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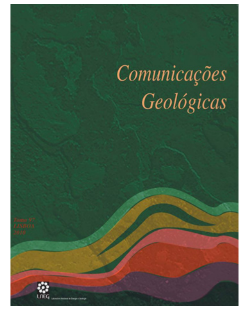
Quantification of synmagmatic flow structures of the Vila Pouca de Aguiar Pluton: a tool for rock structural and rock quality quantification



Quantificação das estruturas de fluxo sin-magmáticas do Plutão de Vila Pouca de Aguiar: uma ferramenta para a quantificação estrutural e da qualidade da rocha

M. Schwindinger[1], M. Peternell[1], B. C. Rodrigues[2*], J. Pamplona[3], E. Queirós[4], M. Oliveira[4]

Artigo Curto
Short Article

Abstract: Mineral distribution pattern of Variscan post-tectonic granites from Vila Pouca de Aguiar Pluton (NE Portugal) were analysed with methods partially based on fractal geometry and, with respect to rock inhomogeneity and anisotropy. The result of the analysis provides information about magmatic flux and mineral equilibrium processes in a crystallizing magma chamber. In addition, the used methods may also provide important information for the ornamental rock industry, because they allow fast and automatic evaluation of economic rock parameters.

Keywords: Patterns of inhomogeneity and anisotropy, Rock quality, MORFA, Map-counting, FROST.

Resumo: Os padrões de distribuição mineral dos granitos pós-tectónicos do plutão de Vila Pouca de Aguiar foram analisados com métodos parcialmente baseados na geometria fractal, atendendo à homogeneidade e anisotropia da rocha. O resultado desta análise forneceu informação acerca do fluxo magmático e dos processos de equilíbrio mineral na cristalização no interior de uma câmara magmática. Adicionalmente, os métodos utilizados ainda disponibilizaram informação importante para a indústria de pedra ornamental, pois permitem uma avaliação rápida e automática dos parâmetros que valorizam economicamente a rocha.

Palavras-chave: Padrões de heterogeneidade e de anisotropia, Qualidade da rocha, MORFA, *Map-counting*, FROST.

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1. Introduction

Methods of automated rock structure quantification are important to better understand the processes of rock evolution (e.g. rock deformation; Peternell & Kruhl, 2009). Their application to rock surfaces may reveal information about the condition during the rock formation. In addition, the pattern of a rock, i.e., the geometrical arrangement of its components (e.g. minerals or xenoliths) characterizes how a rock appears to the human eyes. This has an important impact for the selection of ornamental rocks.

In general rock structures use to be very complex or diffuse and therefore the pattern, which is defined by this complexity, is often hard to determine by classical quantification methods (Kruhl, 2013). However, methods of fractal geometry offer the possibility to analyse such structures. This study applies these methods on mineral distribution pattern of Variscan post-tectonic granites of the Vila Pouca de Aguiar Pluton (NE Portugal). The result of the analysis provides information about pattern inhomogeneity and anisotropy, i.e. magmatic flux directions and mineral equilibrium processes in the crystallizing magma chamber. In addition, the possibilities of an application of the software for the economic classification of the rock are discussed.

2. Geology

The studied outcrops belong to the Vila Pouca de Aguiar Pluton, which is located in the Central Iberian Zone of the Iberian Massif (Fig. 1). The pluton has a NNE-SSW elongated shape and an extension of about 200 km^2. Based on radiometric dating and the crosscut of the pluton, the granites are syn-intrusive to the last deformation phase (D3), the Vila Pouca de Aguiar Pluton is supposed to have a post-orogenic origin (299-290 Ma, Ferreira *et al.*, 1987). The massif itself consists of two main granite facies, which define a concentric zoning in the pluton but, without a clear crosscut between them: the Vila Pouca de Aguiar granite and the Pedras Salgadas granite (PSG, Martins *et al.*, 2009). Both types are porphyritic biotite-granites and are primarily distinguished by their grain size and biotite content. The more leucogratic Pedras Salgadas granite occupies the central position in the pluton, has a smaller grain size and is more homogenous than the peripheral

Vila Pouca de Aguiar granite. All outcrops of the presented study belong to the PSG facies and were located inside the Irmãos Queirós Quarry. Two granite phases of different appearance and economic quality were distinguishable inside the quarry and are separated by sharp contacts: a homogeneous, equal grained granite phase and a large grained phase rich in cumulated feldspar, schlieren and small mafic enclaves. But both have in common that neither a magmatic foliation nor a lineation is visible in the rock.

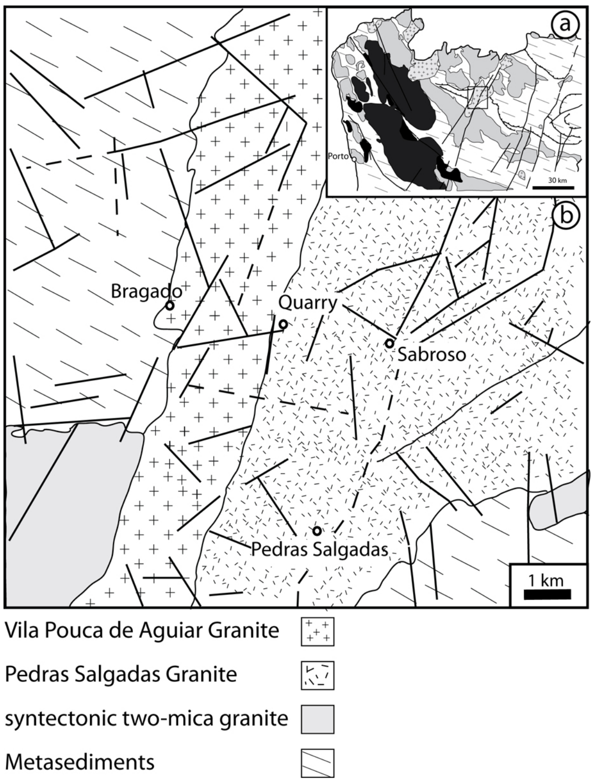

Fig. 1. Tectonic setting of the study area. (a) Syn- to postorogenic granitoids of Central Iberian Zone, modified from geological map of Portugal, scale 1:1 000 000. (b) Study area inside the Vila Pouca de Aguiar pluton, modified after geological map of Portugal, scale 1:50 000, sheet 6-D.

Fig. 1. Enquadramento tectónico da área estudada. (a) Granitos sin- a pós–orogénicos da Zona Centro-Ibérica, adaptado do mapa geológico de Portugal à escala 1:1 000 000 (2010). (b) Área de estudo no interior do plutão de Vila Pouca de Aguiar pluton, adaptado do mapa geológico de Portugal à escala 1:50 000 (Noronha *et al*., 1998), folha 6-D.

3. Sampling and processing

The work, in the active quarry of Irmãos Queirós, has the advantage that large, clean (sawn) cut rock surfaces and moreover cuts of different orientation are accessible for analysis. The source materials for the analysis of the rock pattern are formed by high resolution field photographs taken from six rock surfaces and three perpendicular cuts within the quarry. The high resolution was achieved by taking many single overlapping images of a surface, which were stitched together afterwards. The large connected image is a copy of the surface and ready for further computer-aided processing. The photographed surfaces had an extent of several square meters with 4.75 m^2 being the smallest and 19 m^2 the largest surface. To obtain an illustration of the geometric pattern of specific mineral phases, the images were converted in ImageJ and Photoshop software® to binary representations of the mineral. Parallel to the phase segmentation the images were cleaned by artificial artefacts to avoid an influence on the following pattern quantification. Typical occurring artefacts were reflections of water and the sun on rock surfaces and dirt or scratch marks produced by the heavy machines of the quarry. Figure 2 illustrates the difference between a raw surface and a processed image of it.

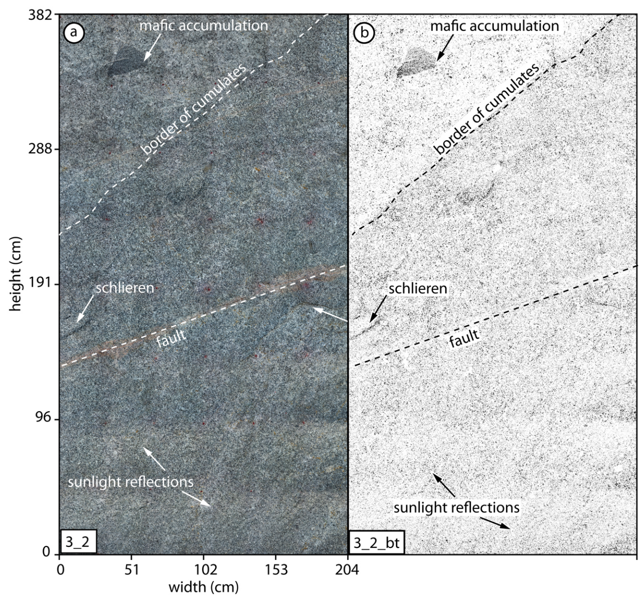

Fig. 2. Image processing. (a) Raw, stitched image of a horizontal plane. The surfaces contain features such as mafic accumulations, schlieren, rock spalling, faults and a transition between fine-grained Pedras Salgadas Granite and the cumulative phase. (b) Same image after the clean up and the segmentation of biotite.

Fig. 2. Processamento de imagem. (a) imagem não tratada, montada num plano horizontal. As superfícies contêm aspectos tais como acumulações máficas, "schlieren", fragmentação da rocha, falhas e uma transição entre o Granito de Pedras Salgadas, de grão fino, e a fase cumulativa. (b) A mesma imagem após limpeza e a segmentação da biotite.

4. Methodology

The binary images of the two mineral phases biotite and feldspar were analysed with MORFA and MapCounting-software (Peternell *et al*., 2011). The software applies principles of fractal geometry to determine anisotropy and inhomogeneity of a geometric pattern in very high resolution. Both methods result in a color-coded map of the analysed structure with a pre-defined resolution. In case of MORFA the colours indicate the strength of the pattern anisotropy and are paired with a vector marking the pattern preferred orientation. In case of Map-counting the map shows the variation of the patterns fractal dimension. The software also enables to calculate statistical bulk orientation vectors of a pattern. This allows both to visualize domains of preferred anisotropy, just as a general trend of the direction.

With respect to the applied resolution of the software and the size of the analysed rock surface, 4838 – 20037 single measurements were performed for each rock surface for MORFA. In case of Map-Counting, 129717 – 533976 measurements were performed. Because the code in Map-Counting allows a much faster computing it is possible to set a higher resolution.

5. Discussion

5.1. Rock structural analysis

The classical spatial representation of MORFA revealed a very diffuse alignment of the anisotropy vectors. Each surface reveals many different domains with a varying pattern orientation and, the pattern often appears completely isotropic. This coincides with the general very weak measured anisotropy intensity. Intensities range between 0.7 and 0.9. High anisotropy patter would have values below 0.7. However the diffuse data can be useful if they are plotted into a bivariate diagram to determine the frequencies of the anisotropy directions and their intensity. This statistical evaluation results in a bulk orientation vector that varies in strength, dependent on the orientation of the analysed rock surface. Since feldspar and biotite are igneous grown minerals with generally strong shape preferred orientation, their alignment in a pluton can be indicative for a magmatic foliation (Paterson *et al*., 1989). Therefore it is possible to use the varying bulk anisotropy strength and direction to determine magmatic flow directions. In case of the outcrop, an extreme weak subhorizontal magmatic foliation (012/15 NW) and a subhorizontal lineation (15/010) were estimated statistically out of the dataset (Fig. 3). The moderate westward dip has an alignment parallel to the external pluton contacts typical for magmatic foliation (Paterson *et al*., 1989). Furthermore, the measurements are in good coincidence of earlier anisotropy magnetic susceptibility (AMS) results of Sant'Ovaia (2000) and Sant'Ovaia & Noronha (2005) in the region. A more accurate comparison between the two methods would need a higher amount of AMS data from exactly the same quarry. Because AMS drillings are like pinpricks in the rock and do not cover spatial variation, it may be difficult to rate the accuracy in a very weak anisotropic rock. So sampling in a rock with a very heterogeneous pattern, such as the studied granite, will be very sensitive to the location of the sample.

During the pattern inhomogeneity analysis with Map-Counting a for all cuts valid mean fractal dimension of D_b=1.55 was determined. The correlation of determination R^2 is for almost all measurements above 0.994 by which fractal behaviour in the mineral arrangement is likely (Peternell & Kruhl, 2009). The homogenous results for most surfaces are indicative for near equilibrium conditions of mineral crystallization during emplacement of the pluton. Therefore processes acted during rock formation were similar for homogenous areas of all cuts. Schlieren, enclaves or artificial relics locally change the mineral pattern and can be easily identified by a changed fractal dimension. Locally, the feldspar cumulated phase show wider D_b-ranges caused by processes such as magma mixing and extraction.

5.2. Rock quality evaluation

Apart from the structural and petrological point of view, an application of the methods for the ornamental rock industry is possible. Quarries active in the mining of ornamental rock have to evaluate the quality of their products. In general, stones with very homogeneous patterns are of higher value for the stone industry. As a natural material, formed by the interaction of various geological processes, granite is not homogeneous over large scales. Schlieren, mafic enclaves, variation in grain size or the cumulative phase in the studied quarry mark heterogeneities which are undesirable and lower the market value of the rock (Taboada *et al*., 1999). During the application of Map-Counting these features can be visualized by contrasting Db-values (Fig. 4).

As far as homogeneity is an essential criterion for economic quality of the rock, the method may be used to determine quarry internal homogeneity distribution and to build up a classification scheme that discriminates various degrees of homogeneity. In this way, the former objectively rock homogeneity can be quantified with absolute numbers and certificated if wanted. As the economic market prefers homogeneous granites, companies owning this high quality rock can stand out against other by a certification. Low quality rock would consequently get no certificate and has to be sold at lower prices. With time customers may prefer certificated granite and a demand is created.

This classification is also advantageous for the end-user, because it offers him a possibility to compare offers and to understand prices. Problems may arise from quarries with less homogeneous rocks, which do no benefit from the classification. But homogeneity is more an aesthetic criterion and relies on natural processes and it is doubtful if the classification should only be based on this single parameter.

Additionally, quantification and knowledge of inhomogeneity and anisotropy distributions in a quarry can provide important information for a mining engineer in directing the mining operations. Based on images taken from superficial rock surfaces it is possible to quickly determine anisotropy directions from mineral distributions, which form preferred directions in the mining.

6. Conclusions

Based on high resolution and large-scale recording and quantification of mineral distribution pattern from three perpendicular cuts inside a granite quarry, the presented study shows:

(1) For rocks with no visible anisotropy direction, nor in outcrop neither in thin section, it is possible to determine tendencies of preferred mineral orientation. The implementation of the histogram representation enables to calculate bulk orientation vectors and hence to obtain a 3-dimensional distribution of the vectors from different section.

(2) Map-Counting visualizes pattern inhomogeneity distribution and allows conclusions about internal crystallization conditions. Mostly homogeneous distribution of Db-values indicates near equilibrium conditions during pluton crystallization. Slight disequilibria in the cumulates are indicated by broader ranges of fractal dimension in Map-Counting and by the occurrence of a higher numbers of schlieren and enclaves.

(3) A possible future application of the method lies in the quality assurance of ornamental quarries. The methods have to be improved in a way to integrate and automate the structure recording and quantification in the rock treatment process. In this way, quarries can develop a quality classification scheme, which is based on homogeneity. A certification benefits both the quarry owners by standing out against other and the end-user by providing him comprehensible criteria of different prices.

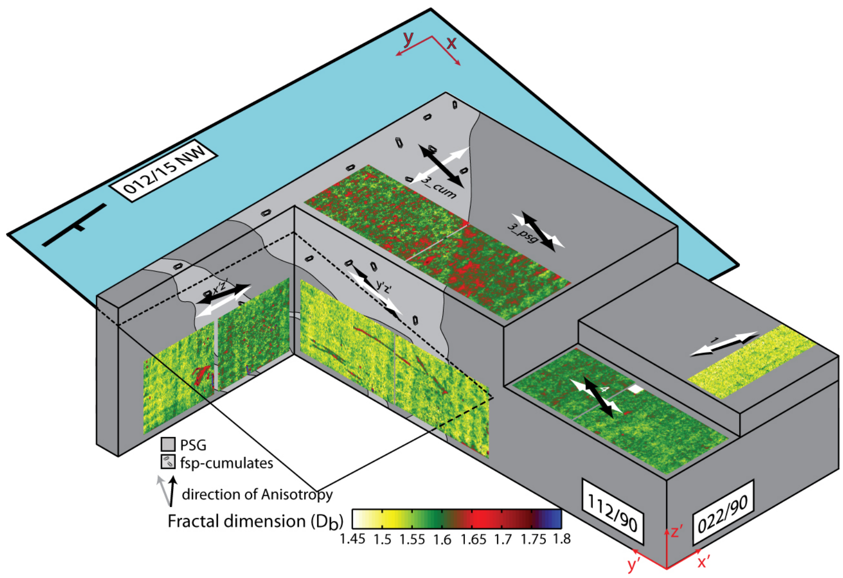

Fig. 3. Summarized results of the pattern analysis. The coloured planes show the Map-Counting results at their original position in the quarry. The bulk orientation vectors of MORFA-analysis are indicated by black and white arrows representing biotite and feldspar results on for each surface. Based on this result the estimated orientation of the foliation plane was drawn into the sketch (blue plane).

Fig. 3. Síntese dos resultados da análise de padrões. Os planos coloridos mostram os resultados do "Map-Counting" obtidos na sua posição original na pedreira. Os vectores de orientação da análise MORFA, indicados por setas pretas e brancas, representam os resultados obtidos para a biotite e o feldspato em cada uma das superfícies. Com base nestes resultados a orientação estimada para o plano de foliação foi desenhado no esquema (plano azul).

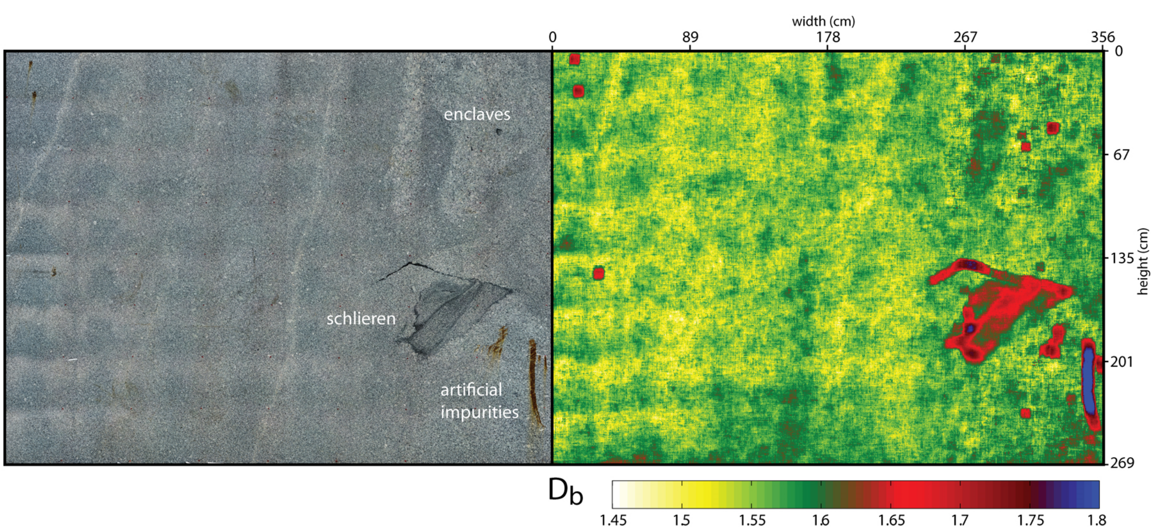

Fig. 4. Analysis of a granite surface with Map-Counting. Inhomogeneities, as an impairment of quality, strike out by higher D_b-values.

Fig. 4. Análise duma superfície do granito com "Map-Counting". As heterogeneidades, sendo um aspecto comprometedor da qualidade da rocha, são identificadas através dos valores elevados de D_b.

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