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SOME REMARKS ON THE APPLICATION OF IMAGE ANALYSIS AND IMAGE PROCESSING FOR THE DESCRIPTION OF THE GEOMETRICAL STRUCTURES OF ROCKS

The paper presents results the aim of which was to examine the possibility of applying the methods of image analysis and mathematical morphology to petrography and rock mechanics. These methods have not found so far greater application to the microscopic analysis of rocks, chiefly due to the variety of rock structures. On the other hand, their application may enable considerable improvement of the conducted geometrical measurements of rock structures. The study discusses the results obtained due to the operation of algorithms of automatic analysis for 3 rocks: granite (from Strzelin), dolomite (from Rędziny) and sandstone (from Lipka and Radlin). In order to evaluate the correctness of the automatic methods, the obtained results have been compared with the results obtained in a standard (non-automatic) analysis. The obtained results allow to state that in the case of the examined rocks the author has proposed fairly correct method of image analysis of rock structures based on the image analysis and mathematical morphology transformations.

INTRODUCTION

Microscopic image analysis supplies much information on the mineral composition of rocks, which is helpful and sometimes just indispensable in problems concerning, for example, the classification origin of rock. However, the qualitative and descriptive microscopic observations of rock are often of higher value when they are accompanied by numerical information. Such information can be obtained by the application of stereological methods. In order to determine the stereological parameters of rock structures, many measurement methods are used, out of which the most important are the methods of point and linear analysis. These methods, when applied to a non-automatic measurements, are time consuming and toilsome for the observer. For this reason, in the stereological investigations there are used, on an increasing scale, the instruments for automatic analysis. This refers in particular to metallurgical, biological and medical investigations, as well as those connected with

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material engineering. Unfortunately, the automatized microscopic observations have not found as yet wider application to geology and rock mechanics. This is attributed, first of all, to the great diversity and changeability of the microscopic rock structures.

The paper presents the results of investigations the aim of which was the recognition of the possibilities of the application of the methods of automatic image analysis to the determination of the stereological parameters of selected rock structures. It has been admitted that the application of these methods to petrographic investigations will enable their worked improvement as well as the elimination of all problems connected with the fatigue of the observer.

It has been admitted that the proposed measuring methods should be as universal as possible and should not be limited to the analysis of singe image. For this reason the aim of the study was to create such algorithms which could be used, without changes, for the analysis of a great number of images or even series of thin or thick sections. This task is fairly difficult to realize, especially in reference to the analysis of such complicated and varied structures as the structures of rocks, i.e. structures for which a correct segmentation even of individual images sometimes produces great problems.

The presented paper concentrates on the presentation of the obtained results for 3 rock: granite (from Strzelin), dolomite (from Rędziny) and sandstone (from Lipka and Radlin). On account of the limited volume of the paper the modes of creating and detailed presentation of the applied algorithms are not be discussed here. The respective description can be found in the study by Młynarczuk (1998). Similarly, the basis for the image analysis and mathematical morphology can be found in a monograph study by Gonzalez (1987) and by Serra (1982).

ACCURACY OF MEASUREMENT

One of the basic problems, which should be solved, concerned the mode of determining the accuracy of the conducted automatic measurements. It can be admitted that in the computer image processing the main source of error is to be found at the stage of segmentation, i.e. automatic identification of the objects which are interest for the observer (e.g. particular grains). The measurement itself of the geometrical parameters of the already segmented objects does not contain any essential errors. For this reason, in order to assess the errors of an automatic measurement, we must assess the error of segmentation, i.e. the error of the transformation of an image into image. It is an extremely difficult task. In the present study we have decided that in order to determine the error of automatic measurement, the analysed structure will be measured also by means the standard, non-automatic measurement methods (stereological point and linear analysis). The aim of such measurements was the determination of the same geometrical parameters as the obtained in the automatic analysis. As the error of the automatic measurement it has been decided to treat the difference between the results obtained in the standard non-automatic analysis and the results obtained in the tested automatic analysis.

ANALYSIS OF THIN SECTIONS OF GRANITE FROM STRZELIN

The aim of the analysis of thin sections of granite from Strzelin was the determination of the volume fraction of biotite. It has been established that the analysis of single photographs of the analysed field (Fig 1a) does not provide information sufficient for correct segmentation. This is connected with the fact that biotite as a pleochroic mineral is characterized by variation of colour during the rotation of the specimen in relation to the polarizer. For this reason some plate of biotite, hardly noticeable at one position of the polarizer, become visible at the other positions. Basing on this property, it has been decided that each time 3 images of the same field registered at different positions of the polarizer will be subjected to analysis. It has been admitted that in such a case, each mineral of biotite will be at least on one image distinctly darker than the mineral surrounding it. Next, an artificial image was created (Fig 1a) defined as the minimum of three input images. The image, on which all the plates of biotite are visible, was subjected to the future processing (Młynarczuk, 1998), the result of which was a binary image, on which the biotite minerals were represented (Fig 1b). The binary image was the starting point to carry out the automatic measurements.

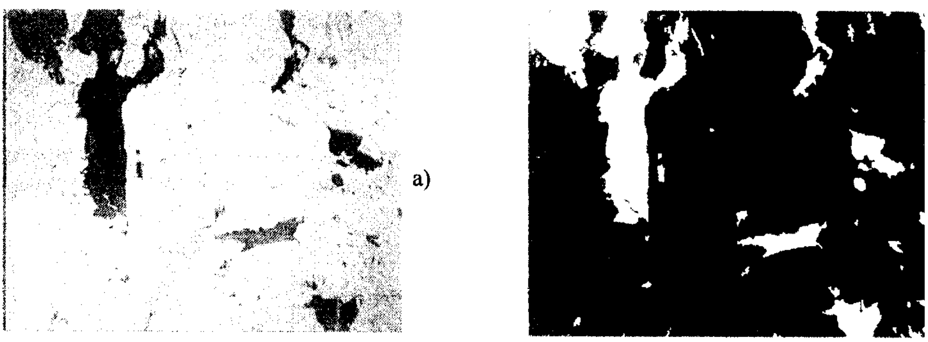

Fig. 1. Artificial image of granite (a), the final result of the image processing (b)

Rys. 1. Sztuczny obraz granitu (a), końcowy rezultat przetwarzania obrazu (b)

In order to carry out the automatic measurements of the volume fraction of biotite in granite, there have been registered 25 fields uniformly distributed on the analysed thin sections. Each field was registered at 3 different positions of the polarizer. Next, by means of the created algorithm, a fully automatic analysis was carried out. The results of such an analysis (for 3 different thin sections of granite) are presented in

Table 1. In order to verify the automatic method there have been carried out non-automatic measurements of the volume fraction, utilising the stereological point analysis. The results of the analysis are listed in Table 1.

Tab. 1. Lists of the results of the determination of the volume fraction of biotite from an analysis of 3 thin sections

Tab. 1. Rezultaty wyznaczania ułamka objętościowego biotytu z analizy 3 szlifów cienkich granitu

Denotation of the specimen	V_V from non-automatic analysis	V_V from automatic analysis	Difference $V_{V[2]} - V_{V[3]}$	Deviation % $(V_{V[2]} - V_{V[3]}) / V_{V[2]}$
1	3	2	4	5
G 5.1	0,100 ± 0,006	0,099	0,001	1,0
G 7.1	0,051 ± 0,005	0,050	0,001	1.9
G 1.1	0,042 ± 0,004	0,040	0,002	4,8

From Table 1 it can be concluded that a fully automatic algorithm of the analysis of plates of biotite from Strzelin has been created. The basis for the success was the utilisation of number of images for analysis of the same field. This allowed to make use of the biotite property named pleochroizm, and resulted in correct segmentation of the biotite plates. The results referring to the volume fraction V_V of biotite in granite, obtained in automatic analysis, deviate on the average by about 3% from the results obtained in non-automatic analysis. It should be noted that these results are within the errors of non-automatic measurements. As a result of the application of the method of automatic measurements it was possible to shorten the time required for the analysis of the entire thin section from about 8 hours (stereological point analysis) to about 50 minutes (automatic analysis). It should be noted that most time during the automatic analysis, about 45 minutes, is absorbed by the registration of images into the computer memory. It is connected with the speed of the table that carries thin sections, and if necessary, this time may be distinctly shortened.

ANALYSIS OF THIN SECTION OF DOLOMITE FROM RĘDZINY

In the described investigations dolomite was treated as a monomineral rock, i.e. rock comprised in 100% of dolomite grains. The aim of the analysis was to identify the grain shape, which was reduced to the detection of the grain boundaries. Information about the route of the boundaries of grains was obtained directly on the basis of their colour, or indirectly, on the basis of the difference in shape or colour of the neighbouring grains. A negative feature of the dolomite structure is the occurrence of cracks on the dolomite grains. As the result of the above measurements, it was expected to obtain the mean length of the grain chord, the distribution of the chords of grains and the value of the specific surface.

Basing of the experience resulting from the analysis of the thin sections of granite, the author decided not to use single image in the investigations. It has been decided that black and white images do not provide enough information to carry out correct segmentation and, consequently, it has been decided to analyse colour photographs. It has been observed that additional information on the route of the grain boundaries can be obtained thanks to a change in the angle of the position of the polarizers. In the microscope of the author's disposal it was possible to change this angle between 90° and 0°. Figure 2 shows 2 images of the same field registered at different angles of the position of the polarizers. In these images a change in the contrast of the grains as the result of the applied operation is visible. It has been decided that for each field there will be registered 9 images of different angles of the position of the polarizers.

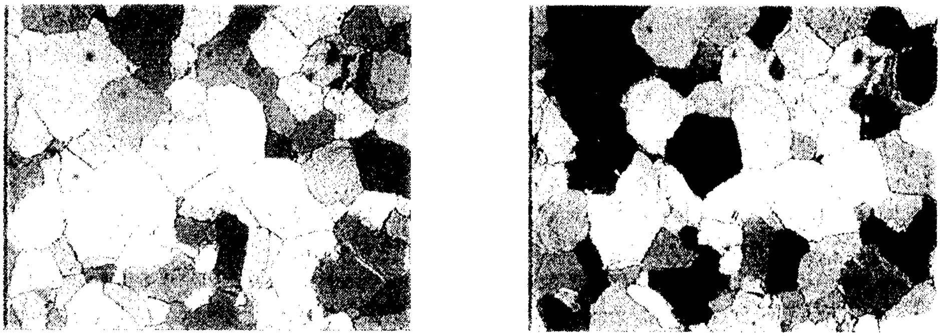

Fig. 2. Two images of the same field registered in two difference angle of position of the polarizers

Rys. 2. Dwa obrazy tego samego pola zarejestrowane przy 2 różnych kątach położenia polaryzatorów

It was admitted that the algorithm of segmentation of the dolomite grains should be based on the watershed transformation (Beucher, 1990). The idea of the algorithm utilising this transformation consist in that the input image or several input images are transformed in such a way as to obtain two images: the image of mask (being most often the image of the morphological gradient) and the image of markers. When these two images are obtained, the watershed is used. As a result, a segmented image is obtained. In the case of the here described investigations the image of the mask was obtained relatively easily. It has been admitted that it should be based on the morphological gradients of all 3 components RGB for all 9 colour images of the same field. This gives a total of 27 component images for which the morphological gradients must be calculated. It has been admitted that the image of the mask is formed as the maximum from all 27 gradients. Obtaining a correct image of the markers was much more difficult. It has been decided that it will be the image of the minima of the mask image. This has been done in spite of the fact that as a result an oversegmented image (Fig 3a) is obtained, i.e. image on which there are definitely more objects than they are in reality. A detailed inspection of the obtained result, however, leads to the conclusion that all grain boundaries have been correctly detected. The only defect of the result is the fact that the particular grains have been divided into smaller fragments. Thus further treatment consisted in combining the divided grains.

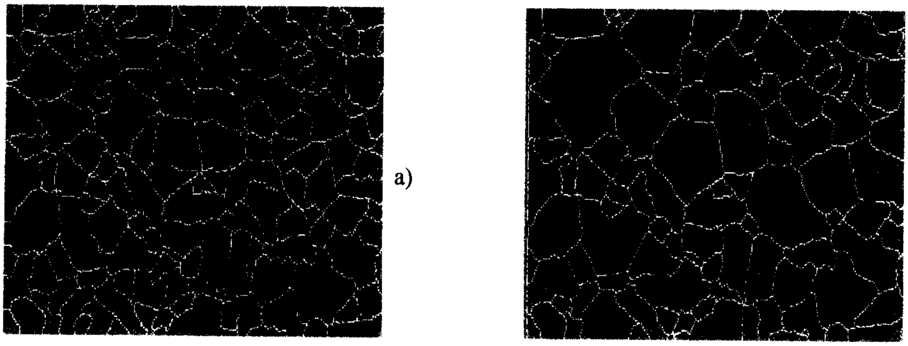

Fig. 3. Oversegmented image (a), and correctly segmented image of dolomite from Rędziny (b)

Rys. 3. Obraz przesegmentowany (a), oraz poprawnie posegmentowany obraz dolomitu z Rędzin (b)

It has been admitted that two neighbouring areas are fragments of the same grain if: 1) they have similar mean colour, 2) they demonstrate similar variation of colour when the angle of the position of the polarizers is changed, and 3) between these fragments there is no distinct gradient on the image of mask, which may indicate the existence of the grains boundary. Adopting these assumptions was resulting in obtaining a correct final result (Fig 3b).

In order to carry out automatic measurements of the mean length of the chords of dolomite grains (in the directions X and Y), 25 uniformly distributed fields over the entire analysed thin section were registered. Each field was registered at 9 different angles of the position of the polarizers. The results of analysis of 3 different thin sections of dolomite, utilising the algorithm of automatic analysis, are shown in Table 2. The table lists also the results of non-automatic analysis (stereological linear analysis), which has been carried out on the same thin sections, in order to verify the obtained results.

Verification of the automatic method by comparing its results with those obtained by a way of non-automatic analysis shows that the deviation in the determination of the mean length of the chord oscillate at a level 5% (Table 2). Also the inspection of the graphs of the chords distributions (Fig. 4) shows good agreement between the measurements of automatic and non-automatic analysis. The obtained results of the measurements of the specific surface were a little worse, as the results differed within the range 4-10% (Table 3). It is worthy to note that as a result of the automatic analysis an additional parameter – the total mean specific curvature (Bodziony, 1965) was determined (Table 3). This estimator cannot be determined by way of linear or point analysis.

Tab. 2. Lists of the results of the mean length of chords, for the analysis of 3thin sections of dolomite

Tab. 2. Zestaw wyników średniej długości cięciw dla analizy 3 szlifów cienkich dolomitu

Thin section	Dire-ction.	Mean length of chord from non-automatic analysis [μm]	Mean length of chord from automatic analysis [μm]	Diff. between the results: [4] – [3] [μm]	% deviation between the results: (|[4]-[3]|)/[4])*100%
1	2	3	4	5	6
D 9	Y	129.7 ±3.40	131.50	1,80	1.4
	X	141.8 ± 4.71	134.91	- 6,89	5.1
D 4	Y	103.7 ±3.06	113.45	9.75	8.6
	X	131.8 ± 3.97	124.86	- 6.94	5.6
D 2	Y	127.31 ± 3.48	133.76	6.45	4.8
	X	124.00 ± 3.47	130.07	6.70	5.1

Figure 4 shows the distribution of the chord lengths of a thin section D4, obtained from automatic and non automatic analysis.

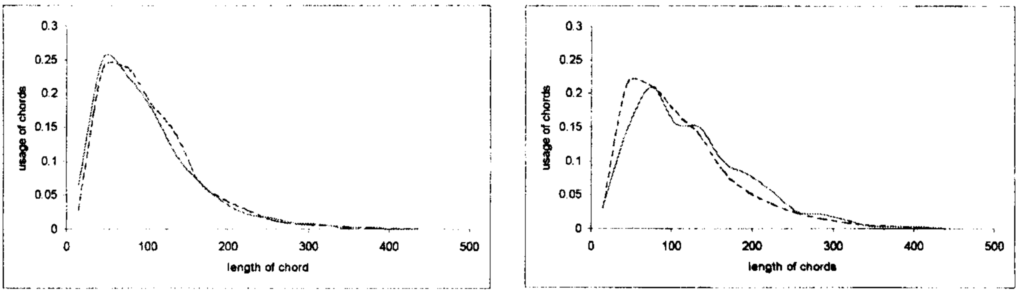

Fig. 4. Distribution of the chord length in two directions (X and Y) for automatic (dot-line) and non-automatic analysis (continuous line)

Rys. 4. Rozkład długości cięciw w 2 kierunkach (X oraz Y) dla analizy automatycznej (linia przerywana) oraz nieautomatycznej (linia ciągła)

ANALYSIS OF THIN SECTION OF SANDSTONE

From the point of view of automatic analysis the structure of sandstone was regarded as quartz and the binder. Larger, moderately uniform objects were treated as grains, while the binder represented a collection of small, irregular intrusions, filling the intergranular space. As a result of the conducted measurements it has been expected to obtain the mean length of the grains chords, distribution of the grains chords, value of the specific surface and the volume fraction of quartz grains in the analysed sandstone.

Tab. 3. List of the results of the specific surface (S_V) and total mean specific curvature (K_V) for analysis of 3 thin sections of dolomite from Rędziny

Tab. 3. Zestaw wyników powierzchni właściwej (S_V) oraz krzywizny średniej właściwej (K_V) dla analizy 3 szlifów cienkich dolomitu z Rędzin

Thin section	S_V from non-autom. analysis [μm^{-1}]	S_V from autom. analysis [μm^{-1}]	Difference: [3] – [2] [μm^{-1}]	% deviation: (|[3]–[2]) /[3])*100% [%]	K_V [μm^{-2}]
1	2	3	4	5	6
D 9	0.0298	0.0331	0,0033	9,97	0,004041
D 4	0.0347	0.0384	0,0037	9,64	0,001950
D 2	0.0319	0.0331	0,0012	3,63	0,004252

To carry out the analysis of a single field of sandstone a series of colour images registered at 5 different angles of the position of the polarizers was utilised. Thus the procedure was almost the same as in the case of the dolomite. As a result of the observation of the geometrical structure of sandstone (Fig. 5a) and changes of colours of its particular components, occurring when the angle of the position of the polarizers was changed, there have been defined some criteria enabling to distinguish the quartz grains from the binder. It has been noticed that: 1) in principal, the grains demonstrate greater variation of colour than the binder at a change of the angle of the mutual position of the polarizes, 2) in principle, the grains are characterised by grater uniformity of texture than the binder. The algorithm of automatic analysis has been elaborated on the basis of these 2 criteria. As a result of its operation a binary image such as shown in Fig 5b was obtained. In this image the quartz crystals are correctly distinguished from the binder. However, the crystals frequently contact each other, and on the binary images they are treated as one, larger object. Many attempts have been done to separate the combined objects. Best results were obtained from the algorithm based on utilisation of the watershed transformation, proposed by Beaucher, (1990). This results in a correct separation of the objects (Fig 5c).

Unfortunately, although the operation of the proposal algorithm for the separation of quartz grains was correct over more than a half of the analysed fields, it cannot be used for a fully automatic analysis of all fields. At present, work is continued to modify this algorithm or to suggest another one, which would in a fully automatic way perform the separation of the combined objects.

a) b) c)

Fig. 5. Input image of sandstone (a), binary image obtained after proposed algorithm (b), segmented image obtained after separation of the objects (c)

Rys. 5. Wejściowy obraz piaskowca (a), obraz binarny otrzymany w wyniku zastosowania proponowanego algorytmu (b), obraz posegmentowany po separacji obiektów(c)

Because of the difficulties of the separation of the combined grains it was not possible to determine such geometrical parameters as the length of the grain chords, grain boundaries etc. The only stereological parameter, which could be defined, was the volume fraction of quartz in the sandstone. An automatic analysis of 2 thin sections of sandstone (from Lipka and from Radlin) was carried out. On each of the section 16 fields were registered, each at 5 different positions of the polarizers. To verify the obtained results, a non-automatic linear analysis of the same thin sections was performed. The results obtained in these two analyses are listed in Table 4.

Tab. 4. List of the measurement results of V_V for thin sections of sandstone

Tab. 4. Rezultaty pomiarów V_V dla szlifów cienkich piaskowców

Thin section	V_V from non-automatic analysis	V_V from automatic analysis	Difference $V_{V[3]} - V_{V[2]}$	% deviation $(V_{V[3]} - V_{V[2]}) / V_{V[3]}$
1	2	3	4	5
P- Lipka	0.66 ± 0.02	0.64	0.02	3.1
P- Radlin	0.60 ± 0.03	0.63	0.03	4.8

On the basis of the obtained results the conclusion can be drawn that the obtained values for the volume fraction of quartz V_V in the sandstone from Lipka and Radlin are correct. This means that it was possible to divide the pixels into those belonging to the quartz grains and those belonging to the binder.

CONCLUSIONS

To sum up the results it can be said that the methods of mathematical morphology and image analysis, which are successfully applied in such branches as metallurgy, biology, medicine, etc. can be also used to the analysis of structures of certain rocks. From the performed investigations it follows that although creating of such algorithms for petrographic purposes is connected with great difficulties, it is not a task that must end in a failure. Application of these methods will enable considerable improvement of measurements of the geometrical structure of rocks.

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W pracy zaprezentowano badania mające na celu zbadanie możliwości stosowania metod analizy obrazów i morfologii matematycznej w petrografii i analizie skał. Metody te nie znalazły do tej pory większego zastosowania w analizie mikroskopowej skał, głównie ze względu różnorodność struktur skalnych. Natomiast ich wykorzystanie pozwolić może na znaczne usprawnienie prowadzonych pomiarów geometrycznych struktur skał. W pracy zaprezentowano rezultaty osiągnięte w wyniku działania algorytmów automatycznej analizy dla 3 skał: granitu (ze Strzelina), dolomitu (z Rędzin) oraz piaskowca (z Lipki i Radlina). W celu określenia poprawności metod automatycznych, osiągnięte rezultaty porównane były z rezultatami otrzymanymi z analizy standardowej (nieautomatycznej). Otrzymane rezultaty pozwalają stwierdzić, że w przypadku badanych skał udało się zaproponować w miarę poprawne metody automatycznej analizy struktur skalnych bazujące na przekształceniach analizy obrazów i morfologii matematycznej.