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Note

Geometallurgical flowsheet development and specification at Verdalskalk AS

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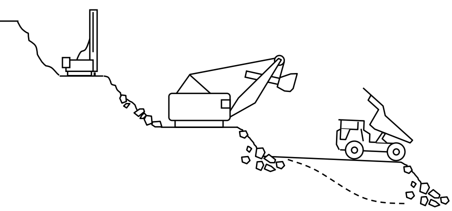
Geometallurgy emerged first as a discipline used in metal mining, but InRec project's goal is to test the applicability of geometallurgical approach to industrial mineral operations. The Verdalskalk AS case study followed by the geomatellurgical flowsheet design is the work package no. 1 within the project, realized as a PhD research at NTNU.



1. BACKGROUND

1.1 Geometallurgy for industrial minerals

Geometallurgy is a cross-discipline approach that combines geology, metallurgy and mine planning. Several definitions exist in the literature, varying from broad to more restricted view. For example it is seen as combining geology and metallurgy in order to create a predictive, spatially-based model for mine operations (Lund and Lamberg, 2014), or as "an integration of geological, mining, metallurgical, economic and environmental information to maximize the Net Present Value (NPV) of an orebody while minimizing technical and operational risk" (SGS, 2015). Geometallurgy aims to improve the understanding of resource economics. The geometallurgical approach include unlocking the way the rock will behave, from drilling and blasting through to mineral recovery and waste management and building this knowledge in to a predictive block model. This is the innovation in comparison to "traditional" mining where the disciplines mentioned above are often seen as separate and do not combine well into one integrated information source.

The geometallurgical concept has been first applied for the changing needs in mineral processing of ores. The main reasons for it are more and more low-grade, high-tonnage deposits that are currently exploited and environmental regulations and rules that become tightened (Lund, 2013).

The geometallurgical approach that leads to better prediction of process behavior can also be tested on industrial mineral commodities. Contrary to ore deposits where the most important factor is the element grade, within industrial minerals there are usually additional requirements or set of requirements to the product, for example mechanical strength or whiteness. These parameters can create a broad source of variation that might be affecting the production and efficiency of the mine facilities. Also, ore concentrate grade as the main definition of the price on the metal exchange does not imply to industrial minerals. Here, prices are negotiated and regulated by confidential agreements. Furthermore, the industrial mineral price is not affected by raw material quality as much as the stability of the quality delivered. Nowadays the mining companies in Norway do use geometallurgical elements within value chain, but without referring to the geometallurgical concept (Aasly and Ellefmo, 2014).

1.2 InRec Project

This PhD research is a part of the InRec project that was designed to implement some aspects of the geometallurgical approach as an integrated part of planning, control and execution of the activities included in Norwegian mining industry. The project is financed by the Norwegian Research Council registered with a number 236638/030, and co-funded by the industry partners. The full project name is “Increased Recovery in the Norwegian Mining Industry by Implementing the Geometallurgical Concept”.

The InRec project has been divided into three work packages, this PhD project being the work package no 1. The general objective of this package is the development of so called geometallurgical flowsheet (to be explained later in the description) while the packages no 2 and 3 focus on establishing techniques for effective sampling and statistical analysis of MWD (measurement while drilling) data (Ellefmo and Aasly, 2013). The work package no. 1 consists of a case study of Verdalskalk calcite mine in Nord-Trøndelag.

1.3 Verdalskalk AS

Verdalskalk AS company is a part of the Franzefoss Minerals group. It produces limestone, quicklime and slacked lime. The company consists of three units: Tromsdalen, (Municipality of Verdal), where the quarry and a crushing plant are located, Verdal harbour (Municipality of Verdal) being a transport site, and Hylla (Municipality of Inderøy) where the quicklime and slaked lime is produced.

The deposit in Tromsdalen is considered pure, low metamorphic calcite marble ($CaCO_3$) of the Ordovician period, approximately 460 Ma old. It is important to note that within the company it is referred to as limestone but in geological terms marble or meta-calcite is a more accurate term. The deposit is assumed to be approximately 7.5 billion tonnes, having a length of 6 km and maximum width of about 2.2 km (Gautneb, 2012).

The deposit is one of the purest in Norway and worldwide, but some impurities still occur. Those are mainly iron oxides and iron sulfides (limonite and pyrite), siliceous minerals (quartz, feldspar, biotite), and manganese minerals (rhodochrosite). The company has divided the marble into qualities regarding the impurities amount. Nowadays the qualities that are exploited are divided into: pure, standard and cement quality. The pure quality is used for quicklime and slacked lime production in the facility of Hylla (J. Rojas Ruiz, 2015, personal communication).

The parts of the deposit are blasted and transported to crushing plant. Before blasting and after crushing the geochemical analysis of the stone is conducted to avoid mixing of the qualities. The rock used in the kiln is crushed and sieved to the size of 30-100 mm.

At the Hylla facility crushed marble is burnt in two-shaft Maerz furnace in temperature that reaches 1000- 1200°C in the burning zone. The quicklime (CaO) is created due to the reaction:

$$CaCO_3 + \text{Heat} \rightarrow CaO + CO_2 \uparrow \tag{1}$$

The burned lime is crushed down to various fractions and transported to silos for sale.

Slaked lime (also: hydrated lime, milk of lime) is produced through a separate process (slaking) in a reaction:

$$CaO + H_2O \rightarrow Ca(OH)_2 \tag{2}$$

2. OBJECTIVES

The main objective of this PhD research is establishing so called geometallurgical flowsheet. Geometallurgical flowsheet is supposed to cover the description and/or visualization of the relationship between in-situ raw material variations, processing performance in down-stream working processes and the final product quality. The flowsheet relationship to the actual value chain should be described. The IDEF0 function modelling method has been proposed for it and the research on applying that method will be conducted (to be cleared out in the “Research Method” section).

The co-objective relevant for the research is a detailed literature review on state of the art for geometallurgy and related methodology, technology and terminology. As said before, the term geometallurgy itself can have several different definitions. Above chosing one of them there will be also a need to link it to the terms geometallurgical program and geometallurgical model (Lund and Lamberg, 2014) as these terms also need to be clarified in order to link them to a flowsheet design.

In order to establish a general geometallurgical flowsheet, the Verdalskalk- specific flowsheet must be first developed, so that the general flowsheet may be later based on it. The sub-goals that are related to it include:

- defining the deposit variations in terms of mineralogy, texture and surface hardness;
- defining the relationship between in-situ raw material and processing performance;
- investigation on the information flow between facilities in terms of geometallurgical approach;
- extensive mineralogical and geochemical research of the marble variations;
- linking the marble mineralogical variations to a kiln performance;
- linking the deposit variations and potentially other parameters to the final product quality.

3. RESEARCH METHOD

The overall strategy of the research is based on field and laboratory observations. Extensive literature study is conducted in order to follow the state of the art in the matter.

InRec work packages 2 and 3 will also define the specific geometallurgical flowsheet for the respective mine operations. Thus extensive cooperation between research fellows working on the different working packages is required. This joint research will add knowledge to defining the general geometallurgical flowsheet.

3.1 Field study

The field research is based on the case study of Verdalskalk AS. The overall view and then obtaining extensive knowledge about mine facilities, understanding of different working processes and the relations between them is an essential part of the study. During the fieldwork the information flow regarding the quality of the product will also be investigated.

The key part of the field work consists of geological mapping of the Tromsdalen deposit. The main idea is to conduct a random sampling within different blasts and to check if the samples in microscale represent in reality the marble types distinguished by the company. The mineralogy and marble texture (grain size, fabric, and grain boundaries shape) are analyzed in order to distinguish features that may have impact on process performance (see figure 1). The field work will as well involve surface hardness measurements of the parts of the deposit. Surface hardness will be tested using Proceq Equotip device. Equotip principle is based on the dynamic (rebound) method. An impact body is propelled by spring force against the tested specimen. Surface deformation results in energy loss, which is detected by measuring and comparing the velocities of the impact body in both impact and rebound phase. A single impact method, described by Aoki and Matsukura (2007) is used.

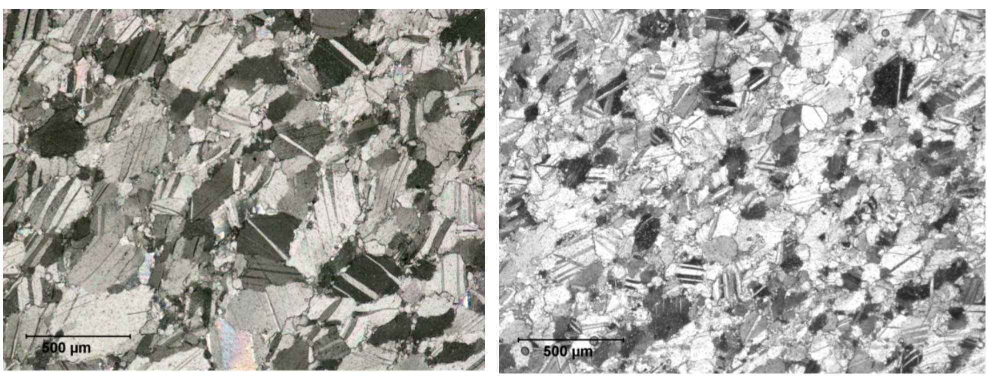


Fig.1: Microphotographs of two examples of Tromsdalen marble, transmitted light, crossed polarizers. Note the differences in calcite grains size.

3.2 Laboratory tests

The laboratory tests consist of:

- Optical microscopy, both transmitted and reflected light mode for observation of textures, mineral assemblage, grain size of the samples;

- SEM-EDS (Scanning Electron Microscopy – Energy Dispersive Spectrometer) for semi-quantitative microanalysis;
- XRD (X-ray Diffraction) analysis to characterize the crystalline phases within the samples;
- XRF (X-ray fluorescence) analysis of the major and trace element composition;
- Optical microscope with heating stage for studying microscopic features or reactions in marble during heating in order to simulate the reactions that occur in the kiln.

All the analyses listed above are conducted at IGP, NTNU. The mineral processing lab at IGP is used for general sample preparation for further testing.

3.3 Other

Part of the study is dedicated to investigation and comparison already existing information from the plant in order to find the variables that can be potentially dependent or independent from each other. The examples of current research on the data and information are:

- Linking the burned lime CO_2 residue measurements to the marble variations;
- Linking the crusher performance (percentage of the fines) to the blast direction and marble variations;
- Linking the lump size distribution to hardness and mineral variations of the marble.

All the tests listed above (CO_2 residue, percentage of fines, size distribution) were conducted by the company.

3.4 Designing the flowsheet

For designing the geometallurgical flowsheet the so called IDEF0 methodology is tested. The Integration Definition for Function Modeling (IDEF0) is a common modeling technique for development, analysis, and integration of information systems and working processes. It is used to show data flow, system control, and the functional flow of processes (DAU, 2001). The main components in IDEF0 modelling are functions (processes, activities or transformations), inputs, outputs and controlling- and supporting (mechanisms) elements (the so-called ICOMs), see figure 2.

In the PhD project it has been proposed to use the IDEF0 methodology to show the working processes within the mine and relate them to the elements that control and support the processes. The same methodology will be used for visualization of the geometallurgical flowsheet that is supposed to be a virtual flow of information and procedures needed to create a geometallurgical model.

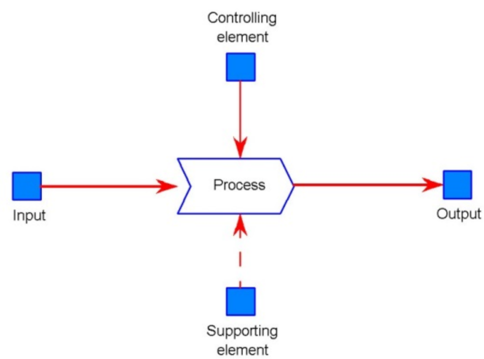


Figure 2: Basic sketch using IDEF0 method. The input is being rearranged during the working process to create an output, with help of controlling and supporting elements.

4. EXPECTED RESULTS

This PhD project shall result with establishing both deposit-dependent and deposit-independent geometallurgical flowsheet. The term will be defined, and its final relationship to other geometallurgical terms like geometallurgical model and geometallurgical program will be formed.

The finished project will also answer the question if it is possible to apply geometallurgy into Verdalskalk mine operation, and to what extent. The relations between the marble variations, process performance and the quality of the final product will be fully understood.

More detailed knowledge on Tromsdalen marble variations in terms of mineralogy and internal texture will be a contribution to current geological knowledge of the area.

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