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Note

Increased geometallurgical performance in industrial mineral operations through multivariate analysis of MWD-data

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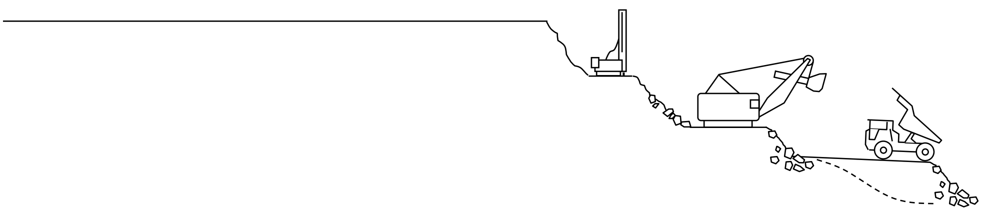
The project discussed here is taking advantage of MWD data analysis to contribute to safety, cost reduction and increased resource utilization along the mining value chain. Using the results from MWD analysis a new and improved geometallurgical model will be developed.



1. INTRODUCTION

This research is a part of a project named Increased Recovery in the Norwegian Mining Industry by Implementing the Geometallurgical Concept (InRec). The objectives of the project are threefold. Firstly, the project aims at developing the concept of geometallurgical flow sheets, its definition and its use. Secondly, the project will look at how in-situ raw material properties influence the performance of magnetic separation process in a Norwegian industrial mineral operation. Thirdly, and the focus of this part of the research is based on the MWD data collected during open pit mining at the Brønnøy Kalk AS mine. Brønnøy Kalk AS is situated near Brønnøysund in North-Norway and produce calcite marble raw material for production of ground calcium carbonate (GCC).

2. GEOMETALLURGY AND MEASUREMENT WHILE DRILLING (MWD) DATA

A drilling rig is used to drill boreholes in the ground in construction, quarrying, and open-pit mining. Measurement While Drilling (MWD) is a technique for collecting appropriate drilling information from the drilling rig for a systematic evaluation of drilling performance. The MWD data can be collected during normal drilling process at a predefined interval. The drilling rigs are equipped with hole navigation system and collect MWD data every 2 cm while drilling the boreholes. The data in this MWD-case consist of; log time (YYYY-MM-DDThh:mm:ss), Depth(m) Penetration rate(m/min), Feed pressure(bar), Percussive pressure(bar), Rotation pressure(bar), Damper pressure(bar), Flush Air pressure(bar) and Hardness (estimated based on the collected parameters). A huge amount of MWD data is collected and stored every year, but has not been properly analysed to obtain relevant information and not been a part of the geometallurgical model at the mine (Ellefmo, 2015).

The Geometallurgical concept ranges from ore characterization to the economic optimization of the mining operation (Lund & Lamberg 2014). Rock materials encountered in mining are highly variable in strength, structure and grade. Currently the raw material quality is derived from lab test and analysis of drill cutting from a collection of boreholes. Analysis of MWD-data is expected to be a useful tool for quantifying rock strength variations that again is expected to give information about lithological differences and information about major structural features. These parameters can have effect on blasting, grinding, crushing, liberation, sampling strategy and product quality.

3. SAFETY AND COST SAVING

In Brønnøy Kalk, for cost saving reasons, the broken ground between the level surface and rock surface is not removed prior to drilling, and the holes are drilled through this overburden. The thickness of the overburden (sylte) may vary considerably depending on the “topography” of the underlying rock surface. However, the boreholes are charged with explosives up to a fixed depth below surface. Thus here is a risk that already broken ground is charged with explosives, which are both unnecessary use of explosives and a high risk of flyrocks which are unsafe. There is also a risk that holes are insufficiently charged, which may create boulders which require hammering.

The first objective is to use MWD data to identify the true thickness of the overburden. By doing this, it is possible to identify specific charging heights for each individual hole. This will improve the safety and optimize the blast in a cost effective manner.

4. ROCK QUALITY AND OPTIMIZED PRODUCTION

In a geometallurgical setting, the ore grade is one of potentially many important factors that determine the quality of an ore deposit. Unlike for the metal ore, for industrial minerals the marble quality should be maintained at a certain level to satisfy the requirements from a customer in the market. Otherwise, the product will be considered as a waste. So retain maximum available good marble is essential to optimize the profit and to fulfil the demand.

At Brønnøy Kalk, every blast approximately contains 100.000 tons of rocks which are divided into smaller blocks of approximately 5000 tonnes. Each of these blocks will have 10-15 boreholes. The division and grouping of boreholes is done based on geometry, i.e. the round is divided into rectangular blocks of approximately equal size. The collective sample of cuttings from a block is then tested in the lab for its quality parameters. The combined mixture of this sample will represent an average blended quality of each block. The main quality control parameters used at Brønnøy Kalk are Brightness, Flotation loss, Reagent consumption, and Acid Insoluble Residue. (Aasly & Ellefmo, 2014).

In reality, there could be significant variations in properties which will not be detected through this sampling scheme. Based on the analysis, the entire block may be produced though part of it should have been discarded as waste (dilution), or the entire block may be discarded as waste though part of it could have been produced (loss). Sub-quality blocks (i.e. blocks with properties near cut-off) might have to wait until high quality material is available for blending, or they must be moved to a temporary storage.

So the second objective is to analyse the MWD data using multivariate analysis techniques to delineate different lithologies and to separate the marble into different types (in-marble variability). This will be useful to improve the sampling strategies by defining new geological blocks which can optimize the recovery of good marble. Finally, the aim is to link MWD-data and other quality parameters.

All rigs are unique and the drilling rigs perform differently dependent on their mechanical properties. Although the methods used to establish the link between the MWD-data and the in-situ geological properties are general, the models themselves will be case specific.

5. RESEARCH METHODS

The research will be conducted through four different stages, which will finally contribute in the development of the geometallurgical model:

1. Separate the Loose rock (Sylte) from the hard marble part
2. Identify and separate different rock type (marble vs other rock types).
3. Identify and quantify the in-marble variability
4. Develop a relationship between MWD data and other quality parameters.

James & Matteson (2014) describes a method to detect abrupt changes in distributional changes in time ordered data using nonparametric changepoint analysis. A principle component analysis will help to reduce the multivariate aspect of the data. These methods will be used on MWD data to detect the loose rock layer over the hard marble part. Different statistical methods such as Cluster analysis and Hidden Markov model will be used and tested to compare the results.

Validating the result is important. To validate the first result, the sylte layer of some boreholes to be measured manually using a GPS after drilling some holes. The real sylte thickness and the estimated sylte thickness using MWD will be compared and result will be verified.

Next step is to identify different types of rocks in the hard marble layers. Three dimensional spatial statistical variogram models will be created along with the principle component analysis and cluster analysis to determine the heterogeneity of different rocks.

An aerial picture of a particular drilled wall and the two dimensional model using MWD data from the boreholes in the same wall will be compared and verified (See example in Figure 1). It is also assessed whether to use down-the-hole imaging techniques to verify the results.

It is shown that the structured PCA method and the method using Eckart-Young theorem outperforms the prevailing unstructured method on initial wireline log data sets and can easily be applied to isolate other depositional environments, particularly in studies involving heterolithic deposits (Brandsegg et al., 2010). The back calculation of wireline log values by the use of the Eckart-Young theorem permits the effective removal of variability due to gross lithological effects and allows for differential interpretation of heterogeneity (Brandsegg et al., 2011).

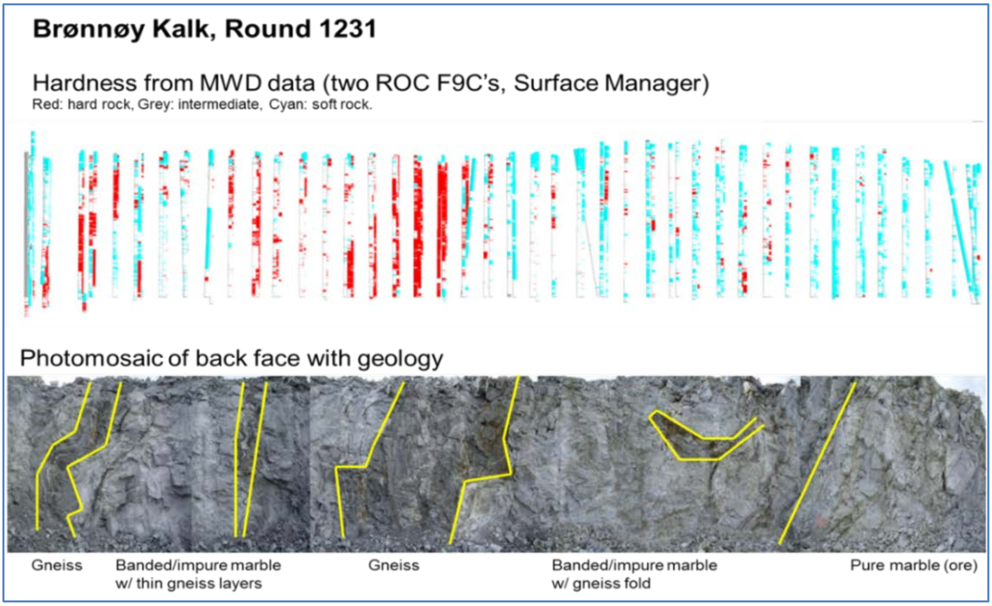


Figure 1. Top: Hardness variations through boreholes. Bottom: Arial view of a wall after a blast (Source: Watne (2016)).

Here the plan is to describe or evaluate the benefits of using structured PCA approach in conjunction with the Eckart-Young theorem to show how marble properties can be decomposed into different orders of variability and to provide additional insight into in-marble heterogeneity. This also includes evaluation of transforming scaleless PC scores by the use of Eckart-Young theorem into decomposed MWD data related to each of the PCs and inversely how the PCs can be back calculated to portray their individual contribution to each of the initial MWD data.

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Finally, a nonlinear higher order regression analysis will be conducted to investigate whether it is possible to develop and utilize a relationship between MWD data and other quality parameters used in the mine.

The computations will be done mainly using R, a free and open source software, with facilitates for data manipulation, calculation and graphical display. Leapfrog Geo will be used to model the geological variations, which allows rapid construction of 3D conceptual models directly from scattered borehole and GIS data without the need for manual digitization.

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