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# Development of a geometallurgical framework to quantify mineral textures for process prediction

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ABSTRACT

A geometallurgical framework was developed in three steps using the Malmberget iron ore deposit, northern Sweden, as a case study. It is based on a mineralogical-particle approach which means that the mineralogical information is the main focus. Firstly, the geological model describes quantitatively the variation in modal composition and mineral textures within the ore body. Traditional geological textural descriptions are qualitative and therefore a quantitative method that distinguishes different mineral textures that can be categorised into textural archetypes was developed.

The second step of the geometallurgical framework is a particle breakage model which forecasts how ore will break in comminution and which kind of particles will be generated. A simple algorithm was developed to estimate the liberation distribution for the progenies of each textural archetype. The model enables numerical prediction of the liberation spectrum as modal mineralogy varies. The third step includes a process model describing quantitatively how particles with varying particle size and composition behave in each unit process stage. As a whole the geometallurgical framework considers the geological model in terms of modal composition and textural type. The particle breakage model forecasts the liberation distribution of the corresponding feed to the concentration process and the process model returns the metallurgical response in terms of product quality (grade) and efficacy (recovery).

## 1. Introduction

Geometallurgy embraces geological and metallurgical information to create spatially-based predictive models (3D) of ore bodies that supply all relevant information for mineral processes (Lamberg, 2011). The industrial application of geometallurgy is a structured effort to bridge all the relevant knowledge of the resource for production planning and management, also called geometallurgical program.

Geometallurgical programs are needed for better resource management and to lower the risk in the process operation related to geological variations within the ore body. It is a vital part of the profitability of the operation. The mine needs to have the capability to adjust the concentration process and the product qualities to meet the requirements of a changeable global market e.g. by a more effective utilisation of the ore resources or the ability to handle larger volumes of lower grade ore. Today there exist different kinds of geometallurgical models depending on the ore, its quality and the mineral processing circuit (e.g., Alruiz et al., 2009; Suazo et al., 2010; Hunt et al., 2012).

Most of the geometallurgical programs are established by using certain steps and rely on metallurgical and geometallurgical testing (Dobby et al., 2004; Bulled and McInnes, 2005; David, 2007; Lamberg, 2011). Commonly a series of representative ore samples is collected and are then tested to measure the metallurgical response directly with a standard methodology (e.g. standard flotation test). There are fundamental reliance on the representativeness of the samples and tests since they link the ore with the metallurgical response. As the sample set should include all variability in the ore this is often called a variability test. Based on the test results, a mathematical model is created to explain the metallurgical response based on the sample characteristics.

Iron mines are big volume operations and the production is driven by throughput. Most iron ore companies produce high volumes of iron ore products with a Fe grade between 62% and 64%. Examples of such production are direct shipping of hematite ores in Australia and Brazil (Poveromo, 1999). The Swedish iron ore producer, LKAB, represents another type of production strategy. They produce custom high grade iron ore pellets (>67% Fe) and fines for blast furnaces and direct reduction (LKAB, 2011). A good

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understanding of the tangible properties of the raw material and its variability is essential in both the strategies. In the direct shipping ores the production chain is very short; normally it includes only crushing and screening, and therefore if the ore is not suitable for the product requirements the tools available in mineral processing to address this are very few. In the high grade products where the tolerable grade of impurities like silica, aluminium, phosphorous and sulphur, are very low, the success of processing is very dependent on the identification of ore quality before it comes to the processing plant.

In the literature there is very little information on existing geometallurgical programs of iron ores, but a few can be found, e.g. from Kiruna, Sweden (Niiranen and Böhm, 2012) and NW Australia (Paine et al., 2011). The technique that is frequently used in evaluating the metallurgical variation in magnetite-bearing iron ores is the Davis tube (Farrell et al., 2011; Niiranen and Böhm, 2012). It is a small-scale magnetic separation test and the ore samples are normally ground to the liberation size before testing. The corresponding concentrate and tail are chemically analysed and the distribution of elements is then calculated. The iron distribution (recovery) and the concentrate quality are used in predicting the metallurgical response in the full scale operation.

The problem with using only the chemical components is that it is not always the typically primary reason for the metallurgical response. As chemical components are bonded in minerals we suggest it is more appropriate to use mineralogy for building the metallurgical functions and the geometallurgical domains. However, minerals do not occur independently in the processes they occur in particles which vary in size, shape and composition. Lund et al. (2013) developed a practical, fast and inexpensive method to derive modal composition from routine chemical assays using an element to mineral conversion technique which formed the first part of a geometallurgical framework of the Malmberget deposit. However, the modal mineralogy alone is not sufficient to describe the ore behaviour when processing the ore. The mineral textures play a significant role and need to be considered when a geometallurgical model is developed.

The texture characterisations are typically subjective (e.g. Bonnici et al., 2008) and traditionally more related to ore characterisation than process mineralogy (Perez-Barnuevo et al., 2012). During ore processing, the effects of mineral textures and the liberation are closely associated. The textures in an ore are one important family of parameters that can limit the ability to upgrade the ore (e.g. Butcher, 2010). The purpose of the comminution stage is to liberate ore minerals appropriately for the concentration process to enable reaching required concentrate quality with adequate recovery.

In mineral processing the relationship between the mineral (micro) textures and liberation has been a separate research subject for a long time. Basically the aim has been to forecast the liberation distribution from a two-dimensional picture of an ore. This is generally called *the liberation model*. The principle was introduced already by Gaudin (1939). Andrews and Mika (1975) developed a graphical presentation and this was further developed by King (1979) and King and Schneider (1998). These models assume random breakage which is unfortunately rarely true especially in grinding Vizcarra et al., 2010). King and Schneider (1998) developed the model further and included a kernel function which overcomes the problem of random breakage. Hunt et al. (2011a,b) used chess-board pattern for crushed samples and reduced the effect of the random breakage assumption. All these methods require a two dimensional microphotographs of an ore sample to be investigated. In a geometallurgical context this means preparation of thin sections or grain mounts, their photographing and image processing for a large number of samples. This is not very practical and an alternative way is needed.

This case study aims to find a solution to allow the incorporation of mineral texture information into a particle-based approach (Fig. 1) modified from a concept by Lamberg (2011). This is done through a case study of Malmberget iron ore deposit, in Northern Sweden. It focuses on mineral parameters, such as modal mineralogy, mineral textures, mineral association, mineral grain sizes and their relationships to liberation characteristics.

The final purpose is to deliver a geological model which can offer quantitative rather than descriptive data to be used in a process model. Firstly, the geological model is complemented with textural information. Secondly, it is demonstrated how such a geological model can be linked with a process model capable of forecasting the metallurgical response such as grade and recovery for any given geological unit (sample, block, or domain).

## 2. Sampling, experiment and analytical work

Two different ore bodies in Malmberget deposit were selected in this study. Fabian ore body that is proved to be one of the larger ore bodies in the deposit and the Printzsköld ore body that was considered for validating the results of Fabian ore but also to identify the differences of the ore bodies in the deposit. In the first dataset were over 100 mineralogical samples selected for polished thin sections aiming to characterise the mineralogy and the textural properties of the ore. The second dataset consist of the metallurgical samples, sampled from five drill cores of Fabian (Fa) and Printzsköld (Pz) ore body of both massive ore and semi-massive ore, referred as ore type in Table 1. The drill cores were carefully logged, and three dominate ore types were identified from the mineralogical study, generating a total of >100 kg in five different composite samples, namely (i) Feldspar (albite and orthoclase) rich ore (Fsp GEM-type) of Fa and Pz, (ii) Apatite rich or of Fa and Pz (Ap GEM-type) and (iii) Amphibole rich ore of Fa (Amph GEM-type), referred as sub-ore type in Table 1. Sampling, sample preparation and analytical methods used for the mineral analyses (optical microscopy, electron microprobe (EPMA)) and the element to

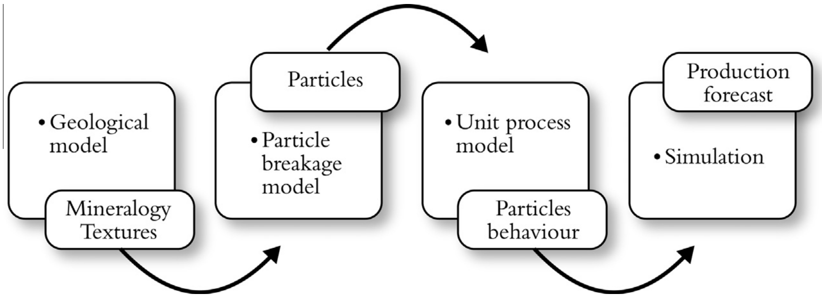

**Fig. 1.** The particle-based geometallurgical concept modified from Lamberg (2011). Modal mineralogy and texture links the geological model and process model. In the process model minerals are treated as particles. From the geological information the particle population is generated through the particle breakage model.

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