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Factors affecting alkali-reactivity of quartz-rich metamorphic rocks: Qualitative vs. quantitative microscopy

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ABSTRACT

Several types of quartz-rich metamorphic rocks (medium-grained quartzite, fine-grained paragneiss, and fine-grained calc-silicate rock) all from the Těchobuz quarry (Moldanubian Zone, Bohemian Massif, Czech Republic) were investigated with the intention to quantify their alkali–silica reaction (ASR) potential, as well as to identify the alkali-reactive mineral phases. Mineralogical-petrographic methods (polarizing microscopy combined with cathodoluminescence, scanning electron microscopy combined with energy dispersive spectrometer, and petrographic image analysis) were combined with experimentally-determined data, obtained by the accelerated mortar bar test (following ASTM C1260). From the mineral and microstructural data of selected quartz-rich metamorphic rocks, the following parameters were proven to correlate positively with ASR susceptibility: quartz content, area, perimeter, and equivalent diameter. No correlations were indicated with shape parameters (shape factor, aspect ratio) or the specific surface. Except for the influence of the quartz content, all of our data were contradictory to the conclusions generally accepted as being connected to the ASR of quartz-rich rocks. Three factors were suggested to explain this contradiction. Quartzite (Samples A and B) and calc-silicate rock (Sample D) were typical of: quartz with an undulose extinction, with formation of quartz subgrains; alteration of plagioclase; and a more homeoblastic fabric (granoblastic microstructure). In contrast, the paragneiss (Sample C) was characterized by quartz, which indicated no deformation features; rare plagioclase alteration; and a heteroblastic fabric (poikiloblastic microstructure). Quartz with an undulose extinction, and the formation of quartz subgrains are accompanied by increased dislocation density in quartz, and by higher ASR potential. The results obtained indicate that a straightforward application of petrographic image analysis, alone, does not necessarily provide the required discriminatory potential. More reliable results were obtained when the petrographic image analysis was combined with qualitative microscopy.

1. Introduction

The alkali–silica reaction (ASR) is one of the most deleterious processes affecting the durability of concrete structures (Mehta, 1991). ASR originates when reactive silica (SiO_2) is present in the aggregate, which under wet conditions can react with alkaline ions in the concrete pore solution (Fournier and Bérubé, 2000). The reaction mechanism consists of several successive steps: initial attack of OH^- compounds on the SiO_2 at the aggregate–cement paste boundary; formation of silanol groups at the SiO_2 surface; formation of siloxane groups, and their polymerization; adsorption of alkaline and Ca^{2+} ions, and formation of alkali–silica gels (Bulteel et al., 2004; Broekmans, 2012; Fernandes and Broekmans, 2013). Pervasive micro- and macro-cracking of concrete structures results from the swelling of alkali–silica gels after their absorption of water molecules (Garcia-Diaz et al., 2006).

A combination of detailed petrographic analysis of the aggregates plus experimental testing methods (e.g., accelerated mortar bar test), is considered to be the most effective tool with which to assess the ASR potential of aggregates that are to be used for concrete (e.g., Lindgård et al., 2010; Castro and Wigum, 2012). Such a methodical approach meets most of the requirements from the construction industry, which requires rapid and sound test results. Petrographic methods are generally based on microscopic investigations of aggregates employing a polarizing microscope. The number of phases contributing to ASR is quantified, based on point counting and/or image analysis (e.g., RILEM AAR 1). The accelerated mortar bar test (e.g., ASTM C1260), and the ultra-accelerated mortar bar test (e.g., RILEM AAR 2) enable the quantification of ASR potential based on expansion values of mortar bars prepared from the aggregates investigated, and it also allows for a satisfactory interlaboratory correlation of both the test methods and results.

Various forms of silica (SiO_2), especially its crystalline variety, quartz, can be found as one of the major rock-forming minerals in many different rock types widely used in the construction industry (e.g., granites, granodiorites, mylonite, gneiss, quartzite, greywacke, phyllite, and argillite) (Broekmans, 2004). The ASR potential of quartz-bearing rocks is highly variable (e.g., Hagelia and Fernandes,

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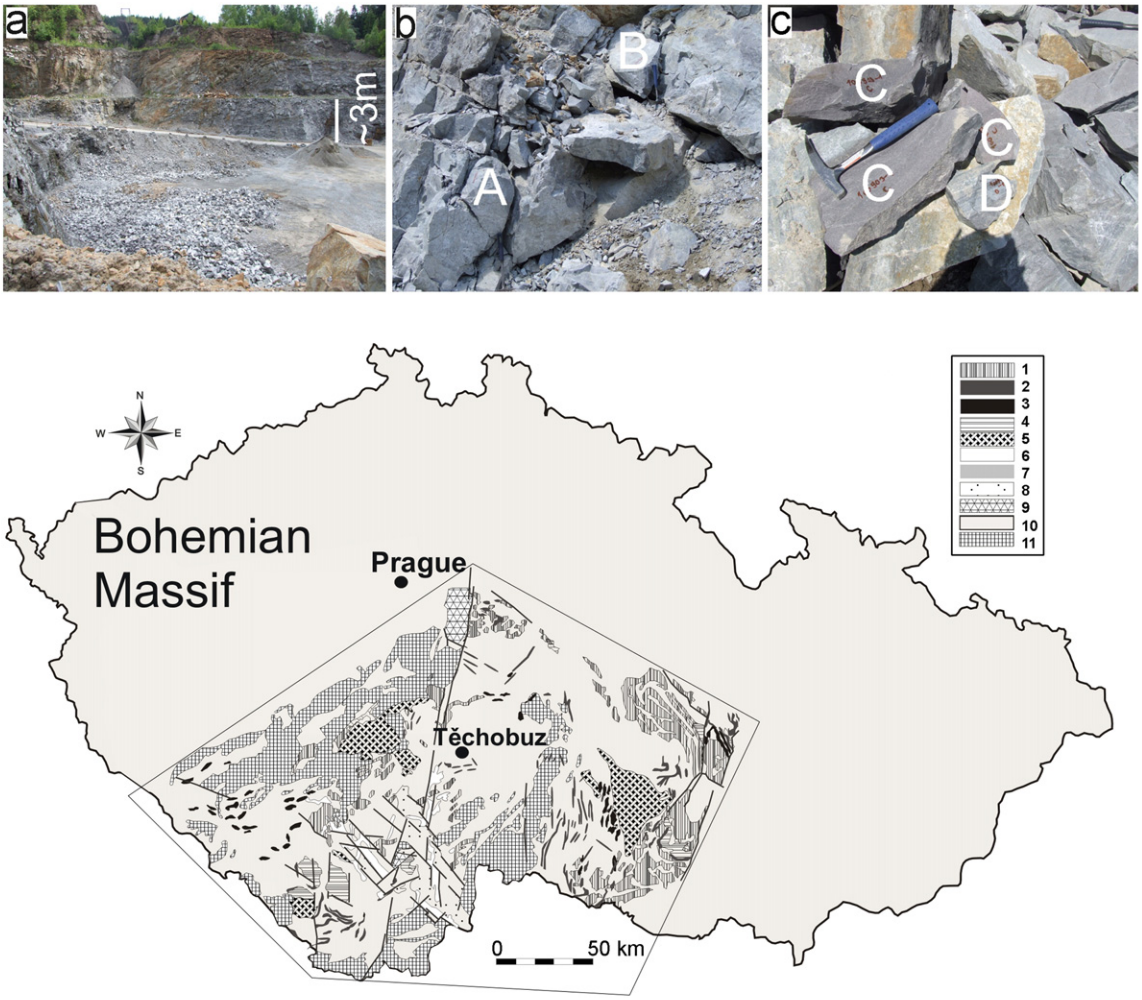

Fig. 1. (above): Overview of the Těchobuz quarry (a) and macroimages of Samples A and B (b), Samples C and D (c); (below): A simplified geological map of the area studied within the Bohemian Massif (Czech Republic, bordered area) showing the position of the Těchobuz quarry: 1 orthogneisses (Proterozoic–Paleozoic); 2 amphibolites (Proterozoic–Paleozoic); 3 crystalline limestones (Proterozoic–Paleozoic); 4 granulites (Proterozoic–Paleozoic); 5 durbachites (Paleozoic); 6 sands, sandstones, clays, claystones (Neogene and Paleogene); 7 volcanites (Neogene and Paleogene); 8 sandstones, marlstones, limestones (Cretaceous); 9 sandstones, siltstones, conglomerates and other sedimentary rocks (Permian); 10 paragneisses, phyllites, granulites, migmatites, eclogites and other metamorphic rocks (Cambrian and Proterozoic); 11 granites (Variscan and Prevariscan). The legend of the geological map is valid only for the area within the pentagon.

Table 1
Definitions of the microfabric parameters, measured and calculated, using the petrographic image analysis.
Modified after Přikryl (2006).

Fabric parameter	Unit	Definition
Area	mm^2	The area of the analysed object (SPSS Inc., 2014)
Perimeter	mm	The length of objects boundary (SPSS Inc., 2014)
Equivalent diameter	mm	Diameter of circle, which has the same area as measured object; Equivalent diameter $= (4 \times \text{area} / \pi)^{1/2}$ (Petruk, 1986)
Major (minor) axis length	mm	Length between the two most distant points on the object (major) or between two most distant points on the object that creates a line perpendicular to the major axis (minor) (SPSS Inc., 2014)
Compactness	–	Shape of the object cross-section; Compactness $= \text{perimeter}^2 / \text{area}$ (SPSS Inc., 2014)
Shape (form) factor	–	Shape factor indicates circularity of investigated object; Shape factor $= 4 \times \pi \times \text{area} / \text{perimeter}^2$, Shape factor of the circle = 1, Shape factor of the line object ~ 0 (Howarth and Rowlands, 1987)
Aspect ratio	–	Calculated as ratio of major and minor axis lengths, Aspect ratio of the circle = 1, Aspect ratio of line object ~ ∞ (Přikryl, 2006)
Specific surface	mm/mm^2	Calculated from total perimeter divided by total area Specific surface $= 4 / \pi * \text{perimeter} / \text{area}$ (García del Amo and Calvo Pérez, 2001)
Index of grain size homogeneity	–	Grain size distribution (homeoblastic vs. heteroblastic); index of grain size homogeneity $= \text{average area} / \sqrt{\Sigma(\text{area of individual grain} - \text{average area})^2}$ (Dreyer, 1973)
Modal composition	vol.%	Modal composition $= (\sum \text{area minA} * 100 / \sum \text{area tot}) + (\sum \text{area minB} * 100 / \sum \text{area tot}) + \ldots$ $+ (\sum \text{area minX} * 100 / \sum \text{area tot})$ (Gillespie and Styles, 1999)