Automatic quantitative analysis of mineral composition and properties of rocks

Algorithms for Rocks

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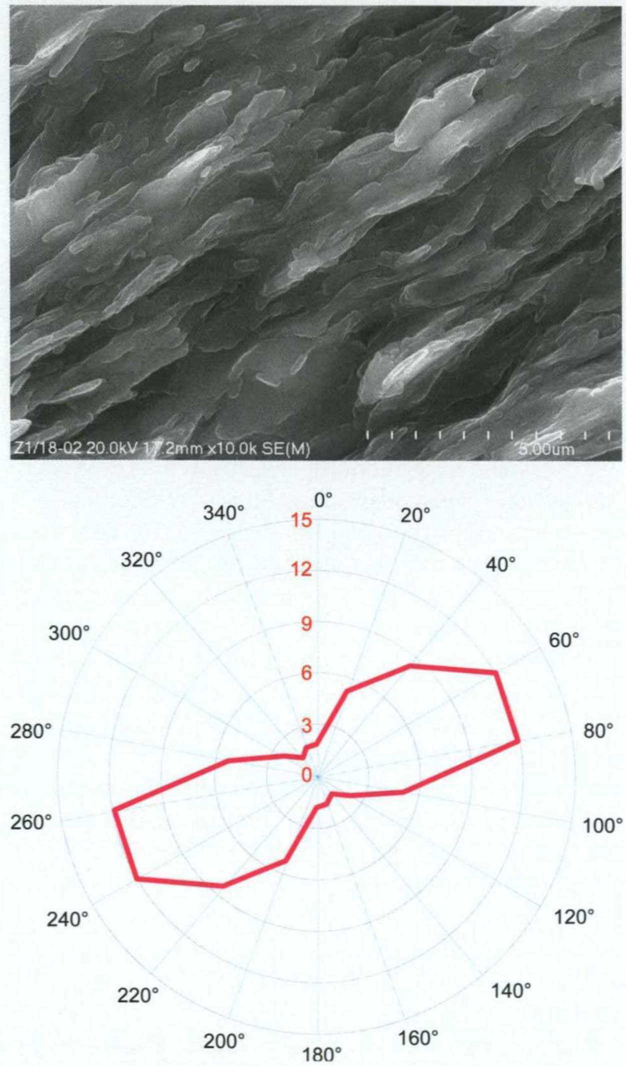
Image processing algorithms are enabling computers to learn to automatically recognize characteristics of what camera images portray. In geological research, speedy computers can relieve researchers from having to perform painstaking measurements on mineral grains

Quantitative analysis of rocks' inner mineral structure as photographed under various sorts of microscopes can unlock a plethora of information about their potential uses. For example, the endurance of a given kind of rock is determined by the shape of its mineral grains, and especially by the degree to which they intermesh. Moreover, microscope assessment of the total surface area occupied by crystals of various types of minerals within a thin section of rock can give us an understanding of the conditions under which it was formed - sometimes more accurately than chemical analysis of the entire sample can.

Not long ago, such quantitative analysis was performed using complex mechanical devices, and was extremely time-consuming. In this modern age, quantitative techniques are naturally developing towards full automation. The Strata Mechanics Research Institute (Polish Academy of Sciences) is working to help harness automated digital image processing techniques for use in characterizing mineral structure.

Digital mosaic

Image processing methods have been developing for decades but the true boom came with the rise of personal computers, which have ultimately displaced the complex analog devices that were still in use in the 1990s. The specialist software now being used makes it possible to access hundreds of ready-made image operations. The process of analyzing an image involves selecting the right operations, finding the proper parameters, and setting up a series of successive operations (i.e. an algorithm). The aim of such an algorithm is usually to transform the input image



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Organic-clay microstructure viewed under a scanning microscope (top) and automatically derived rose diagram for this structure (bottom)

into an output image, whereby all the objects of interest are correctly rendered. This process is frequently called *image segmentation*. Once a correctly segmented output image is obtained, measuring the geometrical parameters of the objects under analysis essentially poses no great difficulty.

Despite their vast potential, image processing techniques have not yet been widely applied in the field of petrography. This is presumably due to difficulties with the high degree of complexity and the wide diversity and variability of rock structures. Thin sections taken from the same rock only several centimeters apart often evidence entirely different structures. Image processing techniques, in turn, can be very sensitive to variations of this sort. Effective algorithms have to take account of the specific nature of the material under study, its variability, heterogeneity, and even a certain dose of unpredictability. Developing such an algorithm, therefore, requires interdisciplinary knowledge on image processing as well as petrography.

The Strata Mechanics Research Institute has developed a set of algorithms capable of analyzing many diverse structures. They include ready-to-use solutions for certain clastic, igneous, clay, and carbonate rocks, as well as ores and coals. The images for analysis may come from optical, cathodoluminescence, or electron microscopes. The analytical algorithms developed can identify the geometric parameters of selected minerals or grains, describe the structure of porosity, or characterize networks of fractures. In each case, great effort was made to design them to be able to analyze a large number of samples in fully automated fashion, without outside intervention.

The main benefit to be gained from such automation lies in the radical acceleration of measurement-taking. For example, it takes the Strata Mechanics Research Institute staff some 20 hours to take measurements from a thin section of sandstone using traditional linear analysis methods. With automated techniques, the most time is taken up by recording the images themselves (some 20 minutes), the analysis *per se* then being performed in less than a minute. Of course, it must be borne in mind that a separate algorithm must be developed for each type of structure, so automatic analysis only makes sense when we plan to take measurements from a large number of samples.

Sizing up morphology

Another benefit of digital image processing is the ability to automatically ascertain a relatively large number of geometric parameters at the same time, such as: the area of objects, their circumferences, Feret's diameters, morphological parameters, centers of gravity, information on the color of objects, and many, many others. This represents a considerable advance over standard quantitative measurements, which can only capture several parameters of the structure.

The results obtained to date indicate that image processing methods can successfully be used in such fields of research as metallurgy, biology, and medicine, and may also find applications in analyzing rock structure. The greatest difficulty to be overcome in developing automatic image processing algorithms for petrography lies in the degree of complexity of the structures studied, yet the results achieved so far are promising enough to encourage research to be continued. ■

Further reading:

Młynarczuk M. (2004). *Potential Use of Image Processing and Mathematical Morphology for the Stereological Analysis of Rock Structures* [in Polish]. Archives of Mining Sciences, vol. 49, s. 117-140.

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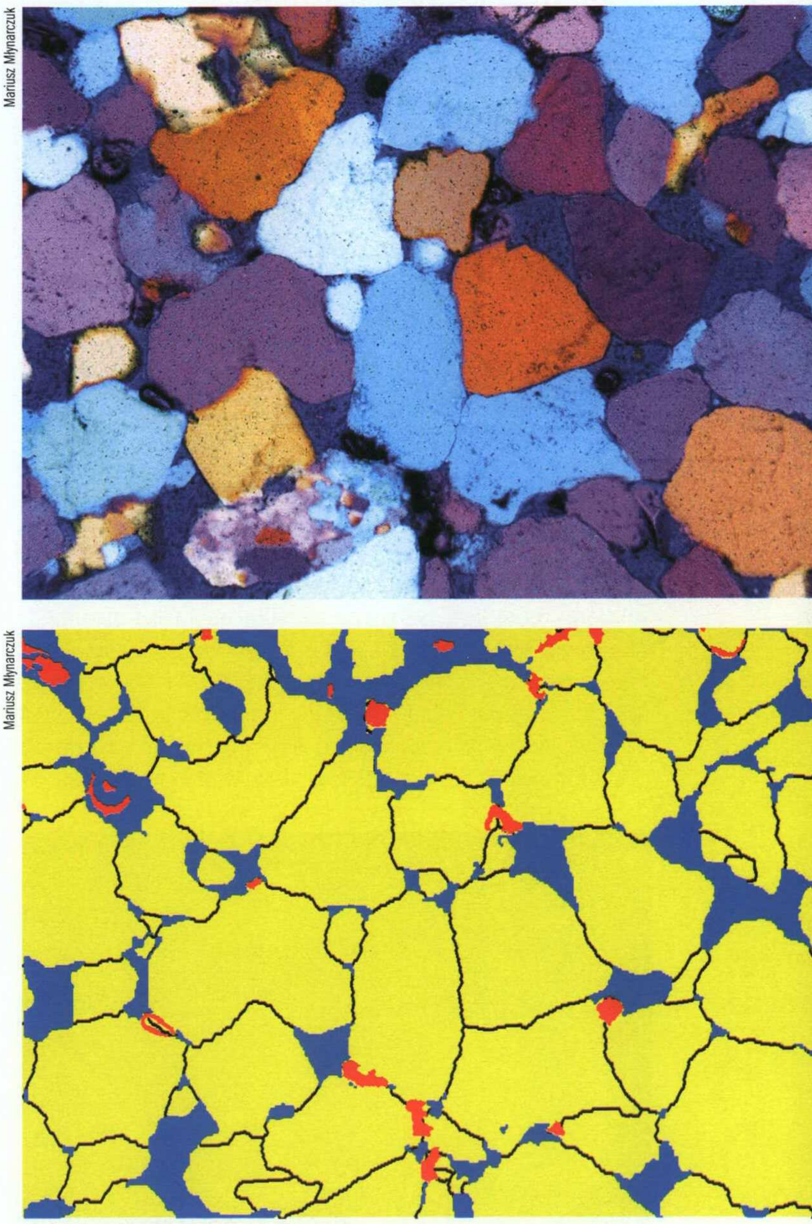

Sandstone viewed under a polarizing microscope at 100x magnification, with crossed nicols plus lambda plate (top) and automatically detected mineral components (bottom): yellow - quartz grains, red - other minerals, blue - pore space