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Former Structures of Rocks Discernible by Image Analysis

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With 8 Plates (in pocket)

Gesteinsstrukturen
Bildanalyse

Contents

Die Anwendung der Bildanalyse auf ehemalige Gesteinsstrukturen

Zusammenfassung

Dünnschliffe von stark diagenetisch verändertem oder metamorphem Gestein wurden mit Hilfe der Bildanalyse untersucht. Reste von vorhergehenden Strukturen wurden abgetrennt und anschließend durch serienmäßige Bildbearbeitung wiederhergestellt. Sowohl die Bild-Verarbeitung als auch die Interpretation werden diskutiert.

Das Hauptgewicht der Untersuchung lag auf Karbonaten. Vier Gesichtspunkte wurden untersucht: ursprüngliche Sedimentteilchen und Struktur des Gesteins; ältere diagenetische und metamorphe Gesteinsstrukturen; Modelle von stärkerer und schwächerer Durchlässigkeit in Ölfallen; sekundäre Mikrostrukturen organischer Skelette (tabulate Korallen).

Abstract

Thin sections of rocks with strong diagenetical changes or metamorphism have been studied by image analysis. Inherited relicts of precedent structures were separated and consequently reconstructed by serial imaging procedures. Both the image processing and the interpretations are discussed.

Main emphasis of the study was directed to carbonates. Four topics were studied: Original sedimentary particles and rock structure; older diagenetical and metamorphic structures of rocks; models of closing and opening porosity in oil-traps; secondary microstructures of organic skeletons (tabulate corals).

1. Introduction

Polyphase up to fluctuated recrystallization of many rocks results in an extremely complicated pattern. Intensive rock reactions are evoked by a changed environment. These changes are evident and largely studied in carbonates (see any of the well known monographies, e.g. LONGMAN, 1981; TUCKER, 1991). High environmental sensitivity of structures has been observed also in sulphates (SKOCEK, 1985) and phosphates (KUKAL, 1986). Although silicate rocks are more stable, they essentially reflect the same, i.e. changed temperature, pressure and rock fluid composition. Recrystallization depends on the balance between rock and fluid, i.e. typical dissolution/precipitation, or the ionic exchange in semi-solid state takes part in this process (WENK et al., 1983). On these facts, the major part of the recent knowledge on diagenesis and metamorphism is based.

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However, the geometrical and transmissivity complex of any common thin section is not so simple as anybody may assume according to photographs or any first view in a microscope. Each of the crystals, as well as crystal aggregates or mixed objects with included subcrystalline locations, contains many dislocations, disturbances and inclusions. Previous positions of crystal defects can be inherited in newly formed textures (WENK et al., 1983). Inherited relict textures enable to trace up to several foregoing stages (HLADIL, 1988). The crucial problem is only how dispersed/clustered, spaced and diversified are the positions of the relicts.

We can arrange a very simple test to illustrate how huge is a superimposition of various patterns that are hidden within a thin-section. Recognizing these patterns we use obviously coherent laser light. The light transmission is diffracted by all the edge- or net-patterns of the transparent tablet (thin section). Resulted Fraunhofer diffraction pattern detects usually all the dominant features (KOMRSKA, 1979; HLADIL & HLADIL, 1981). For example, when we have a photo-negative, we receive as main morphological and dimension patterns of the scenery, as a hexagonal pattern of bromide crystals. Nevertheless, the thin sections contain, as a rule, so much information that resoluted Fraunhofer's are chaotized. There are formed only chaotic spots in the diagrams, so-called speckles.

Summarizing these common facts we must solve an essential task: How can be separated all the individual fine patterns of these very complex rock structures, with special emphasis to relict structures and evaluation of the previous diagenetical stages of the rocks. The task is stimulated by the following requirements of science and technology:

A) Terrane analysis – knowledge on rock history, i.e. history of physical parametres like depth, temperature, stress, fluid saturation, chemical and mass balances as reflected by rock structure.
B) Basin analysis – knowledge on the original composition of the rock, i.e. significant clasts with regard to sedimentology and environment or biostratigraphically important fossils.
C) Oil survey – models of previous porosity sequences and/or an estimation of the original state of the source rock.

Major attention was paid to carbonates because this type of rock is a prominent subject of the oil-survey, yielding simultaneously good inherited structures. In our opinion, image analysis is one of the most promising approaches which solves how the individual structural patterns can be discerned.

2. Image Analysis: Setting up the System, Hardware and Software

The base configuration consists of a computer with an image processor (not necessary at PC 486, 16 MB RAM when systems are working under the WINDOWS), a TV camera, a system monitor, an image monitor, a graphics tablet and a printer.

For our task we needed an image analysis system which yielded sufficient menu of additional routines and which was providing simultaneously a very flexible control of analytical operations. An appropriate tool we have found in LUCIA-S (Scientific) system. LUCIA is an original product of Laboratory Imaging, however, its general philosophy is comparable with other image analysers. LUCIA runs on PC-AT computers almost as a standard program which is controlled by the user via keybord or tablet (mouse). Nevertheless, most of the LUCIA commands call the image processor placed inside the computer. This processor substantially supports image processing, segmentation and analysis (measurement). That is why LUCIA-S is not simply transferable to an usual PC-AT computer with Intel 80386 and higher processors. The image can be stored in a frame buffer and then in disk memories. Buffers make display and operations among images easier. Zoom and overlay are accessible. The default and maximum value of the image is a 24-bit image, i.e. 512 x 512 pixels.

Colours, ranges and distribution functions can be changed: among the major tools are stored and flexible, look-up-tables (LUTs), including the pre-destined palettes which are also flexible. The process is called mapping and takes place in common procedures MAPING, TRESH, THRWIN and internally in many other special functions.

In grey image processing, the following basic procedures are the most appliable:

- ❑ Noise suppression
  The simple noise filter is smoothing (averaging) by SMOOTH function. Modified CLOSE and OPEN procedures, i.e. open, close, erode, dilate, as well as image explorations with user-defined kernels can be used. The very powerful noise filter is a median which orders values from pixel neighbourhood and takes the middle value as a result (RANKF).
- ❑ Sharpening
  All the gradients are selectively or multiplicatively marked.
- ❑ Edge detections
  detects gradients of the predefined image (EDGES)
- ❑ Peak and valley detection
  selects peaks or valleys on the "continuously" recalculated background (TOPHAT functions).

LUCIA enables that many other composed routines might be directly called and the others can be joined in macros to be tailored to any special task. Interactive adjustment of parametres provides the visual checking of the segmented results and consequently the optimal decision. When necessary, some extremely scattered and diversified objects can be artificially marked in image editation. Mathematical operations picture – constant and picture – picture are very important for individual pattern survey.

In our tasks, many other functions were utilized. For example, the function SKELET: Skeleton is mathematically a set of the centers of maximum balls fitting into the object. It is a homotopic transformation realized by homotopic thinning: objects before skeletonizing (net) keep objects and holes. Especially the comparison with previous or initial images confirms the effectivity as well as fidelity of the skeleton procedure.

LUCIA is equipped also for the learning procedures (= the running LUCIA system learns how to discern various objects).

3. Recognizing Techniques: Basic, Composed and Serial Procedures

The selection of appropriate procedures depended on the rocks that were studied: As a rule, strong diagenetical

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and metamorphic structures of the latest metamorphic stage cover the less visible and older relict structures. The actual task is just how to extract these slightly visible patterns. Among the possibilities involved in LUCIA-S basic or derived menu the following procedures were dominant:

Tophat

The Tophat function with deep ranges of erosion (up to 30) extracted relatively darker parts of the image, i.e. locations that were darker in comparison with the background. The best kernel (i.e. flowing pixel matrice) was square 3 x 3 or the first octagon. The resulted image of low contrast was transformed to full dynamic by common arithmetical procedures (addition and multiplication).

This method is a powerful tool but it seems to be very sensitive to the depth of erosion. Small ranges of erosion and recalculated neighbourhood found only small dark valleys while the extremely large ranges led up to the inversion. Quadratic or octogonal artefacts can disturbe the resulted image and they need further transformations.

Procedure based on smoothing

This procedure was developed according to our experience with the tophat. Erosion of the input image was replaced by smoothing with larger surrounding (up to 30, 50 pixels). The smoothed image is, as a rule, much more continuous in comparison with the tophat. Then the original but sharped input image was diminished by the smoothed one [picture minus picture operation] and the resulting image was transferred towards the full dynamic. Profiling patterns of predestined, originally quite hidden darker objects, had to be indicated at this moment. Nevertheless, also this method is not totally free of artefacts. For example, some belts were allowed to grow in places of steep gradients (margins of dark and light domains): Their medium values were not in harmony with the surrounding average values (there was a relatively light belt in a dark background, or a dark belt in a light background). [E.g., when the recalculated neighbourhood was coming into the area of the above mentioned steep gradient, the originally dark neighbourhood embraced more and more points of the light domain – the average intensity was increasing. This disproportion was visible after the diminishing of the values by the smoothed image, i.e. after the picture minus picture P(–)P operation].

Despite the problem of passing the dark/light domain edges, the procedure was very effective: Small objects were detected in small ranges of the SMOOTH and the big ones in its bigger ranges. Slight sharpening appeared to be effective even before the P(-)P operation (especially when small linear objects were detected).

Mask

The both abovementioned procedures, tophat and smoothing, produced some artefacts which were given essentially by the functions themselves. These functions operated with the whole image. [Another possibility is to operate step-by-step, within some predestined segments or automatically identified, i.e. learned, objects]. According to our experience, there is a useful approach how all distinguishable strong, late diagenetical (disturbing) structures can be eliminated.

What are the disturbing structures? They are chiefly big and late metacrystals or coarse crystalline glomeroblasts (pyrite, quartz, albite, mica, chlorite, hornblende, etc.) or major crystal outlines and defects of late crystalline texture. These disturbances can be extracted to a series of separate images. Masks were processed by treshsegregator and/or control-outline procedures. Masked disturbance areas were amputated and they were substituted by average values. For these purposes the serial macros of P(–)P operations were prepared. After some training we were able to eliminate many of the superimposed strong disturbances. The result displayed the formerly less visible defects inherited in our image since the older diagenetical stages. Other joint operations are described as in the previous paragraph on smoothing based procedures, as below in the text.

Procedures analysing very dispersed or scattered relicts

The image of the extraced traces after old structures was many times uncontinuous because the individual locations of the preserved inherited positions were considerably spaced one from the other. The interspaces were almost totally cannibalized (or newly arranged) by strong consequent crystallization. A task arose how to reconstruct the original structure with the minimum loss of information. First attempts were devoted to the erosion by square or octagon kernel.

Nevertheless, this procedure was not always successful: E.g., in some images, the objects were enlarged and separated before any continuous structures could be traced. However, the procedures operating with small kernels which were intercalated by smoothing and sharpening of the images were successful in densely spaced and more continuous relict configurations (continuous due to diffusive dispersals of inherited crystal defects).

There were tested other utilities too in this task.

The first procedure was based on short linear kernels. In fact, this process simulated a shading in parallel lines according to the selected angle. This procedure was successful namely in metamorphic rocks where the relicts were dilated along the metamorphic foliations.

The second procedure was based on the smoothed and treshed binary image transformed in skeletization. Skeleton, eventually, in combination with the overlay of P(–)P products, provided other interesting images of original structures.

The utilization of the procedures or procedure series depended on the specifics of the rocks. Each of the metamorphic or diagenetical rock patterns as well as each of the detected structures needed an optimized procedure series. LUCIA-S software including the developed procedure series made the analysis quicker and more objective in comparison with previous visual and intuitive identification of inherited relict structures. Testing the LUCIA-S possibilities in a survey of original rock structures, we have produced about one thousand images and two hundred final image products of various types. A large scale of various rock structures was included in our experiments. We have obtained a first experience, which can be utilized in the automatical evaluation of larger monothematic series of samples.

4. Examples of Images: Interpreted Old structures

4.1. Original Sedimentary Particles and Fossils; Early Diagenetical Structures of Metamorphic Carbonates

The best introduction to image analysis procedure is the imaging of some well known objects. In this way we can examine the capability of individual imaging tools. Addi-

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tionally we can estimate the fidelity of our products comparing all images that were derived of one root. We can recommend this approach even before the setting up of any image-analysis routine (Pl. 1/1 an eye, Pl. 1/2 a seismic record).

As the first example we have examined the Devonian limestones from the Paleozoic autochthone below the Carpathian Mountains. Boreholes of the Krásná oil-field penetrated brecciated and recrystallized carbonates of this age. Repeated heavy diagenesis took place in the rock alteration because the Krásná oil-field was a part of the Devonian island elevation. Fluctuating dolomitization-dedolomitization, silicification-desilicification as well as replacements of evaporites by calcite or quartz belong to common processes that are recorded in these rocks. Variegated rock types from the KS-9 borehole NE of Ostrava were studied in respect of their possible original sedimentary particles. Despite the previous assumptions that dominant part of the limestones was built by breccias, we have found prevailingly pellets, peloids and lumps as the dominant primary particles of the sediments (Pl. 7/1; Pl. 4/2, 3). Peloidal layers continued with some interruptions through several diagenetical objects. We assume that at least part of the breccias that were hitherto identified here correspond, in fact, to "autobrecciated" sharp-edged diagenetical textures only. Bioclasts were less common than the peloidal particles (an example in Pl. 2/1). The best results were obtained in the rocks where the structure sequence (petrogenetogram) coincides the more fluent transitions of former diagenetical environments. On the other hand, refilled fossilmoldic and vug cavities, larger evaporite crystals replaced by calcite, or nests of coarsely crystallized dolomite provided, understandably, only poor if any data on the limestone sedimentary particles. Some of the investigated samples consisted originally of micrite. In this type of rocks, dominant discernible objects were the indicated aggregates of evaporite crystals (Pl. 4/1).

As the second group of the objects, various types of metamorphic carbonates were evaluated: i.e. probably Devonian limestones of the Upper Branná series of Jeseníky Mts. and Hanušovice Hills; probably Devonian carbonates of the eastern (Lesonice) as well as the western rim (Kadov, Žerotice) of the Miroslav metamorphic series near Znojmo; other metamorphic carbonate belts the Paleozoic age of which is plausible – localities at Skalice village in the vicinity of Znojmo, Moravian crystalline series. Additionally, high metamorphic carbonates of Moldanubian series of Southern Bohemia were also analysed. Generally we can say that the best results are accessible in fine crystalline massive carbonates of grey colour (Munsell Color Chart N3 to N4). However, any insufficiency of rock fluid during the shear or controversially an overflow of hot rock fluids, both indicated in rock history, are evidently serious contraindications of well preserved relict structures. In this relation we have to favour some tectonoclasts of the relatively best preservation or some "armoured" glomeroblasts that were affected by hot fluids in lesser measure in comparison with their surroundings (they were usually coated by fine crystalline aggregates of mica and graphitic coal).

Beginning from the metamorphic mesozone the reconstruction of the primary structures becomes to be difficult. The main reason of this situation are especially the very spaced locations of the oldest inherited structures. Scattered information provides, many times, only tentative possibilities of the explanation. For example, we have received eight significant oldest clusters in our final image but we are not sure how they can be connected, i.e. each of the connecting lines may not be validated. In relation to estimated sedimentary structures, the effectivity of imaged metamorphics is low. An assumption of the effectivity is about 2 % of predestined thin sections (in square 2 x 2 mm). However, the effectivity is increasing when the square is enlarged to 5 x 5 cm (best position – the rock face is parallel to the metamorphic foliation).

Image analysis shows probable small shelly fossils in the limestone of Kaple Hill locality near Znojmo (Pl. 2/3), possible stromatoporoid and shelly remains at Lesonice near Znojmo (Pl. 5/1), an oblique section of echinoid spine in a tectonoclast at Velké Vrbno, west of the Jeseník town (in the vicinity of Konstantin Graphite Mine), some probable crinoidal columnals at Skalice near Znojmo (Pl. 6/1), a possible algal or bryozoan (?) fragment at Stříbrný vrch near Znojmo, etc. Indications of certain bio- or lithoclasts occurred also in Moldanubian material (Pl. 6/2). Interpretation know how of primary structures in metamorphic rocks needs a critical approach to the reconstructed shapes, i.e. how relevant and frequent they are. The presented examples belong to the objects which were found repetitiously having reasonable circumstances of the interpretation.

4.2. A Model of Original Porosity Shape and Closing Porosity Sequence

After reaching the initial stages of the petrogenetogram (early to medium advanced diagenetical stages) we can detect the old aggregates of grains. Grain patterns, i.e. the grain size distribution and the regular or clustered spacing of the grains, determine the primary hollows. Margins of grains are simulated by the skeleton procedure. However, we do stop this procedure several times before the final skeleton product. In this way, we form a model of step-by-step closing hollows. This procedure acquires two input factors which must be defined. First of them is the real grain dimension: The grain dimensions result from pure relict image. The second attribute is the reasonable level of the first break of the skeleton procedure: The level must be determined according to sedimentological analogies. Several models of closing porosity sequence were processed in our experiments, both in non-metamorphic and metamorphic limestones. In metamorphic rocks we evaluated the sections which were parallel in respect to the foliation planes. It is why the model processed for metamorphosed limestone of Stříbrný vrch near Znojmo is quite similar to the non-metamorphic carbonates (Pl. 2/2). The developed technique is utilizable in studies on closing and opening solid collectors of gas and fluid.

4.3. Circular and Oval Sutures Originated in the Time-Interval Between Foliation and Final Recrystallization of Metamorphic Limestones

Many of fine crystalline, massive metamorphic limestones display sharp circular or oval but very thin fissures. Slight relicts of these structures were indicated, as a rule, already in the input image. Image analysis procedures enable the tentative placing of this phenomenon into the stage of continuous degradational recrystallization immediately after the released tectonic strain. Circles and ovals

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are usually arranged concentrically but examples of their excentric up to mutually cut series are common. Dimensions of ovals fluctuate but common ranges which have been observed are between 0.3 and 2.5 mm. The size between 0.4 and 0.6 mm is, as a rule, the most common (Pl. 3/1B, 2A, 2B). The ovals are evidently younger than metamorphic foliation (Pl. 3/2A, 3B). We assume according to the observation of other green schist metamorphics that these sutures are not an exceptional feature although they were never described. Structures of this type are very similar to the perlithic structure of volcanic glass (comp. FIALA 1987). The latter one originates due to volume discrepancies during the cooling and first ultra-fine crystallization. Ionic diffusive flow in a semi-solid state may be assumed as a possible additional factor of this discontinuity formation.

4.4. Separation of Individual Crystal Features: An Example of Organic Skeletal Structures

Tabulate coral microstructures are subject of many contemporaneous discussions. There exist several schools in these studies. The German school represented by K. OEKENTORP presented many evidences for the predominantly very late diagenetical origin of the microstructures (zig-zag structures, etc.). On the other hand the Russian school, in person V.N. DUBATOLOV, argued for the preservation of primary fibral or lamellar microstructures, at least as well visible relict structures. New investigations on microstructures have been based on ultra-thin-sections and wedge sections (F. TOURNEUR, J. LAFUSTE, Y. PLUSQUELLEC). This French school has found that the coral microstructure consists of fine crystalline aggregates in the medium suture zone, eventually of some spherolitic aggregates, but especially of the lamellar zone which consists of tablet calcite crystals. Calcite tablets in tabulate skeleton have been found in many corals. Representants of the French school assume that the tablet texture of peripheral wall layer is primary in origin. This approach was attacked by J. SORAUF during the VI. Fossil Cnidaria Symposium in Münster, 1991. In his opinion, the tablet microstructure is the most common diagenetic transformation of many layered organic skeletal structures.

Image analysis can contribute also to the above mentioned discussion on coral structures. We have analysed several Devonian tabulates of various basins and diagenetic history: e.g. *Favosites goldfussi* of the Barrandian, *Scoliopora denticulata* of the Carpathian basement and *Mariusilites* of the Moravian basin islands. Strikingly, we have received quite similar images in all the examined specimens. Zig-zag skalenohedra and rhombohedra, sometimes accompanied by pseudomicrite recrystallization, were the last (third) stage of secondary microstructures (Pl. 8/2A). The tablet pattern was assigned to the second stage (Pl. 8/1B, 2B). Fan-like diverged bunches of crystal fibres, locally with some skalenohedric decay of the same orientation, were assigned to the first stage (Pl. 8/1A). The secondary origin of the latter stage is confirmed by a very fluent continuation of fibre-crystal bunches from skeleton to cement (Pl. 8/2C). The primary microstructures had to be extremely fine crystalline, being usually prismatic or isometrical in shape of crystal individua, and they were essentially perpendicular to individual growth layers. But these true primary structures are poorly preserved. They are traceable only according to the relict pigment of growth layers being copied, in part, by the fibre bunches of early recrystallization series.

The above mentioned sequence of recrystallization is very simplified because the first changes of crystals precipitated by organic tissue begin, as generally accepted, immediately after the process of biomineralization, i.e. already during the life of the organism.

5. Conclusion

Image analysis appears to be a very powerful tool of detection as well as reconstruction of older rock structures. Although it is a powerful tool, the results of these procedures cannot be overestimated. Briefly, when nothing is involved in the input image then nothing is discovered also in the final image. The image analysis shows many advantages. The major one is the exactness of the operations. In this way, we have confirmed and discovered many significant hidden structures but, on the other hand, we have refused many other assumptive determinations. Another significant attribute of the image analysis is the possibility that we may quickly alternate on display many stored images of the same root. This comparison allowed us to learn much more about the nature of the relict structures.

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