A new method for quantitative petrography based on image processing of chemical element maps: Part I. Mineral mapping applied to compacted bentonites

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ABSTRACT

Most natural rocks or engineered materials display a multi-scale heterogeneity ranging from the nanometer to the centimeter. Their spatial textural heterogeneity can be approached from chemical element maps acquired using various techniques (SEM, EPMA, SXAM, synchrotron µ-XRF, TEM), depending on the chosen magnification. Chemical map processing that yields quantitative petrographic information is improved here according to newly developed mineral thresholding methods that accommodate mixtures and solid solutions. The complex case of an MX80 compacted bentonite is used as a test case. The 14 major chemical elements of this sample were mapped using an electron probe microanalyzer, and chemical map processing yielded a quantitative map of the 18 mineral species of bentonite with a spatial resolution of a few micrometers. The textural heterogeneity of the solid part of the sample is thus visualized and quantified on an area ranging between 0.1–1 cm². The method also provides a complete modal analysis of the sample. The methodology is expected to have broad applications in Earth and materials sciences.

Keywords: Chemical map, mineral map, software, modal analysis, image analysis, texture, microstructure, electron microprobe

INTRODUCTION

Recent advances in quantitative petrology have been achieved through the extensive use of modern image processing techniques. Such methods can provide quantitative measurements of the spatial heterogeneity of rock texture, which can be then used to model petrophysical properties (permeability, diffusion, electrical conductivity, deformation, etc.). In this context, the exact relationships between mineral species and pore space distributions have to be determined accurately, as fluid migration and fluid-rock interactions primarily occur in the voids of the rocks.

Most natural rocks and engineered materials are formed with diverse minerals that are heterogeneously distributed. As bulk analysis techniques such as X-ray diffraction (XRD) do not provide any quantitative information about the texture of rocks, petrographers have long recognized the need to obtain accurate mineral maps and modal analyses at the microscopic scale (Williams et al. 1988). Various detection techniques can be used to derive mineralogical maps: backscattered electron imaging (BSE; Dilks and Graham 1985; Hall and Lloyd 1981; Krinsley et al. 1998; Petruk 1988), cathodoluminescence (Götze and Magnus 1997), optical microscopy (Fueten 1997; Goodchild and Fueten 1998), or chemical colorations (Robert et al. 2003; Sammartino et al. 1999; Sardini et al. 1999a, 1999b, 2001, 2006). The methods based on chemical element maps acquired by scanning electron microscope (SEM) or electron probe microanalyzer (EPMA) are considered the most sensitive and suitable to derive mineralogical maps.

To provide mineralogical maps, the chemical element maps are usually treated by thresholding procedures on the basis of upper and lower limits of concentration using either atomic/oxide weight percentages (Berrier et al. 1997; Cossio and Borghi 1998; Tinkham and Ghent 2005; Tovey and Krinsley 1991; Tovey et al. 1992) or cation formula (CF) calculated for each pixel of the mapped area (Clarke et al. 2001; Cossio et al. 2002). Such procedures are rather tedious and highly subjective in their choice of threshold values. Furthermore, they cannot be easily applied to extended solid solutions through the same sample and are not able to properly analyze mineral mixtures that are often encountered when dealing with finely divided materials. Semi-automatic statistical treatments of multi-elemental maps (De Andrade et al. 2006; Fandrich et al. 2007; Launeau et al. 1994; Michibayashi et al. 1999; Pownceby et al. 2007; Togami et al. 2000) have been