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SPECTRAL REFLECTANCE OF MAGMATIC AND METAMORPHIC ROCKS IN THE VISIBLE AND NEAR INFRARED RANGES

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ABSRACT
The investigation of reflected by natural formations solar radiation within the visible and near infrared ranges (NIR) of the electromagnetic spectrum and occurring changes in its spectral distribution under the action of various environmental factors is a well established technique for aerospace and ground remote sensing, which finds broad areas of application in geology, applied geophysics, ecology and others. In this report we present results from investigations of the spectral reflectance characteristics (SRC) of rock formations (magmatic and metamorphic rocks) with different genesis and chemical composition and contrasting mineral constituents in the spectral range 480 ÷ 810 *nm*. The spectral data were obtained using the multichannel spectrometric system 'Spectrum 256' developed in STIL-B.A.S., which has been operated for many years onboard the manned orbital space station 'MIR'. The studies of SRC were carried out under laboratory conditions on samples of ultramaphic (pyroxenite) and basic (gabbro) magmatic rocks, granitoids (granites, alkaline type granites) as well as regional metamorphic rocks – serpentinite, gneiss, garnet bearing amphibolite and kyanite schist. On the basis of the spectral data and implemented statistical methods the texture of the rock types was analysed and for some of them there were identified spectral subclass objects belonging to a common spectral class in accordance with their mineral composition.

INTRODUCTION

The spectrometric measurements of reflected by natural formations solar radiation in the visible and near infrared (NIR) ranges of the electromagnetic spectrum provide an express and reliable information for the objectives of cosmic and ground remote sensing and for various areas of science (geology, applied geology, ecology, etc.). At a high spectral and spatial resolution featured by the apparatus in use, the spectral data provide for the possibility to recognise main classes of objects, to identify their diversity and states, and to establish the presence of subclasses of objects within the frames of a single spectral class.

One of the applications of data from remote sensing of natural objects is the recognition of geological structures and formations. Already with coming into light of the aerocosmic photos and emerging methods for their usage, the interrelated decoding indications of the geological objects were separated into direct, involving the radiation of the objects themselves, and indirect, related to corresponding salient features of landscape. This was done on the basis of the geological objectives formulated (Trifonov and Schulz, 1986; Moralev and Cheschihina, 1989; Wood and Laserre, 1990; Salisbury *et al*, 1992). The division of the decoding indications into optical and geometrical is of basic importance, because of differences in the methods applied for their use for recognition of geological formations. The optical spectral signs are most informative and characterise the brightness of radiation from the surface of the geological formations in the electromagnetic spectrum. The geometrical signs characterise the structure and the texture of the spatial distribution of signals with different brightness and in the recognition of geological formations it is of no importance if they manifest themselves as direct or indirect.

Depending upon the objectives to be achieved by the particular experiments being carried out, there is a variety of the ground (laboratory and field) remote sensing investigations but two main groups could be specified. A part of them is oriented to ascertain qualitative relationships between the parameters of the natural formations and phenomena on one side and the information provided for the latter by the aerospace remote sensing on the other side. Another part is aimed to reveal the mutual relation between the different components and states of the objects and phenomena, and the factors which exert an influence upon them. The laboratory spectrometric measurements in the visible and NIR spectral ranges show that the spectral characteristics of the elementary natural species are strictly individual (Mishev *et al*., 1989; Salisbury and D'Aria, 1994; Mishev *et al*. 1999). They can easily be subjected to treatment and identified which determines their leading place in the general strategy for recognition of natural formations based on data from aerospace measurements. Because of this, the knowledge of SRC of particular characteristic objects located on the Earth's surface (soils, rocks, water, forest and agricultural vegetation, etc.) is of primary importance for the correct and accurate interpretation of the data from remote sensing.

The aim of the present work is to report on results from laboratory investigations of spectral reflectance characteristics of different rock formations in the visible and near infrared ranges of the electromagnetic spectrum and their applicability for recognition of main types of rocks and their variety by texture and mineral composition.

MATERIALS AND METHODS

Petrographic characteristic of the rock specimens under investigation

The objects under study in the present report are representative specimens of magmatic and metamorphic rocks. The spectrometric measurements were carried out on five basic types of magmatic and four types of metamorphic rocks with different genesis and chemical composition and contrasting mineral constituents.

Magmatic rocks: The rock specimens of magmatic rocks belonged to five main classification groups: ultramaphic rocks (pyroxenite); basic rocks (gabbro); mediumbasic rocks (diorite); acidic rocks (granite) and alkaline rocks (alkaline granite-diorite).

Pyroxenite is a coarse-grained rock of massive texture and coloured in dark green to black. It was built mainly of pyroxene (up to 90%). Small portions in the rock were single grains of olivine and ore minerals.

Gabbro (Figure 1) is a medium-grained rock of massive texture, dark greyish-green of colour. The basic rock forming minerals were plagioclase and amphibole in a ratio of 1 : 2, which determines macroscopically the mesocratic character of the rock and its classification as amphibolic gabbro.

Figure 1. The measured surface of gabbro

Diorite is with a medium up to fine-grained structure, dark greyish-green coloured, with a massive, locally taxite texture. Single epidote veins cut the specimen. Its mineral composition is of primary rock forming minerals – medium plagioclase and amphibole (up to 90%), and minority minerals – single grains, mainly of pyroxene, biotite and quartz. The colour index (M) of the rock was of about 40 ÷ 45 %.

Granite is an unevenly grained (fine to medium-grained), light grey of colour, with a massive texture and a mineral composition of primary rock forming minerals – acidic plagioclase, K - feldspar, quartz and biotite, and minority minerals - amphibole. Because of the unevenly grained character of the granite the spectrometric measurements were performed on two specimens poor in the femic component with an index M up to 7%, and both cases could be specified as leucogranites. The first specimen was with a fine-grained structure, while the second one featured a more coarse-grained up to pegmatite-like texture.

Alkaline granodiorite – dark-coloured reddish-rose rock with a massive texture of locally spotted character. Mineral composition: K-feldspar (main), acidic plagioclase, quartz, biotite, amphibole.

Matemorphic rocks: Specimens of regional metamorphic rocks were studied, as follows: serpentinite, amphibolite, gneiss, and kyanite schist.

Serpentinite (metaultramaphit) – a greyish-green of colour dense rock built of minerals from the serpentinite group, chlorite, talc, ore minerals, and sporadic relicts of olivine and pyroxen. The surface upon which the measurements were taken was textured mainly of talc-chlorite-serpentinite products.

Amphibolite (metabasit) – dark green, fine-grained, with a massive up to locally unclear stripe texture, and mineral composition: amphibole (60 ÷ 65%), garnet (up to 5%), acidic plagioclase (20%), quartz, epidote, and titanate. Macroscopically, the porphyryblastic character of the garnet was clearly visible.

Gneiss (metagranite) – biotite gneiss with an augen-layered texture and mineral composition: plagioclase, quartz (primary rock forming minerals), and muscovite and K-feldspar (minority minerals). The rock is with clear signs of tectonic treatment and features local indications of blastomylonitisation.

Kyanite schist (metapellite) – fine-grained rose-brownish of colour schistose rock with a mineral composition of kyanite (modified into sericite-muscovite), biotite, granite, and quartz. The rock exhibits a strong mineral linearity and a porphyryblastic texture by the mineral kyanite. Two specimens were measured with surfaces of different texture. The surface of the first one (Figure 2) is schistose and with presence of kyanitic porphyryblasts, whereas the surface of the other specimen is pronouncedly cracked and with lacking kyanite porphyryblasts.

Spectrometric measurements of the rock specimens – experimental set up and methods

The SRC of the rock specimens studied were measured using the multichannel spectrometric system ‘Spectrum 256’. This system was developed by scientists and specialists of STIL – BAS in connection with the implementation of the scientific program of the second Bulgarian cosmonaut, and for more than 12 years was operated successfully onboard the manned orbital space station ‘MIR’ (Mishev and Kovachev, 1988; Mishev *et al*, 1990). ‘Spectrum 256’ consists of two blocks - a spectrometric block and a block for data registration. The spectrometric block contains a built-in photographic camera, which is optically linked to it and is operating in an automatic mode. By means of this photo camera it is achieved the link between the spectral data recorded and the objects under study.

For the measurements under laboratory conditions it was used a special experimental set up. Besides the multichannel spectrometric system it incorporates an optical bench, an optical table, a standard white screen, a movable platform for fixing and adjustment of the specimens, and a light source of high stability (three halogen lamps each one energised by an individual regulated power supply). The white screen is a disk with a diameter of 32 *cm*, covered with barium sulphate, and featuring linear spectral characteristics in the visible and NIR spectral ranges. The spectrometric system MS is fixed with horizontally aligned optical axis on the optical table which allows for fine and smooth displacement about X and Y axes in order to realise the scanning of the studied objects. The white screen and the investigated surface of the rock specimens are adjusted perpendicular to the optical axis of the objective of 'Spectrum 256'.

Figure 2. The measured surface of kyanite schist (Specimen 1)

The spectrometric measurements of rock specimens were carried out with 'Spectrum 256' used in an operational mode with 128 spectral channels, each of 2.6 *nm* halfwidth at a spatial resolution of 2 mm^2. Each second the system is recording 40 spectra in the spectral range 480 ÷ 810 *nm*.

The measuring method includes: determination of the optimum conditions for illumination of the specimen studied, so that the recorded reflected radiation to possess a sufficiently high dynamic range in the visible and NIR spectral ranges; determination of the optimum area of the specimens for carrying out the spectrometric measurements; determination of the minimum number of areas (pixels), which is necessary to be spectrally measured, so that the SRCs obtained to yield with a sufficiently high reliability the averaged SRC of the object, considered as being a spectral class

Based on preliminary experiments we have carried out the measurements of the rock specimens under study in 25-30 points (pixels) on average in dependence on the particular texture, chosen adjacent in the horizontal direction. For every rock specimen there are recorded the dark current; the reflected radiation by the investigated area within a given number of pixels; the reflected radiation by the diffuse white screen, and the spectral reflectivity coefficients are determined. For each spectrally measured area there are recorded by 60 spectra on average, and for the white screen and the dark current - by 120.

Every natural object reflects in a specific way the incident upon it radiation, and this determines to be informative the radiance in absolute units or the spectral reflectivity coefficient in relative units. These quantities are multiple-factor photometric functions, being dependent of physical and chemical properties and biological properties of the objects.

The spectral reflectivity coefficient r (λ_i, θ_o, φ_o, θ, φ) characterises the structure of the reflected by the natural formation radiation by both wavelength and conditions of illumination. Under conditions of illumination (θ_o, φ_o), in the direction of the recording system (θ, φ) and range of wavelengths λ_i, $\lambda_i+\Delta\lambda$, the spectral reflectivity coefficient is determined by

$$r(\lambda_i, \theta_o, \varphi_o, \theta, \varphi) = L(\lambda_i, \theta, \varphi) / L_o(\lambda_i, \theta_o, \varphi_o), \qquad (1)$$

where $L(\lambda_i, \theta, \varphi)$ is the radiance of a given object in direction (θ, φ) at wavelength λ_i, $L_o(\lambda_I, \theta_o, \varphi_o)$ is the radiance of an orthotropic fully reflecting surface under identical conditions of illumination.

For determination of the spectral reflectivity coefficients the spectral data recorded by the system 'Spectrum 256' are subjected to a preliminary treatment. It includes averaging of the data of one area spectrally measured, accounting for the dark current, averaging of the data of the standard screen, averaging of the data of all areas being spectrally measured for each rock specimen.

RESULTS AND DISCUSSION

Figure 3 shows the averaged SRCs obtained for the investigated surfaces of the 11 rock specimens. Three clearly displayed groups of SRC can be separated. The most numerous group brings together magmatic rocks with ultrabasic (pyroxenite), basic (gabbro) and medium basic (diorite) constitution and one basic metamorphic rock (amphibolite). The lowest values of the spectral reflection coefficient are associated with the specimens of amphibolite (curve 10) and pyroxenite (curve 11). These rocks are the darkest of colour and feature a massive texture. They are built of various femic minerals, which is manifested by the differences in the spectral reflection coefficient values in the spectral range 480 ÷ 650 *nm*. This conclusion is confirmed also by the result from the correlation analysis of the averaged SRC of these two rock specimens. Figure 4 illustrates the low degree of correlation in a part of the spectral range.

The averaged SRC curves of the serpentinite (curve 7) and diorite (curve 8) exhibit a roughly similar course with a difference in the value of SRC of about 0.07 relative units in the whole spectral range studied. The averaged SRC (curve 6) of the measured area from the surface of gabbro shown in Figure 1 has a rather smooth behaviour and for that group of SRC reaches the highest values. A special note deserves the behaviour of SRC of the alkaline granodiorite (curve 9). It is of particular interest because the averaged spectral reflection coefficient values of this group of spectral characteristics is featuring the highest dynamic range, 0.15 ÷ 0.23 relative units.

The second group of SRC comprises the granites (curves 4 and 5) and gneiss (curve 3), the latter being a metamorphosed granite. The difference in the reflection power of the surface of the two granites studied is related with their different texture (coarse or fine-grained) and the different proportion of femic and ore minerals.

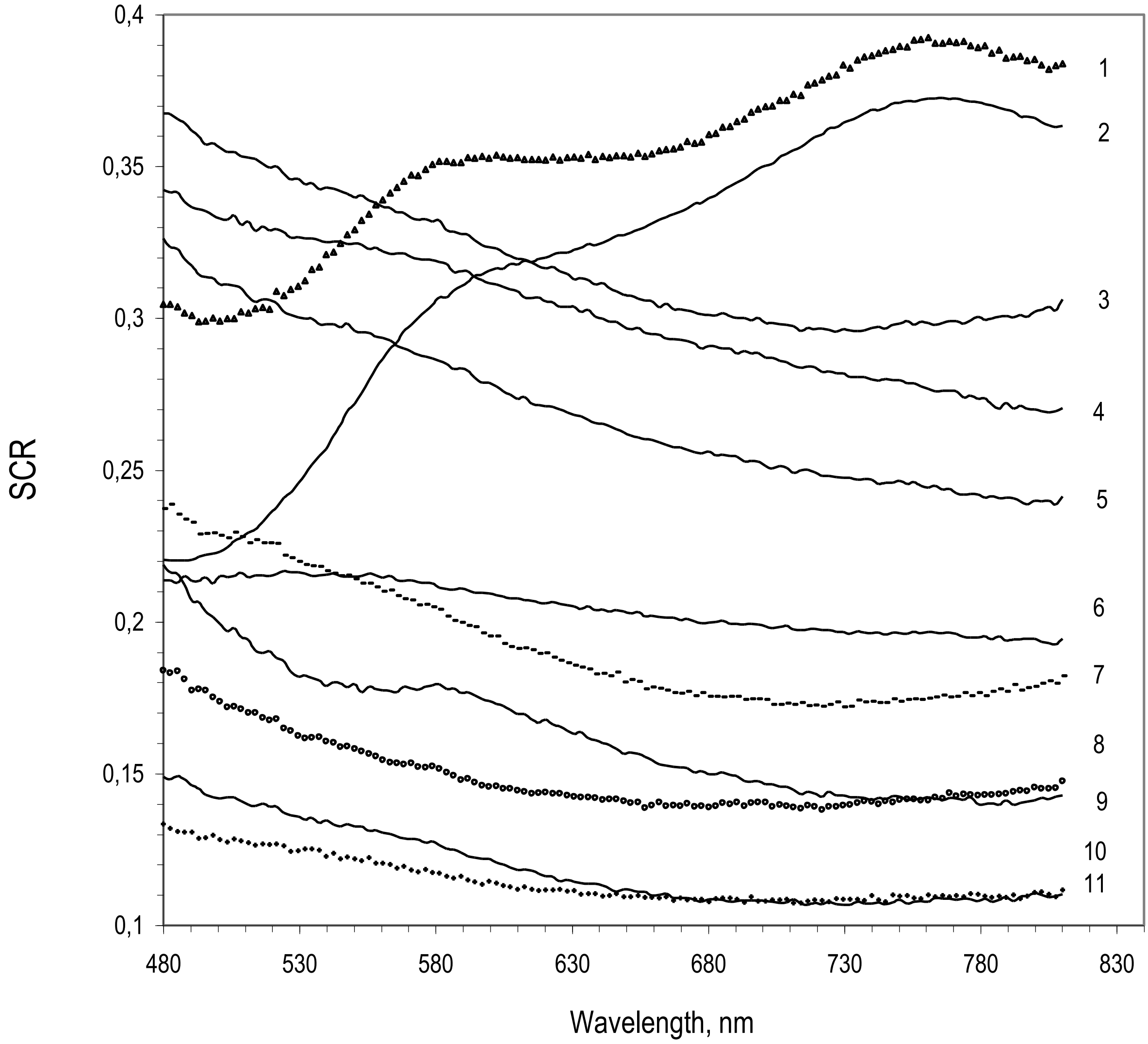

Figure 3. Average SRC of the rock specimens: 1) kyanite schist (specimen 1); 2) kyanite schist (specimen 2); 3) gneiss; 4) granite (specimen1); 5) granite (specimen2); 6) gabbro; 7) serpentinite; 8) diorite; 9) alkaline grnodiorite; 10) amphibolite; 11) pyroxenite

The correlation analysis of the averaged SRCs of the two specimens of granite confirmed the similarity of their constitution, irrespectively of the uneven grain size. This is illustrated in Figure 7.

In the third group of SRC fall the kyanite schist's (curves 1, and 2). The two averaged SRCs have a roughly identical behaviour. The surface of one of the specimens was schistose with presence of large greyish-blue crystals of kyanite and its reflective power is higher (curve 1) than that (curve 2) of the surface of the other representative of this type of rocks where crystals of kyanite were absent. Figure 5 shows the averaged SRC of 27 studied areas, measured on the cracked surface of the secon specimen. The spectral reflectance characteristics form a single spectral class. Figure 6 displays the averaged SRC of 25 areas of sample 1 of the kyanite schist. The spectral characteristics are clearly differentiated into two spectral subclasses. Their presence reflects the differences in the texture of the surfaces due to the kyanite porphiryblasts and the fine-grained quartz-bioite body, respectively.

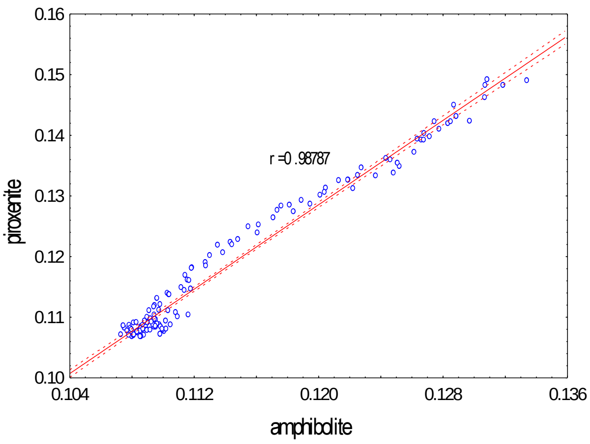

Figure 4. Correlation analysis of SRC of amphibolite and pyroxenite

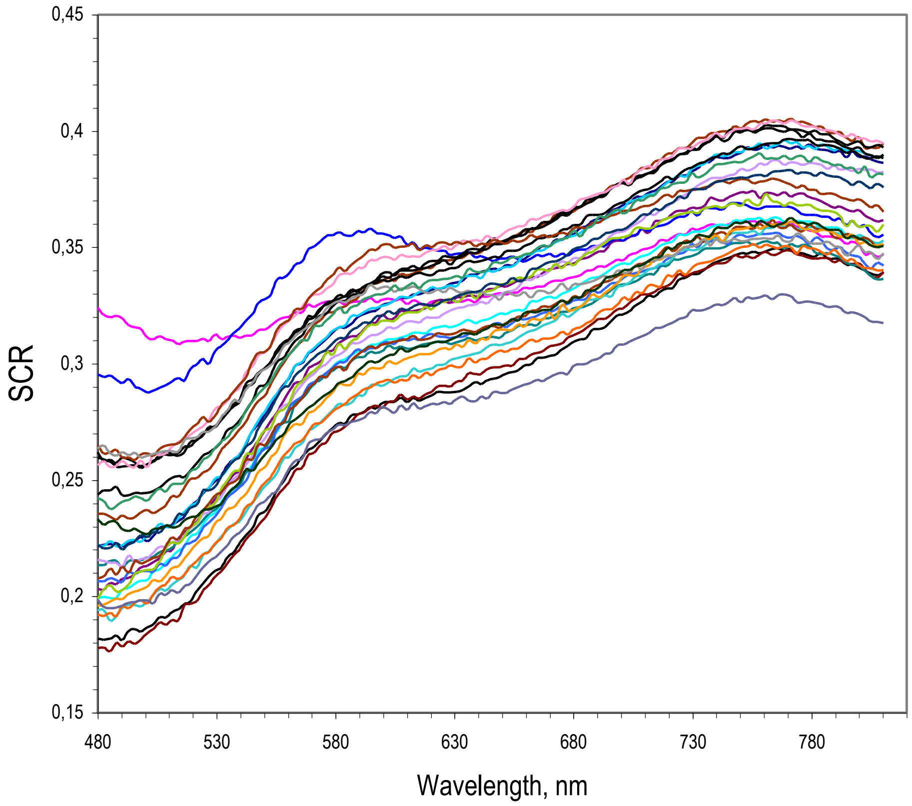

Figure 5. Averaged SRC of the measured areas of the kyanite schist (specimen 2)

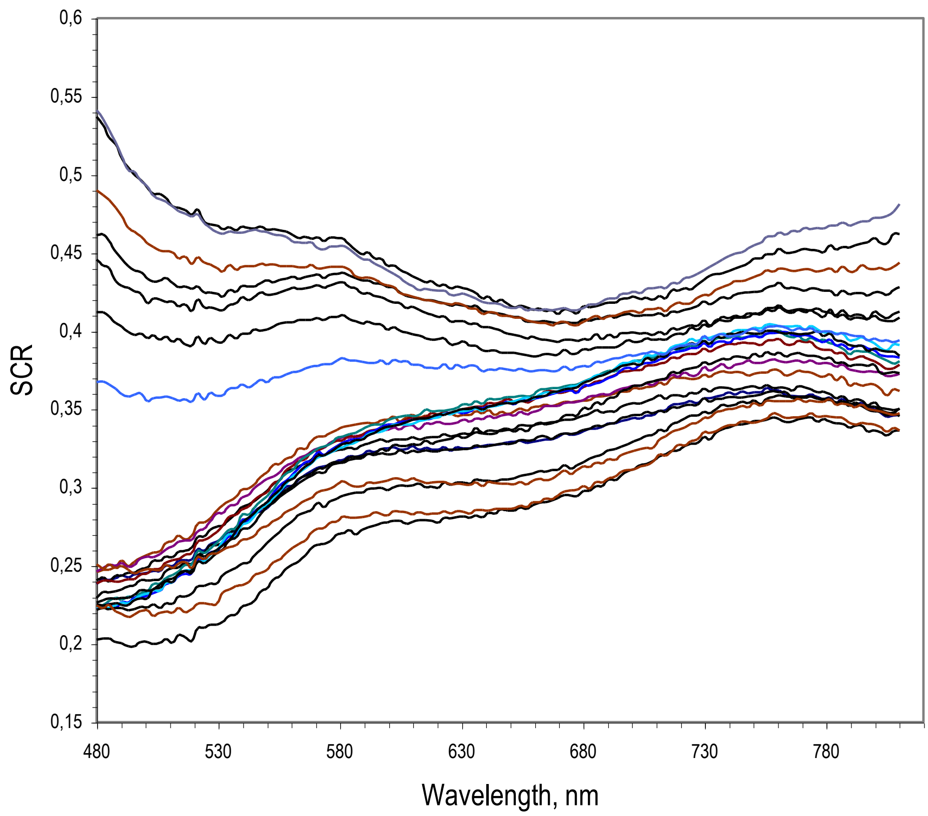

Figure 6. Averaged SRC of the measured areas of the kyanite schist (specimen 1)

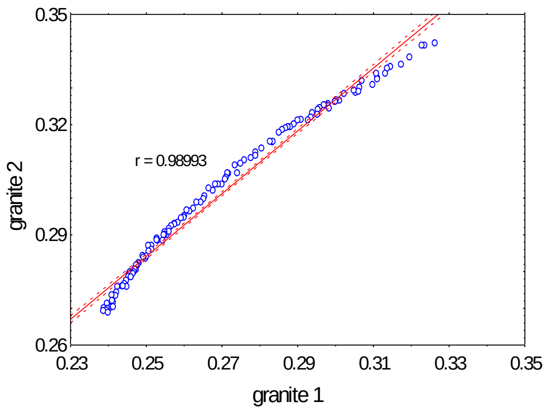

Figure 7. Correlation analysis of SRC of two granite specimens

Figure 8 presents the averaged SRCs of the two subclasses. The results from the cluster analysis of the SRC of the two subclasses are illustrated in Figure 9, where the case of carrying out such analysis for the wavelengths 500 *nm* and 779 *nm* is given as an example.

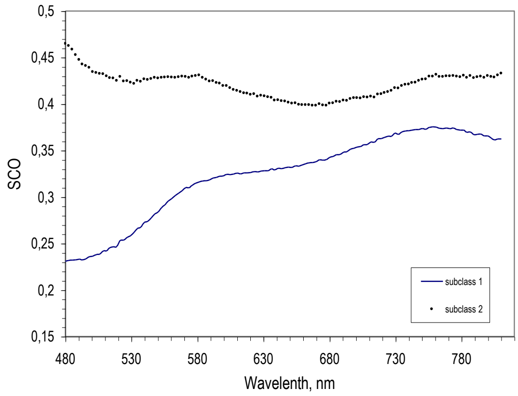

Figure 8. Averaged SRC of the two subclasses of specimen 1 of the kyanite schist

Concluding, we shall note that the spectral reflectance characteristics of studied rock formations give information for their texture features and contribute to the ground remote sensing database necessary for aerospace geological research by spectral indications.

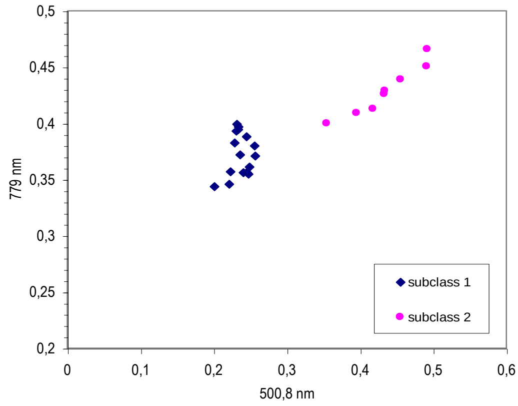

Figure 9. Cluster analysis of the two subclasses of specimen 1of the kyanite schist

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