TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
ENVIRONMENT ENGINEERING | ŚRODOWISKO

1-Ś/2015

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AN ASSESSMENT OF REMOTE SENSING FOR THE CLASSIFICATION OF SEDIMENTARY ROCKS – A CASE STUDY OF TAURON GROUP QUARRY, POLAND

OCENA POTENCJAŁU TECHNIK TELEDETEKCYJNYCH DO KLASYFIKACJI SKAŁ OSADOWYCH NA PRZYKŁADZIE KAMIENIOŁOMU GRUPY TAURON S.A.

A b s t r a c t

This paper presents the results of an analysis of sedimentary rocks in Tauron Group quarry. The main purpose of this study was to assess the possibilities of using remote sensing techniques for the categorisation of rock types. The application of remote sensing systems for the categorisation of rock types allows the evaluation of the volume and mineral composition of the material extracted from the quarry. Rock samples collected from the Tauron Group quarry were classified according to their mineral composition. Spectrometric analyses were also carried out in the spectral range of 350–2500 nm wavelength. Spectral properties and mineral composition characteristics of the samples allow for the evaluation of the potential of using remotely-sensed data for rock classification. Optimal spectral bands for highest separability between individual rock types in the quarry were identified based on the study.

Keywords: *remote sensing*, *classification*, *spectral curves*

S t r e s z c z e n i e

W niniejszym artykule przedstawiono badania skał w kamieniołomie należącym do grupy Tauron S.A. Badania miały na celu określenie potencjału technik teledetekcyjnych do zdalnej klasyfikacji rodzaju skał, co pozwoliłoby na geodezyjne określenie nie tylko ilości, ale też składu wydobytego materiału W kamieniołomie pobrano próbki skał, które sklasyfikowano pod względem składu mineralnego oraz poddano badaniom spektrometrycznym w zakresie 500–2500 nm. Zarejestrowane dla próbek krzywe spektralne wraz z charakterystyką składu mineralnego pozwalają na określenie możliwości zdalnej klasyfikacji utworów skalnych. Wytypowano optymalne pasma spektralne, w których występuje najlepsza rozróżnialność poszczególnych skał w kamieniołomie.

Słowa kluczowe: *teledetekcja*, *klasyfikacja*, *krzywe spektralne*

DOI: 10.4467/2353737XCT.15.192.4397

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1. Introduction

The Czatkowice Limestone Quarry exploits deposits of lower carboniferous limestone. Carboniferous limestone is made of calcium carbonate with traces of heavy metals. Limestone from Czatkowice Quarry has a wide variety of applications in the iron and steel industry (as flux to assist melting), the energy industry, the construction industry, the aggregate industry, and agriculture and glass manufacturing. Czatkowice Quarry is one of the biggest manufacturers of aggregates and the biggest supplier of limestone-based sorbents for the energy industry (used in the flue-gas desulphurisation process). Limestone deposits at the Czatkowice Quarry are extracted using blasting techniques. Excavated material is then loaded on to trucks and transported to the processing facility where limestone is crushed and screened to produce the required products and by-products.

The volume and quality of output is crucial in planning open pit mining operations. At present, the output of a quarry is measured by the number of loads of raw quarried material hauled by trucks and the quality is measured by the laboratory testing of rock samples. Laboratory testing is expensive and requires a high number of samples to be tested due to geological variations in the outcrop. The initial classification at the preliminary fragmentation stage could potentially improve production processes, ensure better use of resources, and minimise the costs of laboratory sample testing. Remote observation of the quarry face is considered to be the preferred technique. This paper presents an analysis of the potential use of remote sensing methods for limestone classification. Spectral reflectance in the visible and infrared range was measured for the selected rock formation. Spectral curves were analysed in order to assess the classification potential of the rock formations using VIS (visible range), NIR (near-infrared range) and SWIR (short wave infrared range) images.

2. Aim of the Study

Conventionally, an assessment of the geology of the quarry wall is carried out based on expensive borehole surveys and laboratory testing. The aim of this research is to assess the potential for using imaging spectrometry for the purpose of limestone rock classification in Czatkowice Quarry. The application of multispectral imaging techniques at the early stage of rock type assessment of a quarry wall earmarked for exploitation is likely to reduce the initial costs of exploitation.

Remote sensing techniques have long been used in geological studies [1–3]. Satellite or airborne remote sensing imaging techniques are most commonly used. The application of remote sensing techniques for exploring rock deposits for quarry operations depends on using ground-based equipment due to:

- geometric parameters of the quarry wall, which is often near-vertical and inaccessible for imaging spectrometry from airborne or satellite platforms (Fig. 1);
- the low resolution of satellite or airborne imagery makes it unsuitable for this type of application.

Ground-based instruments for image registration include cameras and scanners operating in the VIS (visible) and NIR (near-infrared) spectral range. Due to equipment availability, this research was narrowed to ground-based instruments for image registration in the visible and infrared spectral range (wavelength range 400–2500 nm).

Remote sensing techniques utilising the visible and infrared spectral range allow only for surface observation and fail when the surface is contaminated. However, observation

Fig. 1. Czatkowice Quarry Mining Wall

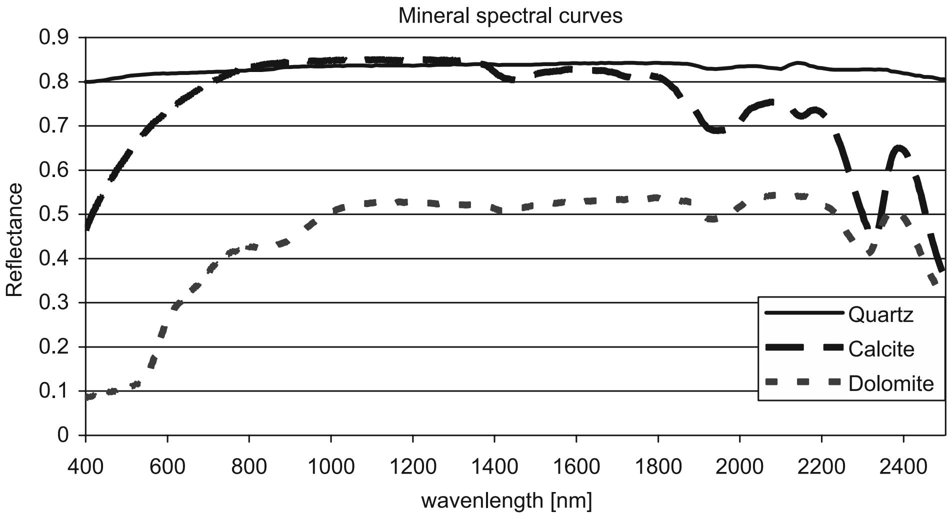

Fig. 2. Mineral Spectral Curves [4] from http://speclib.jpl.nasa.gov/ Quartz – particle size 125–500 micrometers sample TS-1A, Origin: USA Calcite – particle size 125–500 micrometers sample C-5A, Origin: Italy Dolomite – particle size 125–500 micrometers sample C-3A, Origin: USA

of the quarry wall during exploitation is justified. The short duration between blasting operations prevent the crust becoming weathered or soil and vegetation coverage building up (Fig. 1).

The effective application of multispectral imaging techniques in rock classification is possible through the assessment of mineral spectral curves. The different shapes of spectral curves is an essential characteristic for the application of remote sensing techniques. Figure 2 shows mineral spectral curves for calcite, dolomite and quartz (the most common minerals at the Czatkowice Quarry), compiled based on Spectral Library ASTER [4]. This example demonstrates that the highest spectral contrast between these mineral occurs at 400–600 nm and 1900–2200 nm wavelength ranges. However, the spectral curves were produced under laboratory conditions, for pure minerals of uniform grain size (125–500 μm). The Czatkowice Quarry rock formations consist of various minerals of wide-ranging grain sizes; therefore, their specific spectral curves must be analysed to assess their classification potential.

3. Geological characteristics of Czatkowice Quarry

The Czatkowice Quarry is located on the western slope of Krzeszowka Valley, in Czatkowice, approximately 20 km west of Cracow, in the south-western part of the Cracow-Czestochowa Upland. The geological characteristics of the study area are determined by its setting in the Krzeszowka Fault and Debnik Anticline, in the southern part of the Cracow-Silesia Monocline. The outcrops of the Czatkowice Quarry are marine sediments formed in the lower carboniferous era (Tournasian and Visean) represented by limestones and dolomites. In the sub-surface, particularly in the south section of the quarry deposits, sandy-clay sediments of the lower and middle Jurassic eras are prevalent, with Quaternary clay sediment cover [5, 6]. Tectonic analysis of the deposits reveals that the layers are largely inclining towards the west, at an approximately 60–70 degree angle, whereas in the east, the layers are inclined at an approximately 40–45 degree angle.

Based on the chemical composition, carbonate rocks from the Czatkowice Quarry were classified into four main groups (Table 1): limestone, dolomitic limestone, dolomite and silica limestone. The limestone group originates from Visean sediments and represent the main deposits extracted at the Czatkowice Quarry. Tournasian sediments formed silica limestone in the upper section with dolomitic limestone and dolomite prevalent in the lower layer of the quarry.

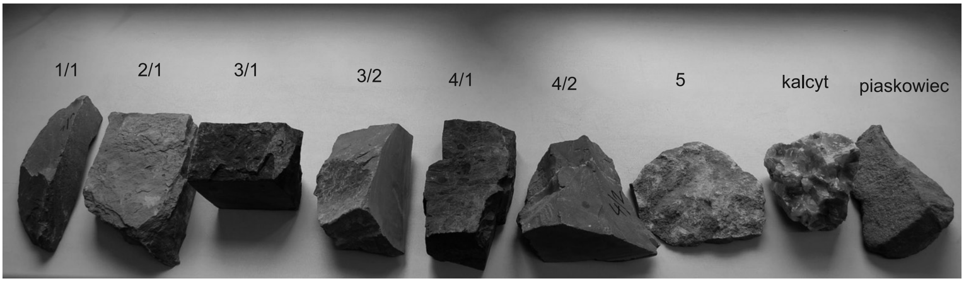

Fig. 3. Rock samples from the Czatkowice Quarry

From many rock samples collected from the quarry, the nine most representative of the Czatkowice Quarry were selected for further analysis (Fig. 3).

Table 1

Incomplete chemical characteristics of selected carbonate rocks found in Czatkowice deposits [6]

Element	Types of carbonate rock and element concentration [wt. %]			
	limestone	dolomitic limestone	dolomite	silica limestone
SiO_2	0.10–3.89 (1.16)	0.14–13.47 (3.59)	1.06–3.06 (1.89)	19.12–33.71 (23.74)
Al2O3	0.02–1.74 (0.26)	0.0–1.16 (0.24)	0.17–0.45 (0.36)	3.42–4.90 (4.06)
Fe2O3	0.08–5.14 (0.27)	0.09–1.91 (0.46)	0.74–1.06 (0.90)	1.64–2.53 (2.09)
CaO	47.6-–56.00 (53.77)	22.54–54.04 (48.48)	34.30–39.44 (35.97)	28.05–37.68 (35.19)
MgO	0.10–1.93 (0.69)	2.02–10.48 (4.06)	13.41–15.96 (14.99)	1.62–2.60 (1.96)

Complete characteristics of the samples studied:

- Sample 1/1 – limestone, dolomitic, microcrystalline, dark beige, slightly stromatolitic texture. This sample represents rock formations of Tournaisian age, which are the oldest within Czatkowice Quarry;
- Sample 2/1 – limestone, microcrystalline, pink dark beige, stromatolitic texture, rock formations of Tournaisian age;
- Sample 3/1 and 4/1 – limestone, microcrystalline, dark grey to black (bituminous limestone), stromatolitic texture, rock formations of Tournaisian age;
- Sample 3/2 – limestone, microcrystalline, light to dark beige, contains some fragments of silica. Contains calcite crystals 1 mm in diameter and some calcite veinlets 2–3 mm wide, latest rock formations of Tournaisian age;
- Sample 4/2 – limestone, microcrystalline, beige. Contains calcite crystals and veinlets partings, approximately 2–4 mm wide. Forms the main deposits extracted at the Czatkowice Quarry, rock formations of Visean age;
- Sample 5 – limestone, microcrystalline, rock formations of Visean age (representing the same rocks as Sample 4/2) dusky-red, creamy-brown. Note – the study was carried out on a heavily weathered surface;
- Sample *K* – calcite, cream, yellowish-brown. The calcite crystals are up to 10 cm high and 2–3 cm in diameter. Calcite is a mineral formed within Visean limestone as a result of intense karstification, creating approximately 10 cm wide, coarse-grained calcite veins;
- Sample *P* – quartz-sandstone, clay cemented, heavily weathered, reddish, creamy-brown. Part of the late and middle Jurassic sandstone deposits.

4. Spectrometric Analysis

Collected and classified samples were analysed using spectrometer FieldSpec 3, measuring 0.35–2.50 μm wavelength range. Spectrometric observations were carried out under laboratory conditions. Several of the samples taken at the quarry were weathered; therefore, the study was carried out on natural fractions as well as on cut, unpolished surfaces. Figure 4 shows spectral curves for dry samples, studied at the natural

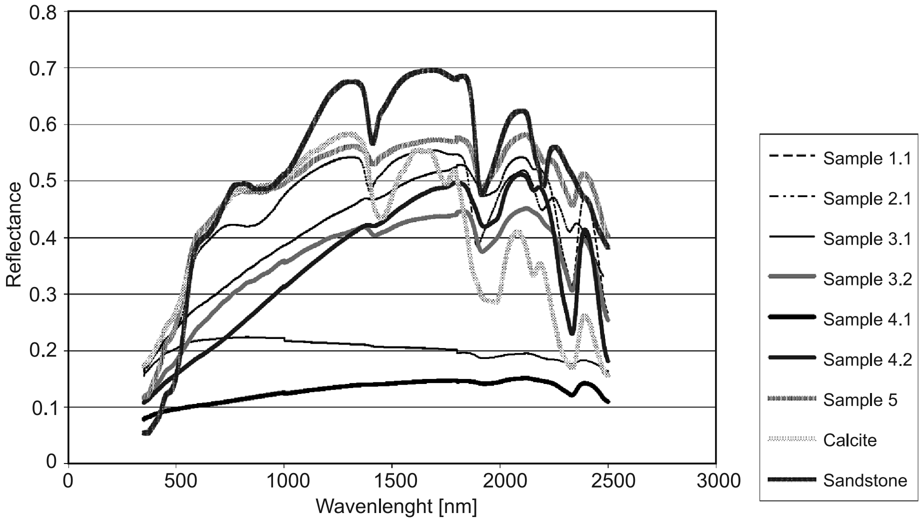

Fig. 4. Spectral characteristics taken for natural surface samples

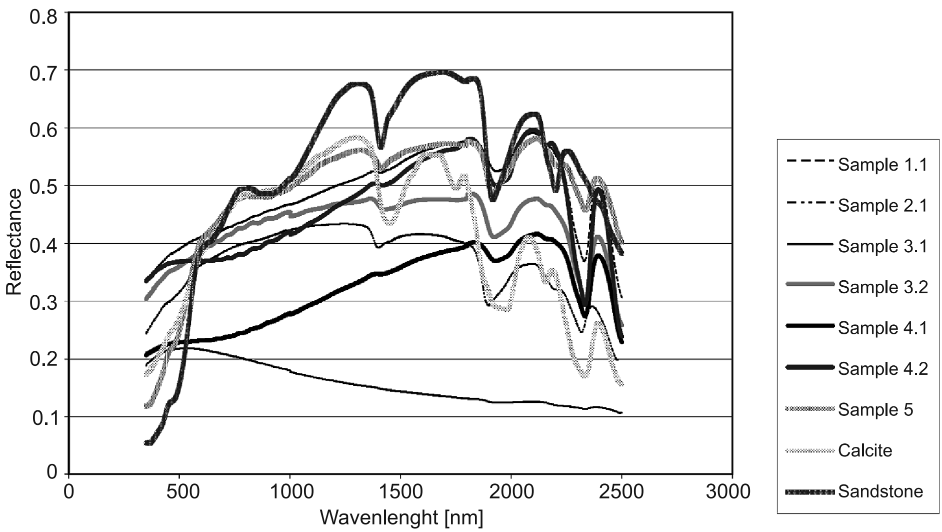

Fig. 5. Spectral characteristics taken for cut, unpolished surface samples

fraction. The curves show mean values for 15 measurements of reflectance for specific wavelengths. In the same way, spectral curves for dry samples with the cut surface were produced (Fig. 5).

Following spectral curve analyses, 5 rock types can be identified:

– Sample 3.1 and 4.1 – bituminous limestone, which has a very low reflectance coefficient within the whole observed spectrum. Relatively easy to separate from other rock types. On natural fraction reflectance below 0.22, is noticeable among other samples in the 700–2200 nm wavelength range. Analysis of the cut surface reduced this range to 700–1300 nm, particularly for sample 4.1;
– Sandstone – spectral curve similar to calcite and limestone residual (sample 5 and 2.1). In the 1100–1800 nm wavelength range, two spikes with reflectance of 0.7 occur, discriminating sandstone from other samples;
– Calcite – spectral curve in the 400–1000 nm wavelength range which is comparable to sandstone and limestone residual (samples 2.1 and 5); however, at 1300 nm range, it gradually falls, reaching a reflectance coefficient value similar to bituminous limestone. In practice, separating Calcite from other rocks based on the reflectance coefficient is difficult, but is achievable by analysing multispectral imagery;
– Limestone residual – samples 2.1 and 5, with properties similar to calcite and sandstone in the 400–1000 nm wavelength. In the higher wavelength, spectral curves gradually move to other limestone samples;
– Sample 1.1, 2.1, 3.2 and 4.2 – limestone, dolomitic limestone, dolomite and silica limestone all have almost identical spectral curves in the 400–1400 nm wavelength range. They significantly differ from other samples in the 700–1100 nm wavelength range. For the longer wavelengths, the reflectance coefficient is significantly dispersed and rock cannot be identified.

Table 2

Rock classification potential for multispectral data sets

<table>
<tr><th>Wavelength range</th><th>VIS</th><th>VIS +
900–1000 nm</th><th>VIS +
900–1000 nm +
1500–1600 nm</th><th>VIS +
900–1000 nm +
1500–1600 nm +
2300–2400 nm</th></tr>
<tr><td rowspan="5">Rock formation for classification</td><td rowspan="2">bituminous limestone, limestone, dolomitic limestone, silica limestone</td><td>bituminous limestone</td><td>bituminous limestone</td><td>bituminous limestone</td></tr>
<tr><td>limestone, dolomitic limestone, silica limestone</td><td>limestone, dolomitic limestone, silica limestone</td><td>limestone, dolomitic limestone, silica limestone</td></tr>
<tr><td rowspan="3">sandstone, limestone residual, calcite</td><td rowspan="3">sandstone, limestone residual, calcite</td><td>sandstone</td><td>sandstone</td></tr>
<tr><td rowspan="2">limestone residual, calcite</td><td>limestone residual</td></tr>
<tr><td>calcite</td></tr>
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The above observations demonstrate that analysis of the visible light images allows, with some level of confidence, the separation of two groups only: limestone and the remaining rocks. These rocks (limestone residual, calcite and sandstone) with soil are among the rock-soil mass For the quarry, rock-soil mass is landfilled useless material. Introducing the NIR and SWIR images to the analysis would result in more accurate classification. Table 2 gives an example of the multispectral data set for rock-type classification.

The spectral bands were selected based on two main criteria. The first criterion was based on the availability of specific instruments. The second criterion was based

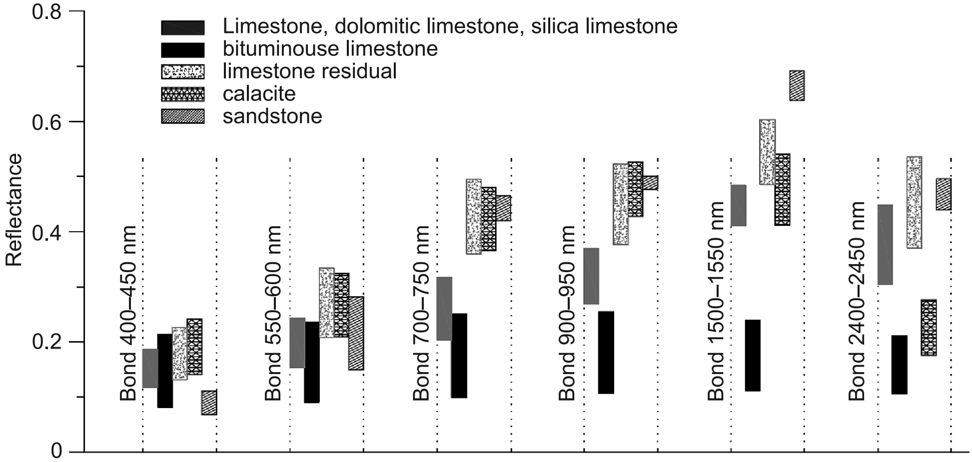

Fig. 6. Reflectance deviation for samples in various spectral bands

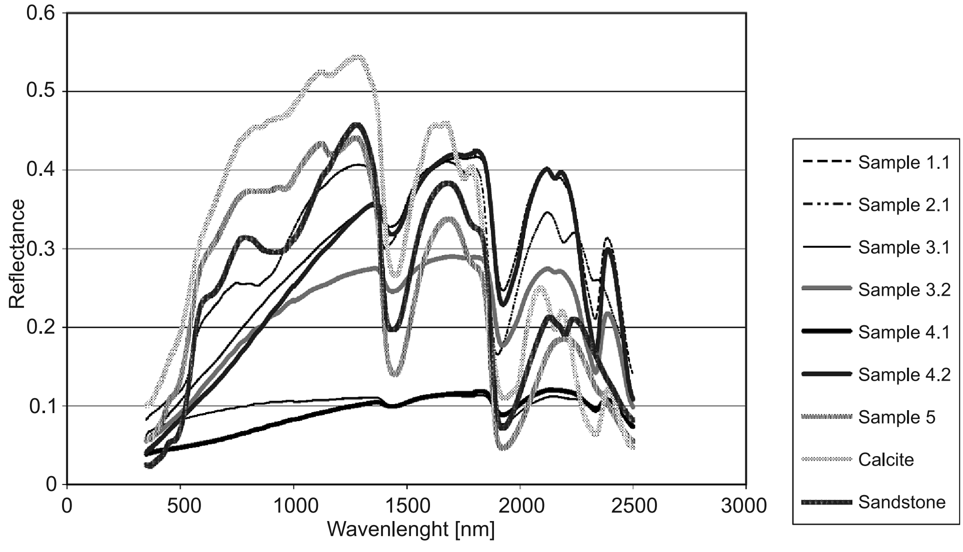

Fig. 7. Spectral curves recorded for wet, natural surface sample

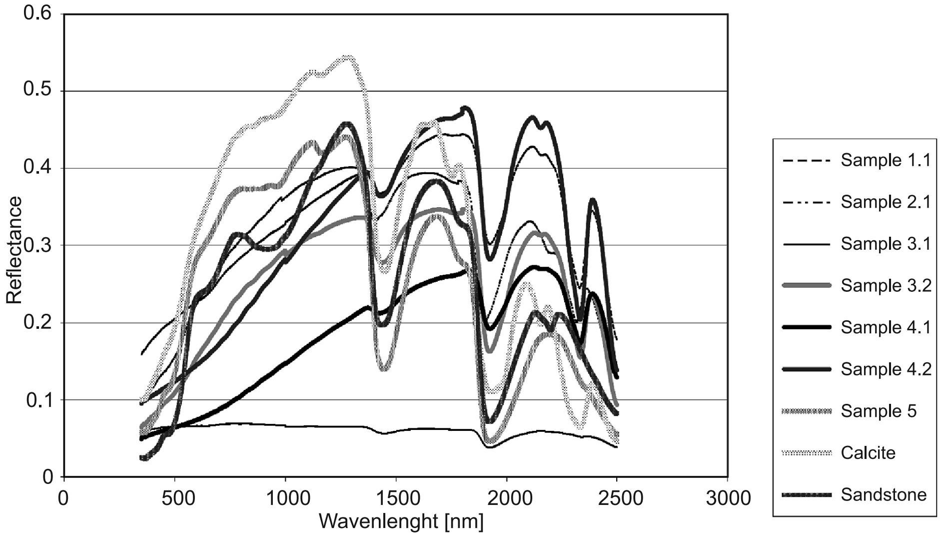

Fig. 8. Spectral curves recorded for wet, cut, unpolished surface samples

on optimal spectral band selection for maximum separability of rock types. Reliable separability of rock types improves the robustness of rock classification. Figure 6 shows the reflectance deviation bands at 0.95 reflectance for specific rock samples. The variation bands were calculated based on the values recorded during the spectrometric analysis for the natural surface samples, at 50 nm spectral range. Overlapping of the reflectance bands (as in 400–450 nm range) for different rock types suggests low separability of rock types.

To determine water influence on the spectral curves, additional analysis of wet rock samples were carried out. Sample moisture replicates the impact of rainfall on the spectral reflectance curves. Spectral reference curves recorded for the natural surface and the cut surface are shown in Figure 7 and Figure 8 respectively. Both reflectance curves show significant spectral instabilities due to water absorption bands [7]. The spectral instabilities make the rock classification very difficult or even impossible. Bituminous limestone can only be identified (with acceptable confidence level), in 600–1200 nm range.

5. Conclusions

The aim of this study was to assess the potential of rock classification in the Czatkowice Quarry using ground-based multispectral and hyperspectral imaging methods. The assessment was based on the laboratory testing of a relatively small number of rock samples. Despite its limited scope, the study produced the following findings:

– Analysis of spectral curves of typical rock formations from the Czatkowice Quarry demonstrated significant variations in the spectral reflectance of the studied samples. These variations create the potential for initial rock classifications within the quarry wall using remote sensing multispectral imaging;

– Imagery recorded within the visible spectrum range (VIS) allow rock classification into two groups: limestone and rock-soil mass including limestone residual, sandstone and traces of calcite;
– Introducing the near-infrared imagery to the analysis, will in addition, allow the identification of bituminous limestone, sandstone and calcite;
– Rock wetness is a significant factor influencing rock classification potential. The increased wetness during rainfall events prevents effective rock classification. Therefore, remote imaging must be recorded for dry rocks;
– Nowadays, ground hyperspectral camera is quite often used in geological applications e.g. for quarry wall classification. Classified images are superimposed onto three dimensional models from terrestrial laser scanning which allows for not only quality analysis but also for quantity analysis [8];
– Use of ground hyperspectral cameras is quite new approach. Today, it is becoming increasingly possible to buy the necessary equipment which can register whole solar electromagnetic region in narrow bands e.g. HySpex camera (Norsk Elektro Optikk) or UHD (Cubert).

Research was funded by the Ś-2/233/2014/DS.

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