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Ore texture breakage characterization and fragmentation into multiphase particles

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ABSTRACT

The ore texture and the progeny particles after a breakage in the comminution have been a subject of interest in mineral liberation studies and are the missing link between geology and mineral processing in the concept of geometallurgy. A new method called Association Indicator Matrix (AIM) established based on co-occurrence matrix was introduced to quantify the mineral association of ore texture and its progeny particles. The Association Indicator Matrix can be used as a criterion for classifying ore texture as well as analyzing breakage behavior of ore texture. Within the study, the outcome of breakage analysis with Association Indicator Matrix was used to forecast particle population of iron ore texture after crushing. The particle size of forecasted particles was taken from experimental and frequency of breakage in phases was defined based on Association Indicator and liberation of minerals. Comparison of liberation distribution of iron oxide minerals from experimental and forecasted population shows a satisfactory agreement.

1. Introduction

Ore texture characterization concept in geology focuses on the geological aspects of the texture such as ore formation and genesis [1,2]. For geometallurgical purposes, ore texture characterization should be quantitative and provide quantitative information regarding progeny particles formed in comminution and their composition, thus on liberation distribution [3]. The significance of ore texture on beneficiation and other downstream processes is recognized and has been evaluated in mineral processing [4–6]. Qualitative or categorical geological classification is not sufficient for mineral processing. In the context of the mineralogical approach to geometallurgy, predicting the particle population from ore texture is a critical step to establish an interface between geology and mineral processing [7,8]. The mineralogical approach to geometallurgy requires information on ore textures to enable quantitative evaluation of mineral liberation distribution and the required crushing and grinding energies for mineral liberation.

1.1. Terminology

The terminology used for describing mineral liberation and breakage has not been harmonized therefore the definitions of the key terms are given below (see Fig. 1):

Particle	A unity consisting of single or multiple grains and single or multiple minerals (particles 1, 2 and 3).
Grain	A unit composed of only one mineral that has a clear interfacial surface with other grains (A and B grains in particles 1 and 3).
Liberated particle	A particle consisting of only one mineral (particles 2 and 3).
Locked particle	A particle consisting more than one mineral (particle 1).
Mineral liberation	a) An action where minerals are liberated (comminution). b) A broad term which describes the mode of occurrence of mineral in particulate material.
Degree of liberation	Mass proportion of mineral of interest occurring as liberated particles in the particulate material.
Liberation distribution	Mass distribution of mineral of interest in particle population.
Preferential breakage	When breakage and cracking more frequently occurs in one mineral [9].
Random breakage	When breakage and cracking are not favored by any mineral or boundary region.

Definition of what encompasses ore texture varies among geologists and metallurgists [10]. A comprehensive review of the definitions for

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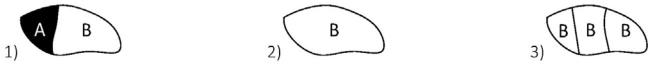


Fig. 1. Composite particle and liberated particle.

ore textures is given by Vink [11] and Bonnici [12]. The common definition for ore texture refers to volume, grain size, shape, spatial distribution and association of each mineral in the ore, thus in intact, pristine stage, i.e. in the unbroken material. The other issue is in what scale textural information needs to be collected. Microtexture term is used for grain-scale features like mineral inclusions in another grain, mesotexture for hand specimen sizes, and macrotextures for scales larger than mesoscale [13]. Ore texture is a generic term that refers to all scales.

1.2. Ore texture measurement

Ore texture measurement is commonly performed on polished thin sections, polished slabs, or drill cores depending on the required scale and details for intact ore or particulate samples. Optical microscopy, scanning electron microscopy (SEM), hyperspectral imaging, and X-ray diffraction mapping are common methods to acquire spatial distribution of phases in a sample. Generally, the mineral map is generated, and parameters of interest are calculated. Image analysis tools are commonly used to measure and quantify ore textural attributes [14–16].

Ore texture and particle composition information is a critical part of the mineralogical approach to geometallurgy. The ore texture and the progeny particles after a breakage in the comminution are the missing link between geology and mineral processing in the concept of geometallurgy. Generally, ore texture is quantified in terms of descriptors (such as covariance function, proximity function and linear intercept length distribution [17]). However, these descriptors are mostly applied for binary systems in practice. In this study, ore textures and particles are quantified by association indicator to show the trend of ore texture breakage in crushing.

1.3. Mineral liberation modeling

In the concept of liberation modeling, various approaches are known. The first approach is to model liberation independently from size reduction modeling and assuming that liberation process is related to the texture of the ore and the target size [18,19]. Usually, the main parameters in this liberation model are the average grade of phases and the size ratio between particles and grains. This approach is also called texture modeling and is achieved by superimposing particles mesh over texture image. This approach further developed from simple textures to consider a variety of ore textures [20] or transformation of textures to simple forms [21]. In this, the key parameters are the volumetric grade of the ore mineral and the interfacial surface area between phases which is related to the grain size.

The second approach was developed by extending the theory of liberation [22,23]. These authors have considered the problem of simultaneously accounting for liberation and breakage in a batch mill. Other approaches have been reported in the literature such as integration of liberation, size reduction and process modeling [24,25].

A fundamental part of liberation models is how the ore texture is defined or is characterized to be used for developing predictive liberation models. The second part of liberation model is how the mineral distribution in particles is defined. This can be described by distribution functions without measurement or measured on by images analysis techniques. A majority of liberation models are based on binary system (i.e. an ore mineral embedded in a gangue matrix), and they lack the capability of forecasting multiphase particles. A comprehensive review of liberation models and their development in 80's and before was given by Barbery and Leroux [26]. Another important part of liberation modeling is how actually fragmentation (breakage) happens. As discussed earlier, a simple approach is to superimpose particle patterns over textures. A recent review of mineral liberation and liberation in comminution is given by Mariano et al. [27].

Practical implementation of mineral liberation models in the mineral processing is rare. This is because the models are mainly for binary systems and taking models to the multiphase system is too complicated. However, in simplified ore textures (binary system) the models have been tested and compared against experimental data [26,28–32].

2. Materials and methods

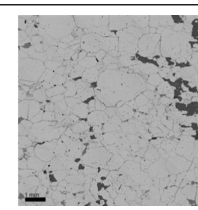
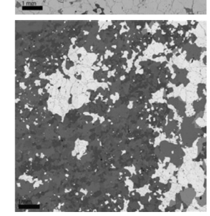
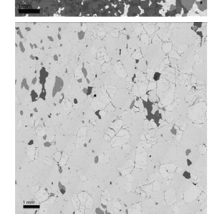
2.1. Materials

Various AQ (core diameter 27 mm) and BQ drill cores (36.5 mm) of iron ore with variation in ore textures were selected from Kiruna and Malmberget ore bodies (Table 1). The drill core samples with minimum 50 cm length were cut along the core axis and then in intervals of two centimeters. Two pieces were used for preparing epoxy block for ore textural analysis; other pieces went through the crushing process. These pieces were crushed in laboratory jaw crusher with closed side setting opening of 3.35 mm. The crushing product was sieved, and subsamples of each size fraction were selected to make epoxy samples for particle measurements (Fig. 2).

Routine analysis of ore textural samples is affected by required details, image resolution, time and cost of analysis. Optical and SEM based automated mineralogy are the common methods of obtaining ore textural image. The image is treated by image processing tools to extract textural and mineralogical information.

Ore textural study was done in optical and scanning electron microscopy. The aim was to analysis particulate and intact rock samples

Table 1
Backscatter image of drill core samples with their brief mineralogy description.

Sample	Sample description	
E	High-grade magnetite ore with broad grain size distribution. Apatite, amphibole group and biotite minerals are dominant gangue minerals.	
D1	Low-grade magnetite ore with finer grain size distribution respect to “E” sample. Apatite, Biotite, Feldspar and quartz are main gangue minerals.	
A1	High-grade hematite/magnetite ore with coarse grain size distribution. Apatite and quartz are main gangue minerals.	
C1	High-grade hematite/magnetite ore with coarse grain size distribution. Main gangue minerals are apatite and feldspar with coarse gain size.