated and silica-undersaturated types. Quartz does not occur in silica-undersaturated rocks.

Among the five main groups, the ultramafic rocks are characterized by very low silica content and a complete absence of quartz as a rock-forming mineral. These rocks consist of SiO_2-undersaturated minerals, with the formation sequence starting with magnesium silicate olivine, followed by sodium aluminosilicate nepheline, then potassium aluminosilicate leucite, and finally calcium silicates like monticellite and melilite.

Main minerals in this group include orthopyroxene, clinopyroxene, olivine, and ore minerals such as magnetite and chromite. Based on their relative abundance, the following rock types are distinguished:

a) Pyroxenites and hornblendites (pyroxene + hornblende)

b) Peridotites (pyroxene + olivine)

c) Dunites (olivine-rich rocks)

Dunites are most common among these them, though ultramafic rocks overall constitute only 0.4% of all igneous rocks. Dunites have negligible aluminum oxide content. Fresh dunite has a bulk density of 3.4 g/cm³, longitudinal wave velocity of

8110 m/s, and porosity of 0.54%. In serpentinite-altered dunites (70% replacement), bulk density drops to 2.6 g/cm³, wave velocity to 5430 m/s, and porosity increases to 1.35%.

Amphibolitized pyroxenites have different properties: bulk density of 3.14 g/cm³ and magnetic susceptibility of 5000 (10^{-6} CGSM) [8].

Small ultramafic bodies are found in Archean and Proterozoic terrains, typically forming small massifs along deep fault zones. In Ukraine, examples include greenstone belt structures such as:

- South-Bilozersky Massif,
- Sursky and Verkhivtsevo regions,

where olivine and pyroxene alter into multi-generation serpentines, anthophyllite, tremolite, talc, and magnesite. Serpentinization releases secondary magnetite, significantly increasing magnetic susceptibility and remanent magnetization [14, 15].

Serpentine-group minerals (antigorite, lizardite, chrysotile) influence porosity, strength, and compressive resistance. Serpentinization of olivine with magnesite and magnetite formation increases volume by 29–37% [8]. Physical Properties of Igneous Rocks (Basic to Intermediate Composition) - Table 1.

Table 1 – Physical Property Indicators of Mafic and Intermediate Igneous Rocks

Rock Type	Density, g/cm³	Porosity, %	Water Absorption, % by wt	Compressive Strength, kg/cm²	Strength, MPa	Compression Coefficient
Peridotites	2.76–3.50	up to 4.71	0.02–0.25	1710–3220	-	-
Gabbros	2.78–3.30 (2,97)	up to 4.0	up to 3.15	381–3750	93 (123)	-
Basalts	2.7–3.30	0.2–43.0	0.01–37.0	71–5000	230 (900–1400)	-
Diabases	2.79–3.30	0.24–10.60 (0.43)	up to 2.70	200–4600 (3090)	147	-
Labradorites	2.69–297 (2.75–2.84)	up to 1.5 (0.4–4.8)	up to 0.9 (0.21)	750–2520	175 (103–166)	1.55
Diorites	2.7–3.0 (2.81)	up to 5.40 (2.76)	0.02–1.20	719–3000 (2360)	81	-
Andesites	2.56–3.07	up to 14.0	up to 4.5	100–3000	-	-
Andesite-basalts	Not specified	0.6–48.7	0.05–5.6	180–3160	-	-

Note: Values in parentheses represent average figures for Ukrainian deposits.

Main Rock Group: Gabbros and Basalts. The group of mafic rocks includes gabbros and basalts. G. Rosenbusch [3] was the first to divide gabbroic rocks into two series: the gabbroic and the anorthositic series. The first series (gabbro, norite, troctolite) is rich in ferromagnesian minerals: monoclinic pyroxene, sometimes containing inclusions of orthopyroxene or rimmed with amphibole. Accessory minerals include olivine, biotite, and hornblende. In contrast, the anorthositic series is almost devoid of such minerals [8, 14].

Common to both series are plagioclases—andesine, labrador, and bytownite. Thus, rocks from the anorthositic series are sometimes named after the dominant mineral, such as andesinites or labradorites, which are characterized by high alumina content. Accessory minerals include ilmenite, magnetite, and occasionally pyrrhotite.

In Ukraine, three types of anorthosite deposits were identified: the Holovynsky, Turchynsky, and Vaskovetsky deposits [16]. The latter consists of non-porphyritic, non-iridescent andesinite-labradorites, which are light gray in color, medium- to coarse-grained, with a bulk density of 2.750–2.840 kg/m³ and porosity of 0.61%.

In the Volyn region, labradorites exhibit porosity of 0.46% and a density of 2.7 g/cm³ [15]. Secondary minerals include sericite, prehnite, epidote, and carbonates. In labradorite-norites, minerals such as olivine, pyroxene, and serpentine are also present.

The compressive strength of gabbro under triaxial stress conditions reaches 123.0 MPa. The appearance of hornblende in gabbro as a replacement for pyroxene is generally associated with the late-stage cooling of the rock, when early-formed pyroxenes transform into amphibole after crystallization, i.e., post-solidification. This amphibolization process is accompanied by a reduction in magnetic susceptibility due to a decrease in magnetite and titanomagnetite content.

Gabbro from the Slipchytsi deposit has a bulk density of 2.963 kg/m³, porosity of 0.47%, true density of 0.29 g/cm³, compressive strength of 157–222 MPa, and tensile strength of 30 MPa.

Among extrusive mafic rocks, basalts are the most widespread exceeding all other volcanic rocks combined by a factor of five. Basalts occur both in orogenic regions—such as the Vihorlat-Gutin Ridge in the Carpathians—and in tectonically stable areas, such as the Volyn series, lava plateaus in the southwestern region (Mokra Volnovakha River basin), and the northwestern part of the Donbas [16, 17]. Regional differences in basalts are reflected in their physical properties – see Table 2.

Table 2 – Physical Characteristics of Basalts in Ukraine [8 and others]

Region	Density, g/cm³	Porosity, %	Magnetic Susceptibility (10^{-6} CGSM)
Zakarpattia	2.63	1.07	3.71
Volyn	2.86	3.02	-
Boreholes (UkrSSR)		3.12 to 6.3-9.2	-

Basalts, by the morphology of their igneous bodies, typically form lava flows and are classified as part of the trap formation, which develops within platform and plate settings. The strength limit of basalt at 300°C ranges from 900 MPa to 1400 MPa, and its flexural failure stress is 37 MPa (at P = 1 MPa).

Basaltic glass is highly susceptible to alteration and is readily replaced by chlorites. In basaltic lava flows, zonal structures can be observed, with alternating layers of small amygdales and the glassy matrix, where voids are clearly visible (see figure 1).

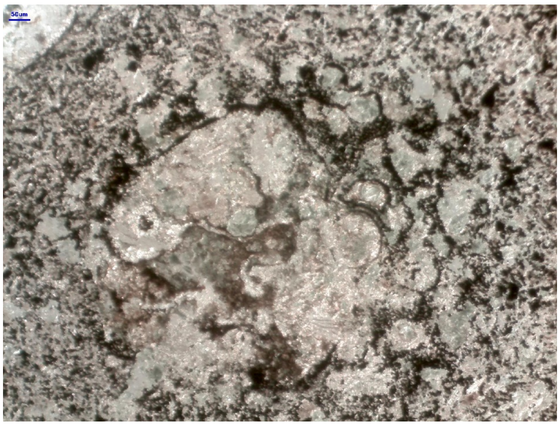

Figure 1 – Basalt lava breccia with voids, sample 4982-a, in crossed nicols, Volyn

During cooling, basaltic lava forms a glassy mass of green or dark brown (nearly black) color. The black glass, known as hyalomelane, is resistant to dissolution in acid. In contrast, green basaltic glass readily alters into an amorphous chlorite-like substance—palagonite—which is soluble in hydrochloric acid upon heating.

The thickness of basaltic covers in Volyn reaches 400–500 meters, with the margins of these flows enriched with various volcanic fragments. According to drill core data, the thickness of lava flows in the Vihorlat-Gutin area of the Carpathians and in the Styr River basin ranges from 7.9 m to 56.0 m, with an average of 12–25 m. The total area covered by basalts is estimated to be around 300000 km^2.

Massive lava flows exhibit low porosity values, though cavities of various shapes—formed by gas bubbles—may still develop. The alteration of normal basalts into spilites occurs due to the interaction between basaltic lava and seawater under subaqueous eruption conditions.

Spilitic rocks exhibit microlitic, pilotaxitic, intersertal, and amygdaloidal textures (see Figure 2).

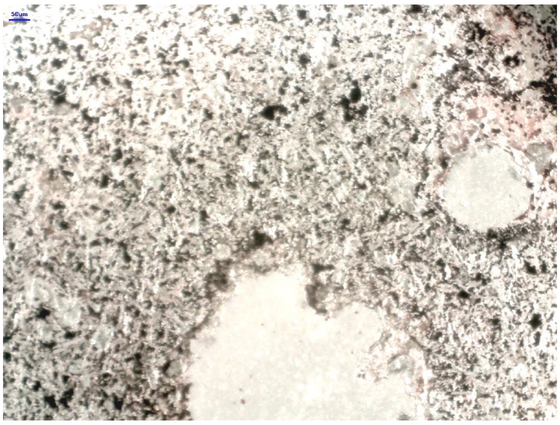

Figure 2 – Amygdules in basalt, sample 4981-1, in crossed nicols, Rafalivskyi Quarry, Volyn

The number and size of amygdules in basalts increase toward the upper sections of the lava flow. It is precisely the amygdaloidal texture that accounts for the wide variability in the physical properties of basalts, especially regarding porosity (see Tables 1 and 2).

Observations reveal amygdules with complex mineralogical fillings, including chlorite, calcite, and chalcedony (see Figure 3).

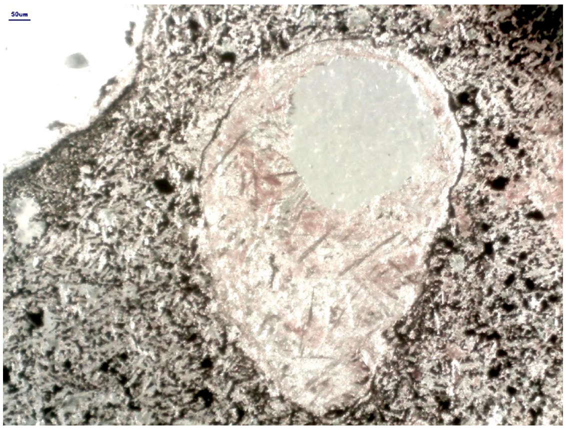

Figure 3 – Amygdule with combined filling, sample 4981-2, in crossed nicols, Volyn

A characteristic feature of spilites is the albitization of plagioclase, which occurs alongside the chloritization of pyroxenes and glass. The secondary mineralization in effusive rocks is well demonstrated by the composition of amygdule fillings. These are typically hydrated low-temperature minerals, such as chlorite, laumontite, prehnite, zeolites, opal, and similar phases. Spilite flows, like those of basalts, are frequently associated with the ejection of significant volumes of tuffaceous material.

Diabases are holocrystalline, fine-grained, dense rocks, typically exhibiting ophitic (diabasic), doleritic, or microdoleritic textures. Their primary minerals (similar to those in gabbros) are unstable: plagioclase often undergoes decalcification, augite is commonly replaced by chlorite, frequently accompanied by the formation of secondary calcite. These transformations are characteristic of paleotypic varieties. In contrast, fresh, kainotypic analogues, such as dolerites, like basalts with aphanitic texture, show high compressive strength. Dolerites are marked by high density and correspondingly low porosity (e.g., Lozivske deposit, Crimea).

The transitional group between basic and acidic rocks includes diorites and their effusive equivalents, the andesites. Diorites are typically characterized by a prismatic-granular (hypidiomorphic) texture and the presence of small amounts of quartz, forming a variant known as quartz diorites. Their texture consists of intermediate plagioclase (andesine) and ferromagnesian minerals, mainly hornblende and pyroxene, occasionally biotite. In Ukraine, diorites are not widespread, occurring primarily in contact zones adjacent to granite and granodiorite massifs.

Diorites of Crimea (e.g., Mount Ayu-Dag, Kurtsivske deposit) have a bulk density of 2.81 g/cm^3, porosity of 2.76%, hardness of 81, and compressive strength of 2360 kg/cm^2.

Andesitic volcanism, unlike plutonic intrusions, covers extensive areas and is represented by a variety of lithologies, particularly transitional types such as andesite-basalts and andesite-dacites. In Transcarpathia, andesite-basalts often exhibit columnar jointing, sometimes with a fan-shaped arrangement of columns (e.g., Radvanske and Siletske deposits).

The group of acidic rocks, with SiO_2 content not less than 64%, includes granites, leucogranites, granodiorites, tonalites, plagiogranites, dacites, and rhyolites – summarized in Table 3.

Table 3 – Indicators of Physical Properties of Igneous Rocks of acidic composition [8,15]

Rock Type	Density, g/cm³	Porosity, %	Water Absorption, % by wt	Compressive Strength, kg/cm²	Strength, kg/mm²	Magnetic Susceptibility, (SI units)
Granodiorites	2.66–2.75	0.7–4.5 to 6.40	up to 3.8	729–1820	-	$50\cdot10^{-5}$
Granites (biotite, alkali)	2.62–3.04	0.0–6.9 (commonly up to 2)	0.07–3.0	480–3700	105	$(20–30)\cdot10^{-5}$ $(5–10)\cdot10^{-5}$
Liparites, Dacites	2.0	up to 19.12	-	780	-	-
Rhyolite	-	3.12–7.47	-	-	-	-
Quartz Porphyries	2.4–2.7	up to 9.0	up to 6.7	760–1800	-	-

A characteristic feature of this group is the presence, in addition to quartz, of such minerals as alkali feldspar, plagioclase, ferromagnesian minerals (in small quantities), and albite. This group of rocks is among the most widespread in Ukraine and worldwide, primarily found on continents. Oceanic regions are not typical for acidic magmatism.

To classify acidic igneous rocks into varieties, two alkali feldspars are used: potassium-sodium feldspar and albite, along with secondary minerals and structural-textural features [18]. Acidic rocks of normal and elevated alkalinity (sublithic) are divided based on the content of sodium and potassium oxides. The most common among all types of acidic igneous rocks are potassium-sodium and high-alumina varieties. Granodiorites and tonalites belong to the latter. Manifestations of the sodium series – plagiogranites, plagioriodacites – are less frequently observed.

Structural varieties of acidic igneous rocks can be porphyritic (Fig. 4) or aphanitic.

Acidic volcanism of both early orogenic and post-orogenic types is observed in continental mobile zones. An example of the manifestations of the latter type is the Carpathian-Rhodope volcanic system.

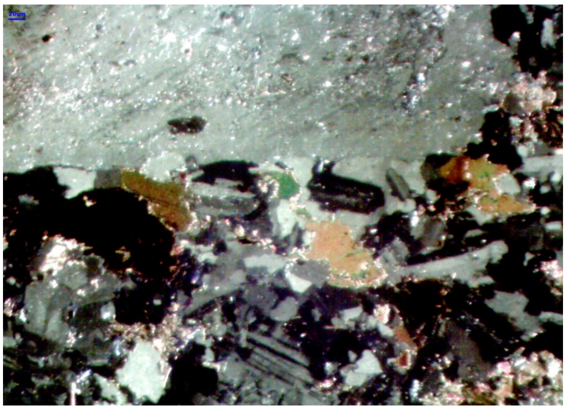

Figure 4 – Porphyritic biotite granite, sample 4978, crossed nicolls, Klesovsky quarry

The formation of spherulites among acidic lavas is a typical phenomenon. For example, to the east of the city of Berehove (Transcarpathia), white-colored glass spherulites were observed in black lavas, ranging from 2 mm to 6 mm in size. As it is known, magmas of acidic composition are characterized by significant gas saturation compared to magmas of basic composition. The presence of gases causes the lava flows to swell and contributes to the formation of porous volcanic rocks. This porosity depends on the composition of the gases and the power of the flow. In thin lava flows, 5–7 meters thick, pores were observed in the upper and lower parts. Their quantity gradually decreased towards the middle of the flow. Due to the zonal arrangement of pores, the rocks have a banded texture. The same texture is caused by the alternation of areas with varying degrees of volcanic glass crystallization. In the thin-banded lavas of Transcarpathia, to the north of Mukachevo, black-colored andesito-basalts alternate with light-gray andesito-dacites. The formation of strips of different composition is caused by gravitational differentiation. According to observations, due to the stretching conditions during the movement of lava (flow) and also the contractional stress during its formation, cracks of primary separability arise in it, i.e., stretching cracks. Contractional cracks are associated with the shortening of the mass of the rock and are oriented perpendicular to the surface. The physical properties of the lavas and their cooling conditions determine various types of cracks, which in turn define certain types of separability (blocky, cubic, platy, columnar, etc.).

According to the glass content in the main mass, acidic volcanic rocks are divided into 4 groups:

1. Obsidian, pumice, and perlite – 80–100%;
2. Glassy – 50–80%;
3. Rich in glass – 20–50%;
4. Glass-bearing – 0–20%.

Perlite and glassy rhyolites are present in Transcarpathia (Ardov deposit), where they often retain a fluid texture. The physical properties of the glass (color, hardness) depend on the water content – in obsidians it is less than 1%, in perlite – more than 1% [Metallic and Non-metallic..., 2006]. The crystallization of glass is characteristic of rocks with an acidic composition and is manifested in the spread of feldspathic and spherulitic structures. Fragments of glass are generally distinguished from pyroclastics near the eruption by their more acidic composition, which is recorded by the refractive index and density – Table 4.

Table 4 – Density of volcanic glass of different composition [Trëger, 1952]

Composition	Density, g/cm³
Liparitic	2.37 (2.33-2.41)
Dacitic	2.50 (2.45-2.55)
Trachytic	2.45 (2.43-2.47)
Andesitic	2.47 (2.40-2.57)
Basaltic	2.77 (2.70-2.85)

Granites that appear the same in outcrops can be divided into strained and unstrained types based on the results of microscopic research. Two areas are observed in the rocks, differing in the number of fractures formed during the deformation process. In the first area, deformation is characterized by homogeneous flow, caused by plastic deformations in the minerals. Under such conditions, the rock becomes compacted, which is reflected in the reduction of the total porosity indicators – from 2.1% to 1.6-1.8% in air-dry condition. The second area is characterized by rapid (avalanche-like) formation of fractures, which leads to the division of the rock into blocks. The disruption of the rock structure due to tectonic movements, combined with weathering, enhances the formation of fractures, and porosity increases, in some cases doubling or tripling – Table 5.

Table 5 – Physical characteristics of granites of Ukraine [15]

No.	Area	Density, g/cm³	Porosity, %
1	Kroshnya (Zhytomyr)	2.638–2.662 (2.68)	0.46–0.87 (0.26–1.08)
2	Tokivskyi (Dnipro)	2.581–2.634 (2.68)	0.46–0.72 (2.24)
3	Klesivskyi (Volyn)	2.63–2.67	0.17–0.43
4	Oriikhivski Khutory	2.56–2.69 (2.54)	0.63–3.07 (1.1)
5	St. Karany (Azov region)	2.626–2.650	0.83–0.90

Variations in the physical properties of granites from the Oriikhivski Khutory area (Table 5) are due to weathering, with the increasing intensity of this process affecting porosity.

The physical characteristics of acidic rock groups are influenced by post-magmatic processes such as greisenization and beresitization. Greisenization occurs at medium temperatures in granites and rocks of similar composition. A characteristic feature of this process is the replacement of feldspar aggregates with quartz and muscovite, sometimes with albite. An example of this type of replacement is the growth and fusion of perthites in feldspars in granites (observed in thin sections of samples from the Kalmius River and other deposits in Ukraine) – Table 5. The same applies to feldspars, whose sericitization increases their porosity to 4.3-5.6%. In unstrained samples of granodiorites, no transgranular cracks were observed in quartz grains, although isolated pores of a few microns in diameter were sometimes found. According to D. Dengler's data [13], plagioclase exhibited higher pore density and smaller sizes than quartz. The diameter of the pores in plagioclase ranged from <1 μm to 3 μm.

Examples of the second variant of post-magmatic changes include propylitization, which is observed in volcanic complexes predominantly of andesitic composition. Typical propylitized rocks consist of albite, epidote, chlorite, calcite, quartz, and pyrite. Under conditions of shallow depths, propylitized rocks are accompanied by adularia – $K[AlSi_3O_8]$, meaning that the propylitization process occurs with a high potassium oxide (K_2O) potential. Research into propylitization in the Vyshkiv intrusions of Transcarpathia showed that, in addition to chloritization, sericitization, and quartzization, pyrite and magnesium-iron carbonates (ankerite and siderite) later form [12].

Thus, the change in paragenesis occurs as a result of the reaction of early minerals with remaining melt residues. Minerals formed in the rock during its cooling and after the crystallization of the melt are considered post-magmatic. The appearance of new minerals can occur in several ways: a) within a single primary mineral (or glass) without changing the composition; b) with significant material movement without changing the composition of the rock; c) mineral formation with the removal and addition of materials. The first case includes polymorphic transformations, breakdown of solid solutions, and crystallization of glass.

4. Conclusions

Based on observations and experimental studies, it is established that:

– intrusive rocks of shield areas have the highest degree of compaction due to long cooling at significant depths, with the porosity of basic and ultrabasic rocks always being lower than that of granitoids. Processes such as serpentinization of ultrabasic rocks and amphibolization of gabbro reduce their magnetic susceptibility, density, and bulk weight due to the removal and reduction of iron content;

– albite substitution in magmatic rocks of basic (spilites) and acidic (granodiorites) compositions leads to increased porosity. For example, albite-substituted granodiorites have 3-5 times greater porosity compared to fresh ones. The highest porosity values are observed among volcanic tuffs and tuff lavas, both from basaltic and liparite, trachydacite series with spherolitic structures. The presence of gases causes swelling of lava flows and contributes to the formation of porous volcanites.

Thus, the use of material-physical information about the changes in the mineralogical associations of magmatic rocks is essential for an objective assessment of their quality and optimization of extraction. The degree of mineral replacement is connected to porosity as a universal indicator of all types of rocks.

Conflict of interest

Authors state no conflict of interest.

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МІНЕРАЛИ-ІНДИКАТОРИ ОСОБЛИВИХ ЗМІН ВЛАСТИВОСТЕЙ МАГМАТИЧНИХ ГІРСЬКИХ ПОРІД

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Анотація. Аналіз мінералогічних асоціацій будь-якої гірської породи дозволяє відтворити її генезис, умови на момент дослідження, історію та шляхи перетворення з наступною зміною властивостей. Варіації тиску, температури, нестійке геохімічне середовище, тектонічні процеси викликають появу нових мінералів з іншими характеристиками, стабільними у конкретних умовах. На основі цих мінеральних асоціацій формуються показники фізичного та механічного стану породи. Мета даної роботи – на прикладі окремих регіонів України оцінити стан досліджень фізичних властивостей мінералів магматичних порід.

Утворення нових мінеральних речовин може відбуватися за допомогою декількох механізмів: а) в межах одного первинного мінералу (або скла) без зміни хімічного складу; б) шляхом значного масопереносу без зміни загального складу вміщуючої породи; в) шляхом утворення мінералів, що передбачає як видалення, так і додавання матеріалу. Процеси першої категорії включають поліморфні перетворення, розчинення твердих розчинів, рекристалізацію вулканічного скла та ін. Всі три механізми знаходять відображення в отриманих мінералогічних збірках. Типовими показниками мінеральних перетворень є серпентин, що заміщає олівін, амфібол, що заміщає піроксен, і серицит, що заміщає польовий шпат. Альбітизація магматичних порід – чи то мафічного (основного), чи то фельзитового (кислого) складу - призводить до збільшення пористості. Найвищі значення пористості спостерігалися у вулканічних туфах і туфолавах, включаючи як базальтові ряди, так і фельзитові різновиди, такі як ріоліти, дацити і трахідацити. Вивчення вторинних мінеральних фаз має безпосередній вплив на зміну фізико-механічних властивостей гірських порід. Інтеграція композиційних і фізичних даних про зміни в мінералогічних складах магматичних порід має важливе значення для об'єктивної оцінки їх якості та оптимізації процесів видобутку. Пористість, яка тісно пов'язана зі ступенем заміщення мінералів, служить ключовим показником для всіх типів гірських порід.

Ключові слова: мінералогічні асоціації, породи, трансформації, перетворення мінералів, властивості.