

# Semi-automatic segmentation of petrographic thin section images using a “seeded-region growing algorithm” with an application to characterize weathered subarkose sandstone



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## ABSTRACT

Accurate imaging of minerals in petrographic thin sections using (semi)-automatic image segmentation techniques remains a challenging task chiefly due to the optical similarity of adjacent grains or grain aggregates rendering definition of grain boundaries difficult. We present a new semi-automatic image segmentation workflow for the quantitative analysis of microscopic grain fabrics. The workflow uses an automated seeded region growing algorithm, which is based on variance analysis of five or more RGB images. The workflow is implemented in the open-source Geographic Information System (GIS) software SAGA (System for Automated Geoscientific Analyses). SAGA provides all required tools for image analysis and geographic referencing. It also features a graphical user interface that allows the user to simultaneously display and link multiple images and, thus, facilitates manual post-processing of the images. SAGA's capabilities for vector data analysis offer instant calculation and visualization of the compiled geometric database within a GIS environment. Specifically, grain contacts are automatically identified by lines of intersection and manually classified by contact type to characterize the mineral fabric of petrographic thin sections. To demonstrate the effectiveness of the workflow, 39 transmitted light images of 13 weathered sandstone samples of the Buntsandstein Formation in northwestern Germany were analyzed. Based on the segmentation results obtained from the samples, a number of parameters, including modal composition, geometry of grain contacts, porosity, and grain size distribution were determined and statistically evaluated. The results of the image analysis are utilized to assess the weathering susceptibility of the sandstone samples and point to the importance of cementation determining the geo-technical properties of a given sandstone sample.

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## 1. Introduction

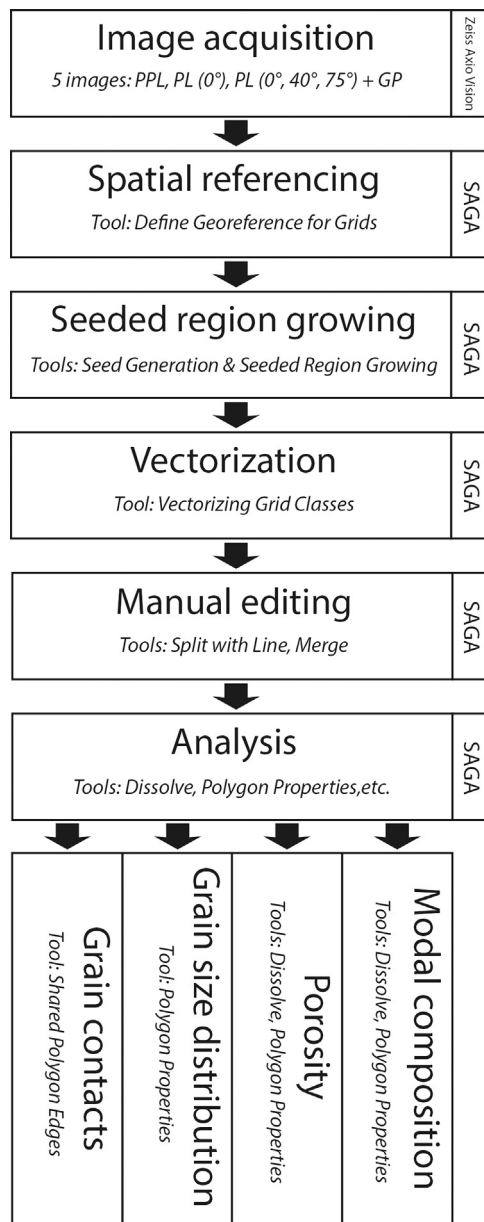
Quantitative analysis of petrographic thin sections regarding mineralogical composition, rock structure and texture is a time consuming task. Therefore, (semi)-automatic imaging methods aimed at quantifying grain size, grain shapes and grain contacts are commonly applied to characterize mineral shape fabrics and determine modal rock composition. Because of the difficulty in analyzing the entire area of a thin section and documenting grain and fabric data in terms of position in a given thin section image, these methods rarely deliver reproducible mineral fabric data (Tarquini and Favalli, 2010). A number of computer imaging techniques for petrographic thin section analysis address the issue

of linking fabric data to a specific reference frame (e.g., Terribile and FitzPatrick, 1992; Launeau et al., 1994; Francus, 1998; Goodchild and Fueten, 1998; Heilbronner, 2000; van den Berg et al. 2002; Barraud, 2006; Choudhury et al., 2006; Li et al., 2008; Tarquini and Favalli, 2010; Gorsevski et al., 2012; Mingireanov Filho et al., 2013; Zhang et al., 2014). Individual approaches include Geographic Information System (GIS) techniques specifically tailored to analyzing petrographic thin section images, such as ImageJ (Abràmoff et al., 2004) and JMicrovison (Roduit, 2008), and commercial image processing software, such as Adobe Photoshop (Zhang et al., 2014). Such computer-assisted approaches aim at creating polygons representing grain boundaries but, with the exception of GIS-based approaches, do not allow editing of polygons (Barraud, 2006).

We present a novel workflow (Fig. 1) that includes the application of a semi-automated segmentation technique and object analysis to characterize mineral fabrics with respect to position in

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**Fig. 1.** Workflow introduced in this study for semi-automatic image segmentation and mineral fabric analysis. PPL: Plane-polarized light, PL: Polarized light, GP: Gypsum plate.

the thin section frame of reference. The workflow encompasses three major components: (i) segmentation of an image into grain objects, (ii) data management, and (iii) assessment of geometric properties of grain objects. The workflow is entirely embedded within the open-source GIS software SAGA (System for Automated Geoscientific Analysis) (Conrad, 2007, 2015). Due to its multi-disciplinary design, SAGA offers tools from the fields of remote sensing, such as the seeded region growing algorithm (Adams and Bischof, 1994) and geometric polygon shape analyses. All tools used in the presented workflow are implemented in SAGA and are ready to use.

The concept of the applied region growing algorithm is based on the detection of spectrally homogeneous areas within a given subregion of a thin section (Tarquini and Favalli, 2010). Our image segmentation approach provides the user with objective, accurate and reproducible results of a slightly over-segmented vector dataset (Barraud, 2006). The segmentation method generates objects

that are spectrally homogeneous, i.e., characterized by similar color values, and allows the user to manually select and trace complex grain objects. This approach is of particular advantage in cases where mineral fabrics consist of e.g., polycrystalline aggregates, crystals with undulatory extinction or a large proportion of secondary minerals (Mingireanov Filho et al., 2013). To demonstrate the applicability of the workflow, fabric data are extracted from a set of weathered sandstone samples of the Buntsandstein Formation (Fig. 2) from the Göttinger Wald area in Germany. More specifically, the fabric data is used to correlate macroscopically identified weathering grades with the micro-structure of sandstone samples. Individual datasets obtained from the mineral fabric analysis include information on grain size, grain contacts, modal composition, and porosity, as well as spatial relationships between grain objects.

## 2. Background information on mineral imaging techniques

Currently, there are four distinct techniques of segmenting a digital image into spectrally homogeneous objects, including (i) threshold, (ii) boundary-based, (iii) region-based, and (iv) hybrid techniques. Collectively, these techniques have been used to identify grain boundaries in thin section images. Threshold techniques merge color values of a certain range to classes, each one of which represents an object type (Terribile and FitzPatrick, 1992; Launeau et al., 1994; Francus, 1998; Zhang et al., 2014). The boundary-based technique assumes an abrupt color change across grain contacts and identifies the boundaries by gradient operators (Goodchild and Fueten, 1998; Heilbronner, 2000; van den Berg et al. 2002; Li et al., 2008; Gorsevski et al., 2012). Region-based techniques merge neighboring pixels with similar color values within a certain distance to outline the target grain objects (Shih and Cheng, 2005; Barraud, 2006; Tarquini and Favalli, 2010; Mingireanov Filho et al., 2013). Hybrid techniques use a combination of region and boundary-based methods (Adams and Bischof, 1994; Shih and Cheng, 2005; Choudhury et al., 2006; Tarquini and Favalli, 2010).

GIS has proven to be a powerful platform for specific parts or even the entire workflow of an image segmentation procedure (Barraud, 2006; Li et al., 2008; Tarquini and Favalli, 2010; Gorsevski et al., 2012). For example, segmentation of grain objects in a GIS provides editable polygonal objects. Moreover, GIS allows the user to simultaneously process raster and vector data. Vector data is of advantage for manual post-processing as data describing polygonal grain objects can be easily edited in a GIS. Each polygon is identified as a single object with various quantitative attributes such as area, perimeter, maximum and minimum diameters as well as composition (Barraud, 2006) resulting in a comprehensive database. Geo-referencing options in a GIS are manipulated to represent the spatial extent and resolution of the thin section image. As a result, the compiled parameters are spatially referenced and, thus, can be spatially related or superimposed on other datasets.

## 3. Methodology

Following image acquisition, the workflow consists of: (i) defining the spatial reference frame for the thin section image, (ii) applying a seeded region growing algorithm, and (iii) manual post-processing (Fig. 1). Subsequently, modal component, pore space, and grain size distribution are analyzed as well as grain contacts identified. The procedure is applied to 13 thin sections, each of which consists of three image subsets as a means to increase the statistical significance of the analysis. For individual

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