sustainability

MDPI

Article

Model to Assess the Quality of Magmatic Rocks for Reliable and Sustainable Constructions

Mihaela Toderaş [1], Roland Iosif Moraru [2,*], Ciprian Danciu [1], Grigore Buia [3] and Lucian-Ionel Cioca [4,5]

[1] Mining Engineering, Surveying and Civil Engineering Department, Faculty of Mines, University of Petrosani, 20 University Street, 332006 Petrosani, Romania; toderasmihaela@yahoo.com (M.T.); danciu_ciprian@yahoo.com (C.D.)
[2] Management and Industrial Engineering Department, Faculty of Mines, University of Petrosani, 20 University Street, 332006 Petrosani, Romania
[3] Environmental Engineering and Geology Department, Faculty of Mines, University of Petrosani, 20 University Street, 332006 Petrosani, Romania; grigbuia@yahoo.com
[4] Industrial Engineering and Management Department, Faculty of Engineering, Lucian Blaga University of Sibiu, 10 Victoriei Blv. Street, 550024 Sibiu, Romania; lucian.cioca@ulbsibiu.ro
[5] Academy of Romanian Scientists, Splaiul Independentei, 54, Sector 5, 010071 Bucharest, Romania
* Correspondence: roland_moraru@yahoo.com; Tel.: +40-723-624-105

Received: 27 September 2017; Accepted: 17 October 2017; Published: 24 October 2017

Abstract: Geomechanical assessment of rocks requires knowledge of phenomena that occur under the influence of internal and external factors at a macroscopic or microscopic scale, when rocks are submitted to different actions. To elucidate the quantitative and qualitative geomechanical behavior of rocks, knowing their geological and physical–mechanical characteristics becomes an imperative. Mineralogical, petrographical and chemical analyses provided an opportunity to identify 15 types of igneous rocks (gabbro, diabases, granites, diorites, rhyolites, andesites, and basalts), divided into plutonic and volcanic rocks. In turn, these have been grouped into acidic, neutral (intermediate) and basic magmatites. A new ranking method is proposed, based on considering the rock characteristics as indicators of quantitative assessment, and the grading system, by given points, allowing the rocks framing in admissibility classes. The paper is structured into two parts, experimental and interpretation of experimental data, showing the methodology to assess the quality of igneous rocks analyzed, and the results of theoretical and experimental research carried out on the analyzed rock types. The proposed method constitutes an appropriate instrument for assessment and verification of the requirements regarding the quality of rocks used for sustainable construction.

Keywords: igneous rock; aggregate; physical–mechanical characteristics; exploitation; conformity; safety level

1. Introduction

Since the dawn of civilization, rocks have been used for construction purposes. In time, the use of rocks under a variety of forms became increasingly complex, as a reflection of cultural and historical trends of the human society [1,2].

On the Romanian territory, the natural occurrence of useful rocks is widely spread on the foreland zone and on the Carpathian structures. These rocks have multiple uses in constructions and various other civil/industrial sectors. Besides being used as raw material in buildings, roads and a variety of miscellaneous engineering works, depending on their petrographic type, these useful rocks are also used for ornamental/decorative purposes [2–4].

Given their wide spectrum of utilizations, the interest for mapping new reserves and prospective areas of useful rocks becomes crucial. This interest is enhanced by the rapid development of the construction industry, with special emphasis on terrestrial transportation infrastructures [5,6]. To acquire the desired construction quality of the terrestrial transportation infrastructures, a thorough understanding of the used materials and their behavior under heavy traffic and weathering factors is required.

The construction, rehabilitation and maintenance of road infrastructures involve the utilization of significant quantities of natural materials, where the natural aggregates play the most important role. Advanced construction technologies together with the quality of rocks, natural aggregates and other road construction materials, drive the achievement of well-built terrestrial transportation infrastructures. In the particular case of aggregates, the diversity of the raw material as a source, the various capabilities of manufacturing facilities, and the market demand present a wide diversity, with direct repercussion on the quality of the aggregates.

Accordingly, the rigorous characterization of the original aggregate quality becomes a paramount aspect in building reliable terrestrial transportation infrastructures. Additionally, based on the variation of raw material and manufacturing facilities, the aggregate characterization becomes a necessary periodic, reiterative step, aimed to bridge the construction needs and the available material. The adequate utilization of each type of aggregate is dictated by the chemical, mineralogical–petrographical and physical–mechanical properties of the source rock.

The periodic analysis of the source rocks and aggregates is managed through specific standards that stipulate threshold values of the physical and mechanical properties specific for each utilization field.

Given all the considerations above, the current paper represents a comprehensive geo-mechanical study of the magmatic rocks from the Southern Apuseni Mountains, rocks represented by a wide range of varieties, such as gabbro, diabase, granite, rhyolite, and basalt used in raw or manufactured form for civil engineering construction and ornamental/decorative works.

2. Geology of Southern Apuseni Mountains

The Apuseni Mountains are located between cross aisles of Mures and Somes, representing the largest and most complex subdivision of Occidental Carpathian [7–9]. They represent an internal arch in relation to Southern and Eastern Carpathian; they close westward the Transylvania Depression. Southern Apuseni represent central compartment of Occidental Carpathians, including a particularly complex area as tectonic and lithology. Morphologically, Southern Apuseni Mountains are delimited between Mures River and the alignment formed by the settlements Bârzava-Mădrizeşti–Hălmagiu-Câmpeni on the south and to the north of Roşia Montană-Sălciua-Ocoliş [10]. Southern Apuseni Mountains are also known as the Ore Mountains.

Although as a major structural geological unit, Apuseni Mountains have a particular position that deviates from the sinuous direction of the Alpino-Carpathian-Balkanides-Caucasian chain, they have resulted from the evolution of a rifting zone that occurred in the Transylvanian—Pannonian microplate. This was divided into two blocks—Pannonian block and Transylvanian block—by means of a breakage that occurred long before the Medium Jurassic. The geologic processes that led to the building of structural-genetic unit of the South Apuseni from Mountains Apuseni were influenced by behavior of edge of Pannonian block, which also resulted in the North Apuseni. The South Apuseni has evolved from a labile area of the Alpino-Carpathian geosyncline before Medium Jurassic (Dogger), in which there were many geological events. Due to these geological events, from stratigraphical point of view, in the structure of South Apuseni Mountains can be distinguished the following litho-structural-genetic units [11]: pre-alpine crystalline massifs (crystalline schist); ophiolitical magmatit; sedimentary pre-laramic; laramic magmatit; Neogene vulcanite; and post-laramic sedimentary from inter-mountain depressions (see Figure 1).

Actual tectonic arrangement of the South Apuseni Mountains is closely linked to their geological evolution in the framework of central and southeast Europe Alpine area [12]. In this context, the South Apuseni Mountains represent the suture or the scar of a labile area, which in its development has known a phase of expansion accompanied and followed by particular geotectonic processes, which can include: magmatic basic activity, processes of shortening the crust, subduction, oceanic crust consumption, etc.

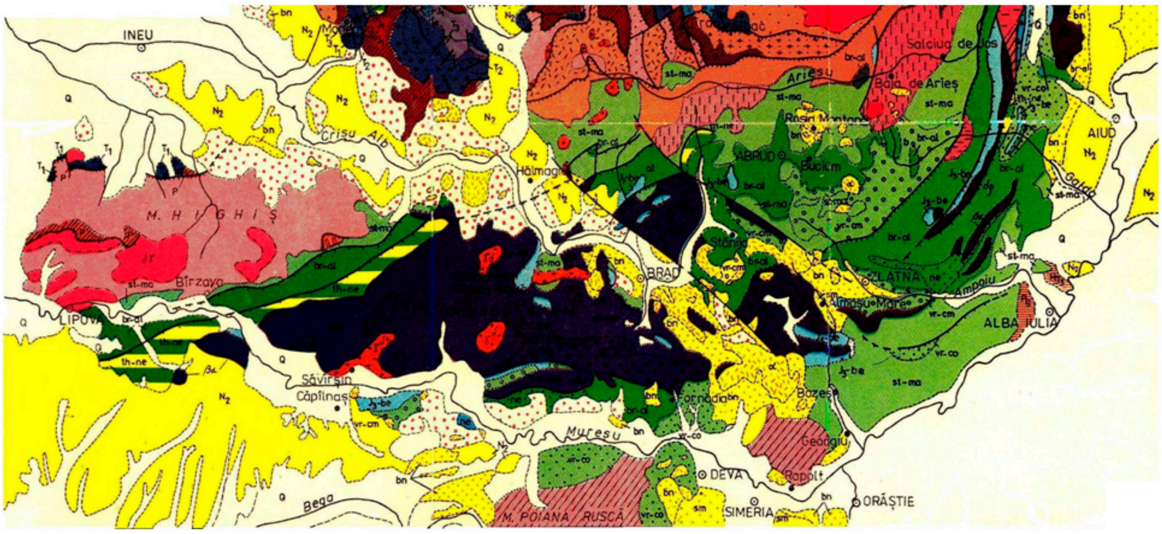


Figure 1. Geological map of Apuseni Mountains (according to Mutihac, 1990).

3. Characterization of Studied Magmatic Rocks from South Apuseni

Magmatic rocks form one of the three major groups of rocks, resulting from cooling and solidification of magma inside the crust or near the surface; relative to the solidification time, these rocks are classified as follows: volcanic rocks stratified or eruptive, with fine grain (acidic rocks and basic rocks that includes mainly basalts) and plutonic massive characterized by the presence of crystals of larger size as compared to the first category (acidic rocks category that includes granite, and basic rocks as gabbro—a classification of igneous rocks was performed in 1966 by Mason and taken up by other researchers [13,14]), classification performed based on the mineral composition and relative to way of formation of these rocks (see Figure 2).

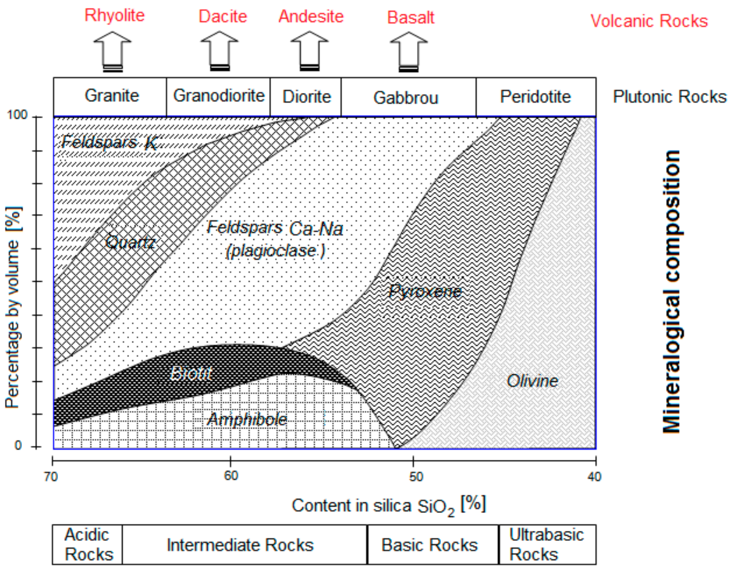


Figure 2. Schematic position of main magmatic rocks depending on their mineralogical composition (according to Mason (1966) cited by Beauchamp).

In Southern Apuseni are known associations of igneous rock formed in three distinct phases of the alpine cycle [15]: Jurassic–Cretaceous lower magmatic rocks, equivalent of ophiolite magmatic rocks; Paleocene–Upper Cretaceous magmatic, equivalent of laramic magmatic rocks;

and Neogene–Quaternary magmatic rocks, equivalent of Neogene effusive rocks. In the characterization of Southern Apuseni, the ophiolite magmatic rocks represented by basalts, andesite, dacite and even rhyolites form a huge mass that extends over a length of 190 km between Aries Valley and town of Zăbalţ on Mureş Valley; these rocks can reach a maximum width of 40 km. In Southern Apuseni, laramic magmatism manifested by lava is represented by occurrences of basaltic andesites from Măgura Brănişca and Măgura Sârbi. In genetic point of view, Neogene–Quaternary volcanism from Southern Apuseni falls into two types, acidic and respectively intermediate calc-alkaline.

3.1. Mineralogical and Petrographical Characterization of Igneous Rocks Analyzed

All the rocks presented in this study were analyzed at both macroscopic and microscopic level to determine the mineralogical and petrographical properties necessary for the further study of parameters defining the geo-mechanical behavior of the rock.

The mineralogical and petrographical study was achieved based on the analysis of thin sections examined with a polarizing microscope. Based on the macroscopic and microscopic analyses, a detailed description of these rocks is presented (see Table 1).

3.2. Chemical Composition of Magmatic Rocks Analyzed

The chemical composition of rocks was determined based on analysis performed on 15 samples. The chemical analysis aimed to identify the main oxides, with emphasis on silica dioxide, as an indicator of the acid, basic or neutral type of the analyzed magmatites. The chemical analysis was performed in the Chemistry Laboratory at the University of Petrosani, using an XRF spectrometer (X-ray fluorescence). The alkali–ggregate reaction emphasizes the reactivity and partial harmfulness of aggregates containing one or more forms of the silica dioxide with lower crystallization (opal, chalcedony, tridymite, and cristobalite) and volcanic glass rich in silica dioxide. The need of testing the reaction alkali–ggregate is dictated by concrete, which comes in permanent or temporary contact with water or, generally, with a humid environment [2,3,16]. Testing of the alkali–ggregate reaction was performed in conformity with standard STAS 5440-70:

1. To determine the reduction of sodium hydroxide solution *Rc*, Equation (1) was used:

$$R_c = \frac{f \cdot (V_3 - V_2) \times 1000}{V_1} \, [\text{mmol/dm}^3] \tag{1}$$

   where R_c represents the reduction of the concentration of sodium hydroxide solution, in mmol/dm^3; f is the factor of chlorhydric acid utilized during titration 0.05 n; V_2 is the volume of chlorhydric acid 0.05 n utilized for titration of analyzed sample in cm^3; V_3 is the volume of chlorhydric acid 0.05 n utilized for titration of witness sample, in cm^3; and V_1 is the volume of diluted solution, in cm^3 (20 cm^3).

2. The quantity of silica dioxide from the filtered sodium hydroxide solution was determined with Equation (2):

$$S_c = \frac{(A_1 - A_2) \times 1000 \times 1000}{5 \times 60.06} [\text{mmolSiO}_2/\text{dm}^3] \tag{2}$$

   where: S_c is the concentration of dissolved silica dioxide in mmol/dm^3; A_1 is the concentration of silica dioxide in g, in 100 cm^3 diluted solution; A_2 is the concentration of silica dioxide in g, in 100 cm^3 witness solution, diluted; and 60.06 is the molecular mass of silica dioxide, in g.

Based on the reaction alkali–ggregates, observations are drawn regarding the suitability of using aggregates with cements to attenuate or annihilate the reactivity. These observations are used in the particular case of the aggregates used to mix cements, which will face continuous contact with water or a moist environment [16]. The results following this analysis are given in Table 2, while the noxious character of the aggregates is determined based on the diagram in Figure 3 and classification in Table 3.

Table 1. Macroscopic and microscopic characterization of magmatic rocks types analyzed.

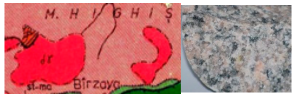
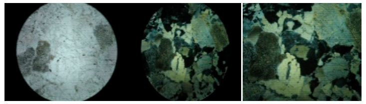
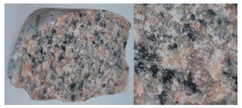
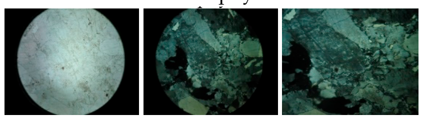
Macroscopic Analysis	Microscopic Analysis
Şoimuş Granite—sample number 1 Sampling location: Şoimuş, Arad District. Geological structure: tardi-orogenic (Banatitic) magmatism. Rock type: magmatic, plutonic, and acidic. Rock structure: holocrystalline, granular hypidiomorphic, slightly porphyritic Rock texture: unoriented (massive), compact. Color: white-greyish, with slight pink hue. Mineralogical composition: quartz, orthoclase and plagioclase feldspars, biotite, secondary minerals. Reaction to acids: none of the rock components reacts with dilute HCl  *Granite*	Structure: holocrystalline, hypidiomorphic-granular, porphyritic. Rock texture: unoriented (massive), compact. Mineralogical composition; quartz, orthose, plagioclase feldspar, biotite, opaque minerals, sericite, kaolinite. Quartz: (32.5%) appears as crystals with non-geometric, xenomorphic contours and variable dimensions, between 0.2/0.1 mm and 2.3/1.8 mm. The quartz presents random feldspar inclusions, rarely intergrown with orthose and forming micrographic, myrmekitic structures. In several occurrences, the submillimeter crystals are grouped as a mosaicated arrangement. Orthose (27.3%) appears hypidiomorphic, allotriomorphic, rarely idiomorphic. Crystals' dimensions vary between 0.3/0.2 mm and 2.7/1.7 mm. This mineral presents incipient to sometimes advanced states of mineralogical alteration. Plagioclase feldspar (26.2%) is represented by its acidic variety (albite); the crystals, mostly hypidiomorphic and rarely idiomorphic, present dimensions between 0.4/0.3 mm and 2.5/1.5 mm. Similar to the orthose, the plagioclase feldspar presents different states of mineralogical alteration. Biotite does not exceed 4.5% from all mineral components; it appears in the rock mass fresh or partially to totally limonitized. Denomination rock: Adamelitic Granite.  *Plagioclase feldspar and orthoclase with equal proportions, quartz crystalized at a later stage, partially corroding the feldspar crystals*
Şoimuş Granite—sample number 2 Sampling location: Şoimoş, Arad District. Geological structure: tardi-orogenic (Banatitic) magmatism. Rock type: magmatic, plutonic, acidic. Rock structure: holocrystalline, hypidiomorphic granular, slightly porphyroidic. Rock texture: unoriented (massive), compact. Color: white-greyish, slight pink hue, dotted. Mineralogical composition; quartz, plagioclase and orthoclase feldspar, biotite, opaque and secondary minerals. Reaction to acids: none of the rock components reacts with dilute HCl.  *Porfiroid Granite*	Structure: holocrystalline, granular hypidiomorphic, slightly porphyroidic. Texture: unoriented (massive), compact. Mineralogical composition; quartz, orthose, plagioclase feldspar, biotite, opaque minerals, secondary minerals. Quartz (33.2%) lacks completely geometric contour and occupies the interstices between feldspars. Quartz crystal dimensions do not exceed a maximum of 1.5 mm, with the majority of submillimeter dimensions. The quartz crystals appear as mosaicated arrangement or intergrown with orthose, as myrmekite. Orthose (37.5%) appears less frequently with geometric, idiomorphic contours, and more frequently as hypidiomorphic and xenomorphic crystals. The orthose crystals dimensions vary between 0.2/0.1 mm and 2.0/1.5 mm. The orthose presents mostly incipient states of mineralogical alteration; sporadically, advanced mineralogical alteration is also observed. Some crystal contours are corroded by finely crystallized quartz. Plagioclase feldspar (25.3%) consists of hypidiomorphic crystals of albite and oligoclase, frequently developed from average to large crystals (0.5/0.4 mm and 0.3/1.8 mm). The feldspar presents different states of mineralogical alteration, such as sericitization and kaolinization. Biotite does not exceed 4.5% from the mass of all components, appearing as fresh or partially to totally limonitized. Denomination rock: Porphyiroidic Granite.  *Porphyiroidic granite. Orthose with twins (macles), phenocryst within metastasis mass of quartz and plagioclase*

Table 1. *Cont.*

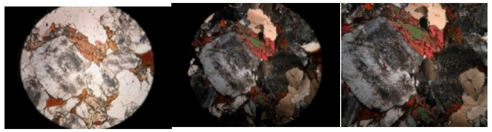
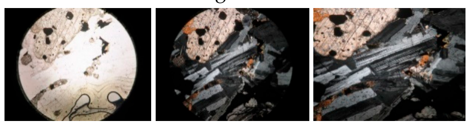
Macroscopic Analysis	Microscopic Analysis
Săvârşin Granite—sample number 3 Sampling location: Săvârșin, Arad District. Geological structure: epeirogenic subsequent banatitic (laramide) magmatism. Rock type: magmatic, plutonic, and acidic. Rock structure: holocrystalline, granular hypidiomorphic, slightly porphyroidic. Rock texture: unoriented (massive), compact. Color: white-greyish, slight pink hue. Mineralogical composition: quartz, orthose, acidic plagioclase feldspars, biotite, accessory minerals. Reaction to acids: none of the rock components reacts with dilute HCl.  *Săvârşin Granite*	Structure: holocrystalline, hypidiomorphic-granular, partially porphyroidic. Texture: unoriented (massive), compact. Mineralogical composition; quartz, orthoclase feldspar (orthose), acid plagioclase feldspar, biotite, zircon, opaque minerals, sericite, kaolinite, limonite. Quartz (25.6%) appears as crystals with non-geometric, xenomorphic contours, and variable dimensions between 0.2/0.1 mm and 2.0/1.7 mm. Small dimension crystals are usually encountered between feldspar interstices, sometimes as a mosaicated arrangement. Orthose (33.5%) is represented by hypidiomorphic, idiomorphic, and subordinately allotriomorphic crystals. The crystals may present bisynthetic twins (macles), with dimensions varying between 0.2/0.1 mm and 2.5/1.5 mm. The orthose mineral presents fresh or incipient to advanced states of mineralogical alteration. Plagioclase feldspar (35.0%) consists mainly of hypidiomorphic and idiomorphic crystals. The plagioclase crystals present dimensions between 0.5/0.4 mm and 2.4/1.6 mm. This mineral is an acid plagioclase, slightly zoned. Similar to the orthose, the plagioclase feldspar presents various degrees of mineralogical alteration. Biotite does not exceed 4.0% from the mass of all components, appearing as fresh or partially to totally limonitized. Denomination rock: Săvârșin Granite  *Banatitic granite with porphyroidic structure*
Şoimoș Diorite—sample number 4 Sampling location: Şoimoș, Arad District. Geological structure: tardi-orogenic (Banatitic) magmatism. Rock type: magmatic, plutonic, intermediate. Rock structure: holocrystalline, granular hypidiomorphic. Rock texture: unoriented (massive), compact. Color: greyish, slightly dotted. Mineralogical composition: plagioclase feldspar, pyroxenes. Reaction to acids: none of the rock components reacts with dilute HCl.  *Augitic Diorite*	Structure: holocrystalline, granular hypidiomorphic. Texture: unoriented (massive), compact. Mineralogical composition; intermediate plagioclase feldspar, pyroxenes (augite and diopside) biotite, quartz, opaque minerals, limonite. Plagioclase feldspar (60.0%) consists of hypidiomorphic crystals and very rarely, subordinately, idiomorphic and xenomorphic crystals. The mineral appears fresh, with polysynthetic twins (macles) and crystals between 0.2/0.1 mm and 1.5/1.0 mm. The plagioclase sporadically contains submillimeter crystals of augite and opaque minerals. Augite (30.0%) is found in the rock mass as hypidiomorphic, idiomorphic and xenomorphic crystals. Augite crystals dimensions vary between 0.3/0.2 mm and 2.0/1.0 mm. Augite appears fresh and presents unidirectional cleavage for crystals sectioned parallel with Z axis and bidirectional (89°) for crystals sectioned perpendicular on axis Z. Biotite, diopside and quartz, finely crystalized, do not exceed 2% from total rock components. Opaque minerals (6%) consist of finely crystalized magnetite, non-uniformly distributed within the rock mass. Denomination rock: Augitic Diorite.  *Şoimoş diorite, fresh, with augite containing inclusions of opaque minerals*

Table 1. *Cont.*

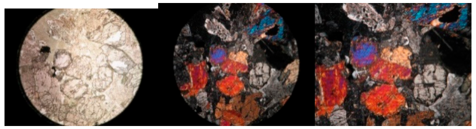
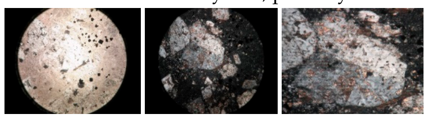
Macroscopic Analysis	Microscopic Analysis
Căzănești Gabbrou—sample number 5 Sampling location: Căzănești, Drocea Mountains, Hunedoara District. Geological structure: alpine ophiolitic eruptivism (initial). Rock type: magmatic, plutonic, basic. Rock structure: holocrystalline, hypidiomorphic and allotriomorphic. Rock texture: unoriented (massive), compact. Color: dark gray, black-greenish. Mineralogical composition; basic plagioclase feldspar, augite, olivine, oxide minerals, secondary minerals. Reaction to acids: none of the rock components reacts with dilute HCl.  *Gabbro with olivine and augite*	Structure: holocrystalline, hypidiomorphic and allotriomorphic. Texture: unoriented (massive), compact. Mineralogical composition; basic plagioclase feldspar, augite, olivine, secondary minerals, saussurite. Basic plagioclase feldspar consists of the series of Labrador-bytownite-anortite, with 65% anortite. The plagioclase feldspar appears as medium and largely developed, presenting various stages of saussuritization alteration, respectively transformation into a fine aggregate consisting of zoisite, clinozoisite, epidote, albite, zeolites and sericite. Olivine (20%) is represented by hypidiomorphic, idiomorphic and allotriomorphic crystals, with dimensions between 1.5/0.5 mm and 0.5/0.1 mm. The mineral appears mostly fresh, where only the contourless olivine presents opacitization and serpentinization. Augite (8%) consists of hypidiomorphic and allotriomorphic crystals with dimensions below 1 mm. The cleavage is unidirectional for crystals sectioned parallel with Z crystallographic axis and bidirectional (89°) for crystals sectioned perpendicular on Z crystallographic axis. Opaque minerals are finely crystallized and non-uniformly dispersed into the rock mass. Denomination rock: Gabbro with olivine and slightly mineralized augite.  *Basic plagioclase feldspar, olivine and augite, with geometric (idiomorphic) contour*
Roșia Montană Rhyolite—sample number 6 Sampling location: Roșia Montană, Alba District. Geological structure: neogenic eruptivism, represented by rooted bodies, lava flows, explosive volcanic breccia and pyroclastics. Rock type: magmatic, neovolcanic effusive, acid. Rock structure: semicrystalline (hipocrystaline), porphyry–vitreous. Rock texture: unoriented (massive), compact. Color: white, slight gray hue. Mineralogical composition: potassium orthoclase feldspar, quartz, calco-sodic feldspar (plagioclase), volcanic glass, pyrite, argillite minerals, calcite. Reaction to acids: feldspar phenocryst, partially or totally calcified, presents a strong reaction with diluted HCl.  *Rhyolite partially altered and mineralized*	Structure: semicrystalline (hypocrystalline), porphyry-vitreous Texture: unoriented (massive), compact. Mineralogical composition; potassium orthoclase feldspar, quartz, plagioclase feldspar, main rock mass as volcanic glass and microlites, opaque minerals (pyrite), secondary minerals (argillite minerals, sericite and calcite). The orthoclase feldspar (50.4%), in most cases, appears as idiomorphic and hypidiomorphic crystals, sometimes with bi-synthetic macles (twins) and with various degrees of alteration. The crystals dimensions vary between 0.4 and 6 mm while the orthoclase, heavily argillized and substituted by calcite, contain idiomorphic and hypidiomorphic crystals of pyrite. Quartz (20.6%) presents laced and rounded contour due to the corroding of the volcanic glass. The quartz crystal dimensions do not exceed 5 mm. Plagioclase feldspar does not exceed 2% from the total mass of mineral components. This mineral appears partially to totally sericitized or calcified. The main rock mass, containing feldspars phenocryst and quartz, consists of microlites of orthoclase feldspar, submillimeter and rarely millimeter pyrite crystals and volcanic glass. Given the hydrothermal metamorphism, these minerals present a variety of alteration degrees. Pyrite, in most occurrences, appears finely crystalized (0.1 mm to 0.7 mm), rarely exceeding 1.5 mm. usually, the pyrite consists of solitary, idiomorphic and hypidiomorphic crystals, dispersed non-uniformly within the rock mass. Same pyrite can seldom appear as agglomerations of nests not exceeding dimensions of 5 mm. Denomination rock: Rhyolite, partially mineralized and altered.  *Hypidiomorphic orthose with an incipient alteration stage and with sub millimeter pyrite inclusions*

Table 1. *Cont.*

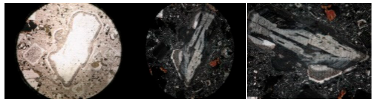
Macroscopic Analysis	Microscopic Analysis
Valea Căpitanului Andesite—sample number 7 Sampling location: Certej–Hondol, Valea Căpitanului, Hunedoara District. Geologic structure: neogenic eruptivism of Apuseni Mountains (Metaliferi). Rock type: magmatic, effusive (neovolcanic), neutral. Rock structure: semicrystalline (hypocrystalline), porphyry-vitreous. Rock texture: unoriented (massive), compact. Color: gray, slightly dotted. Mineralogical composition: plagioclase feldspar, hornblende, microlitic paste. Reaction to acids: none of the rock components reacts with dilute HCl.  *Andesite with hornblende*	Structure: hypocrystalline, porphyry vitreous. Texture: unoriented (massive), compact. Mineralogical composition: neutral plagioclase feldspar, hornblende, microlites, volcanic glass, opaque minerals, secondary minerals. Plagioclase feldspar (32.5%) presents mostly idiomorphic and hypidiomorphic contours, rarely zoned. The crystals have variable dimensions, as follows: from 0.01 mm for microlites and 6.1/3.9 mm for phenocryst. Within the rock mass, the plagioclase feldspar exhibits various stages of alteration. Crystals with kaolinitized and sericitized contours, completely affected by the hydrothermal metamorphism, are also present. Hornblende (20.5%) appears within the rock mass as idiomorphic, hypidiomorphic and allotriomorphic crystals, with dimensions between 0.2/0.07 mm and 8.1/1.2 mm. Crystals sectioned parallel with crystallographic axis Z present good unidirectional cleavage, while the ones sectioned perpendicular to the same axis have clearly defined bidirectional cleavage (124°). Some amphibolite crystals exhibit partial or total opacitization. Opaque minerals (8.5%) consist of idiomorphic, hypidiomorphic and xenomorphic pyrite crystals, non-uniformly distributed within the main rock mass (microlitic and glassy, at 44.5%). Denomination rock: Andesite with hornblende  *Plagioclase feldspar, idiomorphic with completely altered contours (Kaolinitized and sericitized)*
Dealul Motor Andesite—sample number 8 Sample location: Deva, Motor Hill, Hunedoara District. Geologic structure: neogenic eruptivism from Mures Valley. Rock type: magmatic, effusive (neovolcanic), neutral. Structure: semicrystalline, porphyry vitreous Texture: unoriented (massive), compact. Color: gray. Mineralogical composition: neutral plagioclase feldspar, hornblende, rarely biotite lamellae and microlitic paste. Reaction to acids: slight reaction with diluted HCl, due to presence of calcite formed on plagioclase and hornblende.  *Andesite with hornblende and biotite*	Structure: hypocrystalline, porphyry vitreous. Texture: unoriented (massive), compact. Mineralogical composition: plagioclase feldspar, hornblende, biotite, microlitic paste, opaque minerals, kaolinite, sericite, chlorite, limonite. Plagioclase feldspar (24.5%) presents mostly idiomorphic contours, also zoned. Crystal dimensions are variable, from 0.01 mm in microlites up to 6.1/4.5 mm for phenocryst. The cleavage appears distinct for crystals sectioned parallel to crystallographic axis Z. Hornblende (12.5%), similar to the plagioclase feldspar, appears predominantly idiomorphic. The hornblende crystals are sectioned perpendicular to crystallographic axis Z (basal sections) and parallel to same axis (elongated, prismatic sections). In both cases, good cleavage appears distinctly, bidirectional (124°) at basal sections and unidirectional for sections parallel with prismatic faces. Some crystals with idiomorphic contours exhibit partial or total opacitization. Biotite does not exceed 0.6% from all rock mass components and appears generally fresh, sometimes with incipient chloritization and limonitization. Some biotite lamellae, along the unidirectional cleavage, present slight opacitization. Opaque and secondary minerals do not exceed 3.5% of all rock mass components and consists of fine magnetite crystals, either as inclusions within phenocryst or irregularly distributed within the rock mass. Pulverulent kaolinite and finely lamellae of sericite appear on some plagioclase crystals or within the paste. The finely crystallized calcite appears with some plagioclase feldspars richer in anortite and sporadically with hornblende. Denomination rock: Andesite with hornblende and biotite.  *Zoned plagioclase feldspar, with unaltered peripheral zones and central zones partially sericitized-kaolinitized, with biotite inclusions partially resorbed*

Table 1. *Cont.*

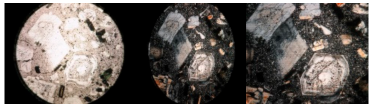
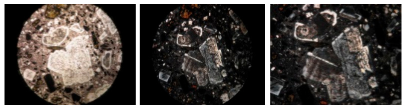
Macroscopic Analysis	Microscopic Analysis
Criscior Andesite—sample number 9 Sampling location: Criscior, Hunedoara district. Geologic structure: tardive subsequent magmatism (neogenic), second cycle. Rock type: magmatic, effusive (neovolcanic), neutral. Structure: semi-crystalline (hypocrystalline), porphyry-vitreous. Texture: unoriented (massive), compact. Color: dark gray. Mineralogical composition: plagioclase feldspar, hornblende, vitreous-microlitic paste, secondary minerals. Reaction to acids: none of the rock components reacts with dilute HCl  *Vitro-porphyry Andesite*	Structure: hypocrystalline, porphyry-vitreous Texture: unoriented (massive), compact. Mineralogical composition: neutral plagioclase feldspar, hornblende, microlitic vitreous paste, opaque minerals, secondary minerals (kaolinite, sericite, limonite). Plagioclase feldspar (30.5%) is represented by idiomorphic and hipidiomorphic crystals with incipient alteration stages. The plagioclase feldspar appears mostly zoned, with crystals dimensions varying between 0.3/0.2 mm and 2.0/1.0 mm. Central zones of the plagioclase feldspar, with higher anortite content, appear sometimes transformed into kaolinite and sericite. For most of the cases, the microlitic plagioclase feldspar appears not-altered. Hornblende (4.5%) appears with the rock mass as hipidiomorphic crystals, with dimensions below 1 mm. For most of the cases, the crystals contours are opacitized; sometimes, the amphibole is completely transformed into a secondary product through oxy-hydration. The vitreous-microlitic paste (55%) in this rock type consists of amorphous volcanic glass, where the feldspars microlites appear non-uniformly distributed. As the feldspars, microlites are predominant, the resulting macroscopic color is dark gray. Denomination rock: Vitreous-porphyry Andesite.  *Idiomorphic zoned plagioclase feldspar, centrally altered and with non-altered, clear, periphery contours. Two joint hypidiomorphic plagioclase crystals*
Săcărâmb Andesite—sample number 10 Sample location: Săcărâmb, Hunedoara District. Geologic structure: neogenic eruptivism of Apuseni Mountains (Metaliferi), second cycle. Rock type: magmatic, effusive (neovolcanic), intermediary. Structure: hypocrystalline (semicrystalline), porphyry vitreous. Texture: unoriented (massive), compact. Color: grey, slightly dotted. Mineralogical composition: plagioclase feldspar, hornblende, vitreous microlitic paste, secondary minerals. Reaction to acids: none of the rock components reacts with dilute HCl.  *Andesite with hornblende, partially altered*	Structure: semicrystalline, porphyry vitreous. Texture: unoriented (massive), compact. Mineralogical composition: neutral plagioclase feldspar, hornblende, vitreous microlitic paste, secondary and opaque minerals. Plagioclase feldspar (25.5%) consists of idiomorphic and hipidiomorphic crystals exhibiting different stages of kaolinization and sericitization. The anortite content, partially or totally altered, appears more frequently within the central zones, as opposed to the outer layer which appears usually fresh, without any transformation into kaolinite and sericite. Plagioclase feldspar crystal dimensions vary between 0.2/0.1 mm and 5.0/3.8 mm. Hornblende (8.3%) appears within the rock mass as idiomorphic and hipidiomorphic crystals, some unaltered, some partially or totally sericitized. Good cleavage, bidirectional for basal sections, is observed; unidirectional cleavage characteristic for longitudinal sections appears either distinct or completely opacitized. The microlitic and vitreous paste presents an advanced grade of alteration into kaolinite and sericite. Fresh microlites are rare and belong to the same type of plagioclase feldspar. Opaque minerals (2%) consist of submillimeter crystals of pyrite and chalcopyrite, not exceeding dimensions of 1.7 mm. These crystals are non-uniformly distributed within the rock mass. Denomination rock: Andesite with hornblende partially altered.  *Plagioclase feldspars partially altered, with non - transformed crystals contours, welded crystals of plagioclase and opacitized idiomorphic hornblende, idiomorphic and hypidiomorphic submillimeter pyrite*

Table 1. *Cont.*

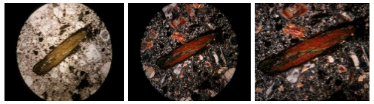
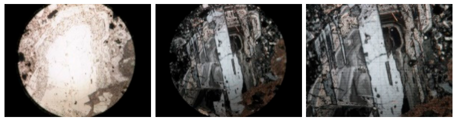
Macroscopic Analysis	Microscopic Analysis
Albinii-Haneș Andesite—sample number 11 Sample location: Albinii-Haneș, Alba District. Geologic structure: neogenic eruptivism of Apuseni Mountains (Metaliferi). Rock type: magmatic, effusive (neovolcanic), intermediary. Structure: hypocrystalline (semicrystalline), porphyry vitreous. Texture: unoriented (massive), compact. Color: grey, slightly dotted. Mineralogical composition: plagioclase feldspar, hornblende, microlitic paste. Reaction to acids: none of the rock components reacts with dilute HCl.   *Andesite with hornblende*	Structure: semicrystalline, porphyry vitreous. Texture: unoriented (massive), compact. Mineralogical composition: neutral plagioclase feldspar, hornblende, microlitic, volcanic glass, secondary and opaque minerals. Plagioclase feldspar (23.8%) consists mostly of idiomorphic and hypidiomorphic crystals, rarely zoned. Plagioclase feldspar crystal dimensions vary from 0.01 mm for microlites and 6.2/4.3 mm for phenocryst. For thin sections parallel with crystallographic axis Z and presenting polysynthetic macles (twins), the unidirectional cleavage appears distinctly. Hornblende (12.6%) appears within the rock mass as idiomorphic, hypidiomorphic and xenomorphic crystals with dimensions between 0.2/0.08 mm and 10.3/1 mm. The sections are either parallel or perpendicular on crystallographic axis Z. Good cleavage appears distinctly, as bidirectional (124°) or basal sections and unidirectional for sections parallel with prismatic faces. Some of the idiomorphic and hypidiomorphic crystals present partial or total opacitization. Microlites (50%) are feldspathic, non-uniformly distributed within the volcanic glass. Opaque minerals (4.5%) are finely crystalized, idiomorphic, hipidiomorphic and xenomorphic, chaotically distributed within the rock paste and consisting of pyrite and oxidic minerals. Secondary minerals, represented by kaolinite, affect partially some plagioclase phenocrysts and microlites. Denomination rock: Andesite with hornblende.  *Millimeter idiomorphic crystal of hornblende, with opacitized contour*
Roșia Poieni Andesite—sample number 12 Sample location: Rosia Poieni, Alba District. Geologic structure: neogenic eruptivism (second cycle), represented by rooted structures, lava flows and andesitic pyroclastics. Rock type: magmatic, neovolcanic, neutral (intermediary). Structure: hypocrystalline (semicrystalline), porphyry vitreous. Texture: unoriented (massive), compact. Color: grey, dotted. Mineralogical composition: plagioclase feldspar, hornblende, calcite, pyrite. Reaction to acids: calcite deposited at a later stage along fissures reacts strongly with diluted HCl.   *Poieni hornblendic andesite*	Structure: semicrystalline (hypocrystalline), porphyry vitreous. Texture: unoriented (massive), compact. Mineralogical composition: neutral plagioclase feldspar, hornblende, microlitic vitreous paste, kaolinite, sericite, calcite, pyrite. Plagioclase feldspar (chalco-sodic) (20.5%) consists of idiomorphic and hipidiomorphic crystals, rarely allotriomorphic, with dimensions between 0.4/0.2–6.2/3.2 mm. In several instances, the plagioclase feldspar appears zoned, with an incipient alteration stage (sercitization and kaolinitization). Hornblende (14.3%) appears as the common variety (green) and consists of prismatic crystals (idiomorphic and hipidiomorphic) with dimensions between 0.6/2.5–0.1/0.7 mm. In most cases, hornblende appears partially or totally opacitized. Kaolinite and sericite, as secondary products, appear in smaller percentages in some plagioclase feldspar crystals, as well as in the rock's paste, along with microcrystalline pyrite. Calcite was deposited at a later stage along the micro fissures and contraction fissures found within the rock mass. The microlitic paste (55.2%) is represented by feldspar and volcanic glass. Denomination rock: Poieni hornblendic andesite  *Plagioclase phenocryst, zoned and with peripheral alteration*

Table 1. *Cont.*

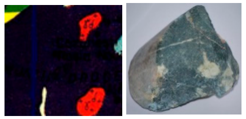
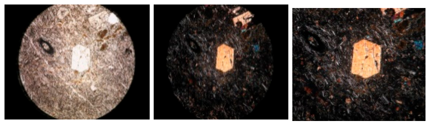
Macroscopic Analysis	Microscopic Analysis
Căzănești Diabase—sample number 13 Sample location: Căzănești, Drocea Mountains, Hunedoara district. Geologic structure: initial eruptivism Rock type: magmatic, effusive, paleovolcanic. Structure: devitrified, ophitic. Texture: unoriented (massive), compact. The rock presents a system of millimeter fissures, colmated with carbonates and pyrite. Color: grey, slightly green hue. Mineralogical composition: plagioclase feldspar, pyroxene, carbonates, pyrite, secondary minerals, dolomitic limestone enclaves. Reaction to acids: calcite ($CaCO_3$) reacts strongly with diluted HCl.  *Mid-ophytic diabase partially altered and mineralized*	Structure: mid-ophytic Texture: unoriented (massive), compact. Mineralogical composition: plagioclase feldspar, augite, olivine, calcite, dolomite, pyrite, chlorite, serpentine. Basic plagioclase feldspar (58.5%), initially basic (anortitic), in the majority of cases partially albitized, is represented by idiomorphic crystals with dimensions between 0.2/0.09 mm and 0.05/0.03 mm. The plagioclase from the fundamental rock mass is completely transformed into kaolinite, calcite and magnesium. Augite and olivine (22%) consist of allotriomorphic submillimeter crystals, grown into the interstitials between the intersected prismatic plagioclase crystals. Most of these minerals are transformed into chlorite, bastite and serpentinitic minerals. Calcite, dolomite and pyrite (15%) have hydrothermal origin, with very fine crystallization, deposited at a later stage on the contraction fissures of the diabasic lava. Denomination rock: Medio-ophitic diabase, partially altered and mineralized.  *Diabase with ophitic structure, medium-crystalized and albitised plagioclase (spilitized)*
Brănișca Basalt—proba 14 Sample location: Branisca, Hunedoara district. Geologic structure: Mures valley Neogene eruptivism. Rock type: magmatic, effusive (neovolcanic), basic. Structure: hypocrystalline, porphyry intersertal. Texture: compact, partially vacuolar, unoriented and oriented (fluidal). Color: dark grey. Mineralogical composition: plagioclase feldspar, pyroxene, olivine. Reaction to acids: none of the rock components reacts with dilute HCl.  *Dark Grey basalt, Branisca type*	Structure: semicrystalline, porphyry intersertal. Texture: unoriented (massive), compact and oriented (fluidal), partially vacuolar. Mineralogical composition: neutral and basic plagioclase feldspar, olivine, pyroxene, opaque minerals, alteration minerals (sericite, bowlingite). Plagioclase feldspars are predominant (75.3%), represented by two types of crystals; crystal dimensions vary between 0.5/0.1 mm and 0.3/0.04 mm, while the predominant microlites vary between 0.1/0.03–0.05/0.01 mm. Basic plagioclase (calcic) appears from fresh to partially or totally replaced by calcite. Olivine does not exceed 2% from all rock mass components. The olivine hipidiomorphic and allotriomorphic crystals have submillimeter dimensions, respectively 0.75/0.35–0.25/0.15 mm. The olivine presents an advanced state of alteration, along with formation of secondary minerals, such as bowlingite and asbestos. Pyroxenes are represented by idiomorphic and hipidiomorphic crystals, constituting less than 1% from the total minerals components. Pyroxene is represented by fresh augite. Opaque minerals, with submillimeter dimensions (0.03–0.04 mm) are also found in the rock mass (paste). Denomination rock: Dark gray basalt, Branisca type  *Idiomorphic augite, non-altered and with fluidal rock texture*

Table 1. *Cont.*

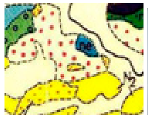
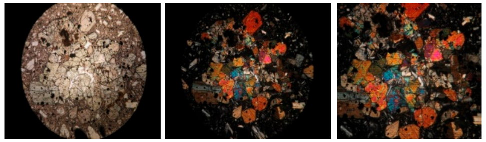
Macroscopic Analysis	Microscopic Analysis
Dobra Basalt—sample number 15 Sample location: Dobra, Hunedoara district. Geologic structure: Mures Valley Neogenic eruptivism (basaltic pyroclastics pyroclastics, post Sarmatian age). Rock type: magmatic, effusive (neovolcanic), basic. Structure: hypocrystalline, porphyry intersertal. Texture: unoriented (massive), compact. Color: dark grey. Mineralogical composition: plagioclase feldspar, olivine, secondary minerals. Reaction to acids: none of the rock components reacts with dilute HCl.   *Olivinic basalt, Dobra type*	Structure: semicrystalline (hipocrystaline), porphyry intersertal. Texture: compact, non-oriented. Mineralogical composition: basic and partially neutral plagioclase feldspar, olivine, augite, volcanic glass, opaque minerals, secondary minerals. Plagioclase feldspars (73.4%) consist, according to their dimensions, of phenocryst (0.6/0.2 mm and 0.4/0.05 mm) and microlites (0.1/0.02–0.04/0.01 mm). Plagioclase feldspars appear fresh, as idiomorphic and hipidiomorphic crystals, chaotically spread within the rock mass. Olivine does not exceed 3.5% of rock mass and is represented by the varieties forsterite and fayalite. Forsterite, a magnesian olivine, appears fresh, as idiomorphic, hipidiomorphic and xenomorphic crystals, with dimensions between 1.5/0.8 mm and 0.4/0.2 mm. The forsterite presents conchoidal breakage and imperfect cleavage. Fayalite, feriferic olivine, with submillimeter dimensions, appears partially to totally altered (opacitized). Augite is rarely encountered, partially altered, with submillimeter dimensions. Opaque minerals, with dimensions between 0.03–0.06 mm, appear in the rock mass and in some olivine crystals. Denomination rock: Olivinitic basalt Dobra Type  *Olivine phenocryst (fayalite), strongly fissured*

Table 2. Average values for alkali–ggregates reaction.

Rock Type	Sampling Location	S_c (mmol/dm^3)	R_c (mmol/dm^3)
Andesite	Certej Valea Căpitanului	51	19.4
Andesite	Deva Dealul Motor	53.4	21.6
Andesite	Crişcior	53.5	22.7
Andesite	Săcărâmb	55.4	23.4
Andesite	Albinii (Haneş)	51.3	16.9
Andesite	Roşia Poieni	49.3	19.1
Basalt	Brănişca	6.5	19
Basalt	Dobra	6.3	21

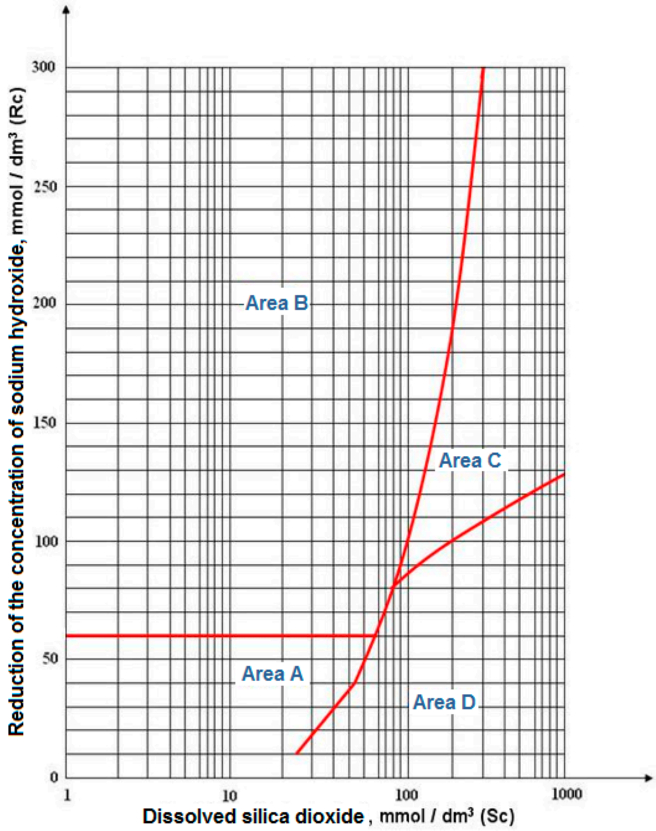


Figure 3. Verification of the reaction alkali–ggregates: aggregates from zone A are non-reactive and are recommended for utilization; aggregates from zone B are generally unreactive; aggregates from zone C are characterized by a potentially significant reactivity; and aggregates from zone D are considered harmful.

Table 3. Rock and aggregate characterization relative to S_c.

Class	Rock and Aggregate Characterization Relative to S_c (mmol/dm^3) and R_c (mmol/dm^3)
A	Unreactive
B	Generally unreactive
C	Potential significant reactivity
D	Harmful

Based on Table 3 and Figure 3, rocks are classified into four classes, from A, as non-reactive rocks, to D, as harmful rocks.

3.3. Physical and Resistance Properties of Magmatic Rocks

The physical rock state enables a quantitative description as well as an estimate of resistance characteristics. This description and estimate was accomplished by determining physical characteristics, such as specific density, apparent density, apparent porosity, compaction, natural moisture, and water absorption [2,3,17]. The physical and resistance properties were determined according to valid standards, as per recommendation of the International Bureau of Rocks Mechanics and International Society of Rocks Mechanics. The measuring of physical and resistance properties has been made in accordance with specific protocols, recommendations of the International Bureau of Rock Mechanics and International Society of Rock Mechanics (see Tables 4 and 5).

Table 4. Average values of physical characteristics of magmatic rocks from Southern Apuseni Mountains.

Sample Number	Rock Type	Physical Characteristics					
		Specific Density $\rho \cdot 10^3$ (kg/m^3)	Apparent Density $\rho_a \cdot 10^3$ (kg/m^3)	Porosity n (%)	Compaction C (%)	Natural Moisture W (%)	Water Absorption at Normal Pressure, a_i (%)
1	Gabbro	2.8887	2.8449	1.5162	98.4837	0.2271	0.4274
2	Diabase	2.7852	2.7499	1.2673	98.7326	0.3922	0.6951
3	Granite	2.6350	2.6195	0.5881	99.4117	0.1463	0.3193
4	Granite	2.6458	2.6240	0.8225	99.1773	0.1227	0.2988
5	Granite	2.6455	2.6254	0.7597	99.2401	0.1488	0.3144
6	Diorite	2.9648	2.9513	0.4564	99.5434	0.1867	0.3625
7	Rhyolite	2.6490	2.5667	3.1042	96.8957	1.9273	2.6834
8	Andesite	2.7712	2.6682	3.7167	96.2831	0.9595	1.6190
9	Andesite	2.7325	2.6129	4.3744	95.6254	1.0867	1.6690
10	Andesite	2.6558	2.6397	0.6061	99.3937	0.7963	1.4089
11	Andesite	2.6515	2.4574	7.3201	92.6797	2.7668	3.4895
12	Andesite	2.6931	2.6734	0.7339	99.2660	0.6404	1.1652
13	Andesite	2.7124	2.6440	2.5229	97.4769	1.1630	1.9805
14	Basalt	2.7289	2.7046	0.8916	99.1082	0.7758	1.2342
15	Basalt	2.7248	2.6994	0.9309	99.0689	0.9018	1.3361

Sampling location of rock sample was: 1, Căzăneşti; 3, Şoimos (F21); 4, Şoimoş (F31); 5, Săvârşin; 6, Şoimoş; 7, Roşia Montană; 8, Certej-Valea Căpitanului; 9, Deva-Dealul Motor; 10, Brad-Crișcior; 11, Săcărâmb; 12, Albini-Haneş; 13, Roşia Poieni-Dealul Jgheabului; 14, Brănişca; 15, Dobra.

Table 5. Average values of resistance characteristics of magmatic rocks from Southern Apuseni Mountains.

ID	Rock Type	Resistance Characteristics					
		Breaking Resistance at Uniaxial Compression (MPa)		Abrasion of Aggregate by Los Angeles Machine (%)	Shattering Caused by Compression in Dry State (%)	Freezing–Thawing Resistance	
		Dry State	After 25 Cycles Freezing–Thawing			Gelivity Coefficient (%)	Freezing Sensitivity (%)
1	Gabbro	150.173	124.644	12.204	95.083	0.022	16.942
2	Diabase	161.117	129.017	15.815	93.760	0.033	19.882
3	Granite	172.189	158.055	11.15	95.855	0.005	8.142
4	Granite	212.220	192.615	11.820	96.226	0.008	9.154
5	Granite	168.488	156.272	10.161	95.799	0.011	7.237
6	Diorite	183.860	171.727	10.44	94.936	0.015	6.608
7	Rhyolite	122.997	85.731	23.907	88.797	0.110	29.919
8	Andesite	110.194	91.039	12.753	88.540	0.136	17.383
9	Andesite	131.934	105.181	16.877	90.078	0.255	20.234
10	Andesite	143.538	125.297	16.369	92.016	0.127	12.715
11	Andesite	123.674	94.235	20.052	85.367	0.270	23.819
12	Andesite	142.404	122.420	11.138	92.492	0.113	13.997
13	Andesite	129.632	103.753	15.4	91.694	0.130	19.949
14	Basalt	170.839	157.856	13.724	95.951	0.057	7.619
15	Basalt	179.586	166.613	14.825	93.111	0.075	7.187

Sampling location of rock sample was: 1, Căzăneşti; 3, Şoimos (F21); 4, Şoimoş (F31); 5, Săvârşin; 6, Şoimoş; 7, Roşia Montană; 8, Certej-Valea Căpitanului; 9, Deva-Dealul Motor; 10, Brad-Crișcior; 11, Săcărâmb; 12, Albini-Haneş; 13, Roşia Poieni-Dealul Jgheabului; 14, Brănişca; 15, Dobra.

3.4. Admissibility Condition of Rocks Based on Provenance

Rocks used for road construction should have homogeneity of their mineralogical and petrographic structure and composition, without any traces of physical or chemical alteration. Pyrite, limonite or soluble salts must not be present in the rock mass; the presence of microcrystalline or amorphous silica is also undesirable, as it can react with alkali from cements [18]. Additionally, it is not recommended to use aggregates from altered, soft, friable, porous and vacuolar rocks, with a granular content exceeding 10% in broken rocks or 5% in chippings. Based on the main physical–mechanical characteristics, the rocks employed for natural rock products are classified into five classes of admissibility, as described in Table 6.

Table 6. Admissibility conditions of rocks for railroad and road construction.

Characteristics		Rock Class [1]					Lab. Method
		A	B	C	D	E	
		Admissibility Conditions					
Apparent porosity at normal pressure, %, max.		1	3	5	8	10	STAS 6200/13
Compression resistance in dry state, MPa, min.		160	140	120	100	80	STAS 6200/5
Abrasion by Los Angeles machine, %, max.		16	18	22	25	30	STAS 730
Shattering caused by compression in dry state, %, min.		70	67	65	60	50	STAS 730
Freezing–thawing resistance:	Gelivity coefficient (μ_{25}), %, max.			3			STAS 730
	Freezing sensitivity (η_{d25}), %, max.			25			

[1] According to SR 667/2001.

Shattering caused by compression in dry state and abrasion by Los Angeles machine are determined on broken rock, sort 40–63. Rocks that do not fulfill the freezing–thawing resistance cannot be used for road construction [18].

4. Assessment Methodology of Rocks

For qualitative assessment of igneous rocks such as granites, rhyolites, diorites, andesites, gabbro, diabases and basalts for use in the form of aggregates, coarse stone or ornamental works, the developed and applied methodology in this case is based on the principle of assessing the conformity and the level of safety considering the requirements of the standards. The aim of conformity assessment was first to verify if the general and specific requirements of rocks used as building materials are in compliance. Conformity analysis is often used in the field of occupational health and safety [19–21]; the proposed method is practically based on definition of conformity encountered in the field of safety, so we established a mathematical model for rock assessment that considers their imposed requirements.

The proposed method consists in achieving a sheet or a set of individual sheets for each rock analyzed; the sheets include the properties according to the general and specific requirements that the rocks must satisfy to be used in construction. Every characteristic of rock was considered a quantitative assessment indicator and noted by granting certain points. The grading system used in this method, namely the assessment of each characteristic, was performed as follows: 5 points, if the requirement described by indicator is totally satisfied; 4 points, if the requirement described by indicator is partly satisfied, maximum 75%; 3 points if the requirement described by indicator is partly satisfied, percentage of 50–75%; 2 points if the requirement described by indicator is partly satisfied, percentage of 25–50%; 1 point if the requirement described by indicator is unsatisfied (less than 25%); and not applicable, if the requirement described by indicator is totally unsatisfied.

Each characteristic regarded as an indicator has an associated weighting coefficient with value of 1, 2, 3, 4 or 5 according to the requirement importance and the class in which the rocks were classified relative to the requirements or conditions of admissibility (Table 6). After assessment of all characteristics (indicators from sheets), the following were determined: conformity level (NC), safety level (NS) and unconformity degree (GC) according to the obtained points (PO) and maximum points (PM) (see Table 7).

Table 7. Proposed methodology for assessing the conformity of rocks and the safety level.

N°	Indicator (Characteristic of Rock)	Rock Type	Rock Class					Points Rated
			A	B	C	D	E	
		Gabbro	Points Rating					
			5	4	3	2	1	
1	Apparent porosity at normal pressure, %	1.516		x				4
2	Compression resistance in dry state, N/mm^2	150.173		x				4
3	Abrasion by Los Angeles machine, %	12.204	x					5
4	Shattering caused by compression in dry state, %	77.326	x					5
5	Gelivity coefficient, %	0.022	x					5
6	Freezing sensitivity, %	16.942		x				4
Total points assigned to the indicators rated 5							A	15
Total points assigned to the indicators rated 4							B	12
Total points assigned to the indicators rated 3							C	0
Total points assigned to the indicators rated 2							D	0
Total points assigned to the indicators rated 1							E	0
Number of applicable indicators with percentage 5							f	3
Number of applicable indicators with percentage 4							g	3
Number of applicable indicators with percentage 3							h	0
Number of applicable indicators with percentage 2							i	0
Number of applicable indicators with percentage 1							j	0
Obtained Points: PO = A + B + C + D + E						PO		27
Maximum Points: PM = 5 (f + g + h + i + j)						PM		30
Conformity Level, % $NC = \frac{PO}{PM} \cdot 100$						**NC**		**90.00**
Obtained Points: PO′ = 5A + 4B + 3C + 2D + E						PO′		123
Maximum Points: PM′ = 5 (5f + 4g + 3h + 2i + j)						PM′		140
Safety Level % $NS = \frac{PO'}{PM'} \cdot 100$						**NS**		**87.8571**
Unconformity Degree %						**GC**		**10.00**

The information obtained by this method refers to the non-conformities according to the conditions imposed by standards, which are not totally satisfied; and the conformity level according to the conditions that the rocks must satisfy and the safety level of rocks used in construction. Depending on NS and NC, the correspondence as against allowable criteria is presented in Tables 8 and 9.

Table 8. Correspondence between safety criterion NS and rocks' admissibility in construction.

Level of Safety (%)	Risk of Use the Rock
91–100 (very high)	Very low risk
81–90 (high)	Low risk
61–80 (medium)	Medium risk
40–60 (low)	High risk
<40 (very low)	Very high risk

Table 9. Classification of rocks according to NC.

Conformity Level, NC (%)	Unconformity Degree (%)
80–100 (very high)	Very low
60–80 (high)	Low
40–60 (medium)	Medium
20–40 (low)	High
<20 (very low)	Very high

5. Results and Discussion

For each type of rock considered in the study, the following have been analyzed: structure, mineralogical–petrographical composition, chemical composition and alkali–aggregates reaction. In addition, laboratory tests to establish the values of physical and mechanical characteristics of the 15 analyzed rock samples were carried out. The experimental data interpretation has lead to the following findings (Tables 1–5):

- Gabbro is homogenous rock from the perspective of structure and mineralogical–petrographical composition, without visible traces of physical and chemical degradation; apparent density of 2.844×10^3 kg/m^3; value of porosity (1.516%) leading to rock classification as "less porous"; a small difference between specific density and apparent density lead to significant compaction of the rock, with an average of 98.483%; water absorption is directly influenced by porosity an average of 0.427% leading to the classification of the rock as "least absorbent"; from the perspective of resistance to breakage due to monoaxial compression, the rock is classified as having "high resistance".
- Diabase is homogenous rock from the perspective of structure and mineralogical–petrographical composition, without visible traces of alteration, despite a system of millimeter fissures colmated with carbonates; volumetric density of 2.7823–2.7876 g/cm^3, with an average of 2.749 g/cm^3, leading to rock classification as "heavy"; 1.267% porosity, leading to rock classification as "least porous"; compaction of 98.732%; water absorption of 0.69%, leading to the classification of the rock as "least absorbent"; from the perspective of resistance to breakage due to monoaxial compression, the rock is classified as being "resistant".
- Granite is homogenous rock from the perspective of structure and mineralogical–petrographical composition, without visible traces of alteration; volumetric density of the three granite types are 2.619–2.625 g/cm^3, leading to rock classification as "heavy"; porosity of 0.58–0.82% leading to rock classification as "less porous"; water absorption from 0.29% to 0.31%, leading to the classification of the rock as "less absorbent"; compaction from 99.17% to 99.41% is regarded as high; mechanical resistance is considered very high.
- Diorite is homogenous rock from the point of view of structure and mineralogical–petrographical composition, without visible traces of alteration; volumetric density of 2.95 g/cm^3, leading to rock classification as "heavy"; porosity of 0.45% leading to rock classification as "less porous"; rock resistance is considered high.
- Rhyolite has various alteration states; following alteration, the volumetric density is relatively low, however the rock is still classified as "heavy"; porosity is high, as a result of the differences between the values of volumetric density and apparent density; water absorption leading to the rock classification as "less absorbent"; porosity influences the compaction, which is 96.89%; mechanical resistance is considered low.
- There are six types of andesites, with the following properties: various alteration states, from incipient to advanced; based on the alteration states, the volumetric density varies accordingly between 2.45–2.67 g/cm^3; alteration affects porosity, which presents different values; under the influence of alteration phenomenon, compaction presents values of 95.62–99.26%; rock moisture varies between 0.64–2.76%; monoaxial compressive strength is 110.19–143.53 MPa.
- There are two types of basalts characterized as follows: no alteration visible, leading to a homogenous structure; volumetric density of 2.69–2.70 g/cm^3; relatively low porosity, 0.89–0.93%; reduced absorption, at 1.23–1.33%; water saturation is 0.62–0.67 leading to rock classification as "moist"; based on their mechanical resistance, these are considered "very hard rocks"; based on deformation property, the rock presents an elastic behavior. For each of the 15 types of rocks analyzed, applying the methodology proposed the conformity level, safety level and unconformity degree were determined. The results are given in Table 10.

Table 10. Summary of results obtained concerning the assessment of analyzed rocks.

Type of Rock	Conformity Level	Obtained Points	Maximum Points	Safety Level	Unconformity Degree
Gabbro (Căzăneşti)	90.00	123	140	87.8571	10.00
Granit (F31)	83.3333	125	150	83.3333	16.6667
Diabaz (Căzăneşti)	93.3333	132	140	94.2857	6.6667
Granit (F21)	96.6667	141	150	94.00	3.3333
Granit (Săvârşin)	96.6667	141	150	94.00	3.3333
Diorite	96.6667	141	150	94.00	3.3333
Rhyolite (Roşia Montană)	56.6667	53	150	35.3333	43.3333
Andesite (Certej)	80.00	100	150	66.6667	20.00
Andesite (Deva)	60.00	58	150	38.6667	40.00
Andesite (Brad)	86.6667	116	150	77.3333	13.3333
Andesite (Săcărâmb)	46.6667	38	150	25.3333	53.3333
Andesite (Haneş)	90.00	125	150	83.3333	10.00
Andesite (Roşia Poieni)	76.6667	95	150	63.3333	23.3333
Basalt (Brănişca)	96.6667	141	150	94.00	3.3333
Basalt (Dobra)	96.6667	141	150	94.00	3.3333

The conditions of admissibility of origin rocks and the values obtained for each type of rock are given in Table 11. Determining the shattering resistance was achieved by compression in dry state, and the abrasion by Los Angeles machine, on broken rock, size class 40–63.

Table 11. Comparison between admissibility conditions and results obtained.

Rock Type	Rock Class	Apparent Porosity at Normal Pressure (max.) (%)	Compression Resistance in Dry State (min.), (N/mm^2)	Abrasion by Los Angeles Machine (max.) (%)	Shattering Caused by Compression in Dry State (min.) (%)	Freezing–Thawing Resistance	
						Gelivity Coefficient (max.) (%)	Freezing Sensitivity (max.) (%)
Gabbro	B	1.516	150.17	12.204	77.326	0.022	16.942
Granite	A	0.588	172.189	11.150	76.888	0.005	8.142
Diabase	B	1.267	161.117	15.815	75.338	0.033	19.882
Granite	A	0.822	212.220	11.820	78.176	0.008	9.154
Granite	A	0.754	168.488	10.161	75.530	0.011	7.237
Diorite	A	0.456	183.860	10.440	78.873	0.015	6.608
Rhyolite	D	3.104	122.997	23.907	64.321	0.110	29.919
Andesite	C	3.716	110.194	12.753	70.521	0.136	17.383
Andesite	C	4.374	131.934	16.877	62.162	0.255	20.234
Andesite	B	0.606	143.538	16.369	72.014	0.127	12.715
Andesite	D	7.320	123.674	20.052	66.261	0.270	23.819
Andesite	A	0.733	142.404	11.138	72.615	0.113	13.997
Andesite	B	2.522	129.632	15.400	69.354	0.130	19.949
Basalt	A	0.891	170.839	13.724	74.061	0.057	7.619
Basalt	A	0.930	179.586	14.825	72.885	0.075	7.187

6. Conclusions

The observations made on rocks collected from South Westerners Apuseni Mountains, Romania (for use in construction) and literature review performed allowed their classification as magmatic rocks associated to the Alpine orogeny. Generally, plutonic rocks presented reduced natural moisture content and low porosity. On prolonged contact with water, until saturation state, they have not lost cohesion.

The proposed method has been designed to facilitate the assessment and verification of the criteria to which the rocks should comply to be used as building materials, given the admissibility conditions imposed by standards.

Applying this evaluation system allows determining the specific parameters of the rock quality requirements, namely the conformity and unconformity degrees, and more specifically the safety level that these rocks can provide if they are used in the construction field, either as aggregates or as construction materials. The proposed method represents an appropriate tool for assessment and verification of the requirements regarding the quality of rocks used in construction. Concerning the proposed classification relating to the correlation between safety criterion and the risk of rock use and their admissibility in construction, the obtained results show that, from the analyzed types of rocks, more than 80% of them fall into the class of rocks with high and very high safety level, which means that the risk of use is very low to low, and, in some cases, even nil, which means high and very high conformity level.

Relative to the imposed conditions of admissibility, provenience rocks were classified into four classes, ranging from A to D, as follows: granite, diorite, basalt and a part of andesite rocks type fall in class A, as high safety degree rocks being very good for constructions; diabases and large part of andesites are included in class B, with a high level of safety and conformity; andesites from Deva–Certej area are included in class C, with a medium level of safety and conformity; and Săcărâmb andesite and Roşia Montană rhyolite have been identified in class D from the viewpoint of conformity and safety level.

Author Contributions: Mihaela Todera° conducted the systematic sampling and measurement campaign and wrote the paper. Roland Iosif Moraru supported the conception of the review, analyzed the data, revised the review results, supported the interpretation of the results. Ciprian Danciu developed and applied the methodology for assessing the conformity of rocks and the safety level, Grigore Buia performed the mineralogical and petrographical characterization of analyzed igneous rocks and Lucian—Ionel Cioca supported the conception of the review and revised the review results and drawn conclusions.

Conflicts of Interest: The authors declare no conflict of interest. Funding sponsors had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, and in the decision to publish the results.

References

1. Renard, M.; Lagabrielle, Y.; Martin, E.; Rafelis, M. *Eléments de Géologie*, 15th ed.; Dunod Publishing House: Paris, France, 2015.
2. Toderaş, M. *Tests on Materials*; Focus Publishing House: Petroşani, Romania, 2008; p. 440, ISBN 978-973-677-141-5. (In Romanian)
3. Danciu, C. *Geomechanics of Magmatites from South Apuseni*; Universitas Publishing House: Petroşani, Romania, 2010. (In Romanian)
4. Tiess, G.; Chalkiopoulou, F. *Sustainable Management of Aggregates Resources and Sustainable Procurement Combined at Regional/National and Transnational Level*; Technical University of Crete: Chania, Greece, 2011. (In Romanian)
5. Beauchamp, J. *Les Roches Propriétés et Utilisation*; Université de Picardie Jules Verne: Amiens, France, 2003.
6. Ivascu, L.; Cioca, L.I. Opportunity Risk: Integrated Approach to Risk Management for Creating Enterprise Opportunities. *Adv. Educ. Res.* **2014**, *49*, 77–80.
7. Ielenicz, M.; Patru, I.; Ghincea, M. *Romania's Sub-Carpathians*; Universitară Publishing House: Bucureşti, Romania, 2003. (In Romanian)
8. Irimuş, I.A. *Physical Geography of Romania I*; Casa Cărţii de Ştiinţă Publishing House: Cluj-Napoca, Romania, 2003. (In Romanian)
9. Velcea, V.; Savu, A. *Geografia Carpaţilor şi a Subcarpaţilor Româneşti*; Didactică şi Pedagogică Publishing House: Bucureşti, Romania, 1982. (In Romanian)
10. Mutihac, V. *Geologic Structure of Romanian Territory*; Tehnică Publishing House: Bucureşti, Romania, 1990. (In Romanian)
11. Cioca, L.-I.; Moraru, R.I.; Babut, G.B. *A Framework for Organisational Characteristic Assessment and Their Influences on Safety and Health at Work*; Book Series: Knowledge Based Organization International Conference; Land Forces Academy: Sibiu, Romania, 2009; Volume 2, pp. 43–48.
12. Săndulescu, M. *Geotectonics of Romania*; Tehnică Publishing House: Bucureşti, Romania, 1984. (In Romanian)
13. Boillot, G.; Huchon, P.; Lagabrielle, Y. *Introduction à La Géologie: La Dynamique de la Lithosphere*, 4th ed.; Editura Dunod: Paris, France, 2008.
14. Pomerol, C.; Renard, M.; Lagabrielle, Y. *Eléments de Géologie*; Dunod Publishing House: Paris, France, 2000.
15. Har, N. *Alpine Basaltic Andesites in Apuseni Mountains*; Casa Cărţii de Ştiinţă Publishing House: Cluj-Napoca, Romania, 2001. (In Romanian)

16. STAS 5440-70. In *Testing the Alcalii–Aggregate Reaction*; Romanian Standard: Bucharest, Romania, 1970. (In Romanian)
17. Brooks, R.H.; Corey, C.T. *Hydraulics Properties of Porous Media*; Colorado State University: Fort Collins, CO, USA, 1964.
18. SR 667/2001. In *Admissibility Conditions*; Romanian Standard: Bucharest, Romania, 2001. (In Romanian)
19. Băbuţ, G.B.; Moraru, R.I. *Occupational Health and Safety Auditing: Practical Application and Projects Guide*; Universitas Publishing House: Petroşani, Romania, 2014. (In Romanian)
20. Cioca, L.-I.; Ivascu, L. Risk Indicators and Road Accident Analysis for the Period 2012–2016. *Sustainability* **2017**, *9*, 1530. [CrossRef]
21. Ionica, A.; Leba, M. Human action quality evaluation based on fuzzy logic with application in underground coal mining. *Work* **2015**, *51*, 611–620. [CrossRef] [PubMed]