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Note

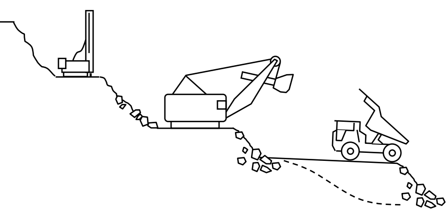
Effective sampling and mineral characterization on nepheline syenite (InRec project – Workpackage 2)

Camilo Andrés Mena Silva [1*]

[1] Dept. of Geoscience and Petroleum, Faculty of Engineering, NTNU – Norwegian Univ. of Science and Technology, Trondheim

** Corresponding author: Camilo.silva@ntnu.no*

Geometallurgy is an interesting discipline for sustainable mining which in the recent years has gained relevance in the industry. Mainly developed on base metal mining, an expansion of it towards industrial minerals is certainly interesting for mining interests, especially when the study case is Norwegian such as Stjernøy. In the following note a geometallurgical project description with its objectives and expected results is presented.



1. THE INREC PROJECT

The InRec project, an acronym of "Increased Recovery in the Nowegian Mining Industry by implementing the geometallurgical concept", is due to the nature of Norwegian mining industry focusing on industrial mineral operations. This project originated from the proven benefits regarding resource efficiency and value increasing, as a result of successful application of geometallurgy, due to a better control over in situ relevant properties and the creation of economic 3D block models based on these key process indicators (KPI). This project is a joint cooperation between The Research Council of Norway (RCN), The Norwegian University of Science and Technology (NTNU), and three industrial partners: Verdalskalk, Sibelco Nordic, and Norsk Mineral. The InRec project is subdivided into three work-packages (WP), from which each of them focuses on one industrial partner and its issues.

2. THE PROJECT

2.1 Geometallurgy and process mineralogy

The present research corresponds to the second work-package of InRec project in collaboration with Sibelco Nordic as industrial partner. It is titled Effective Sampling and Mineral Characterization and is part of the efforts to apply the geometallurgical concept into the Stjernøy nepheline syenite mine, northwest Norway. This project is focused on the implementation of geometallurgy into a developed industrial mineral mine and processing plant. Geometallurgy, defined by several authors, in summary is defined as a holistic mining discipline (i.e. involving mainly geology, mining and mineral processing) aiming to increase the knowledge of the deposit and its processing response by geological and processing means for the prediction of the material behavior during operations, allowing process flexibility and constant optimization, risk reduction due to decreasing uncertainties, and finally increasing the value of the resources available (Aasly & Ellefmo, 2014; Butcher, 2012; Dunham & Vann, 2007; Hoal, 2008; Kendrick, Baum, Thompson, Gilkie, & Gottleib, 2003; Lund & Lamberg, 2014; Williams & Richardson, 2004).

Geometallurgy, as broad discipline, requires the joint work from the different actors involved in the development of a mine from the early stages such as exploration and pre-feasibility (Hoal, McNulty, & Schmidt, 2006; Kendrick et al., 2003) until the final stages during reclamation and final waste storing (Brough, Warrender, Bowell, Barnes, & Parbhakar-Fox, 2013; Edraki et al., 2014). Different tools are required to develop a geometallurgical strategy and one important feature of it is the quantification of different interrelated parameters e.g. comminution behavior during any size reduction processes, kinetics behavior during most of the chemistry-depending processes, classification behavior during physical-depending processes to mention a few (Lund, Lamberg, & Lindberg, 2015; Mwanga, Rosenkranz, & Lamberg, 2015; Suazo, Kracht, & Alruiz, 2010; Tungpalan et al., 2015). Moreover, one of the parameters, unilaterally agreed, to impact the most in any process corresponds to modal mineralogy or the amount of different minerals present in the material. There are many successful examples and techniques when applying mineralogy (Petruk, 2000), as a result from this type of investigation process mineralogy emerged as a new discipline on this matter.

Process mineralogy is one key discipline for geometallurgy and important for describing a materials possibilities and limitations in mineral processing. Several analytical techniques, with different accuracy levels, is relevant for mineral and chemical determination: scanning electron microscope (SEM), x-ray fluorescence (XRF), and x-rays diffraction (XRD), with their various options and configurations (Fandrich, Gu, Burrows, & Moeller, 2007; Goodall & Cropp, 2013; Gu, 2003; Hestnes & Sørensen, 2012; Parian, Lamberg, Möckel, & Rosenkranz, 2015). There are also other options with more modern techniques such as x-ray tomography and hyperspectral techniques (Boesche et al., 2016; Salvo et al., 2003; Schneider, Murphy, & Melkumyan, 2014).

In addition to the relevance of process mineralogy there is another important aspect that deserves equivalent relevance for the development of any experimental work, the sampling strategy with its statistical robustness to represent accurately. There has been considerable development on the theory behind sampling (François-Bongarçon, 2004; François-Bongarçon & Gy, 2002; Gy, 1976, 1979; Minkkinen, 2004; Minkkinen & Esbensen, 2009; Pitard, 2009) but without a full embracement in practical terms by the mining industry. The present project considers essential the implementation of adequate sampling for the present research work.

2.2 Stjernøy background

Regarding the deposit, Stjernøy is a nepheline syenite deposit named after the island where it is located, in the Seiland petrographic province, west Finnmark region. The deposit is exploited by Sibelco Nordic (the industrial partner) for the production of multiple products sold to a broad variety of costumers from the ceramics, glass, and paint industries (Bolger, 1995; Plant Staff, pers.comm., 2016). The petrography of the province where the deposit is located can be considered as well known and it has been described by several authors as summarized by Geis, 1979. It has been found that two main facies separate the deposit in direct relation to the presence of predominant dark minerals: hornblende and biotite (Geis, 1979; Mclemore, 2006; Payne & Shaw, 1967). Additionally, diabase (vogesite) dikes have been mapped all over the deposit, which were mainly found in the underground mine (Geis, 1979), but with the current exploitation stage of the mine they can be found in the pit as well (Plant Staff, pers.comm., 2016).

Several mineralogical descriptions have been done on Stjernøy material (Geis, 1979; Heier, 1961; Li, 2013; Mclemore, 2006; Raaness, 2003; Sørensen, 2016), showing that nepheline syenite present at Stjernøy is mainly composed by feldspar and nepheline, with around 56% and 34% in modal composition, respectively. Minor minerals include hornblende, biotite, aegirine/augite, clinopyroxene, calcite, titanite, and magnetite are present in varying concentrations, depending on the location in the deposit.

The deposit is mined from two main locations: (1) the open pit and (2) the underground mine, from which roughly 80% and 20% feeds the processing plant, respectively (Plant Staff, pers. comm., 2016). The processing chain can be split in three main sections: (1) feed preparation with crushing and drying stages, (2) magnetic separation with multiple magnetic separation stages and classification, and (3) milling and classification with different mill-classification stages Figure 1.

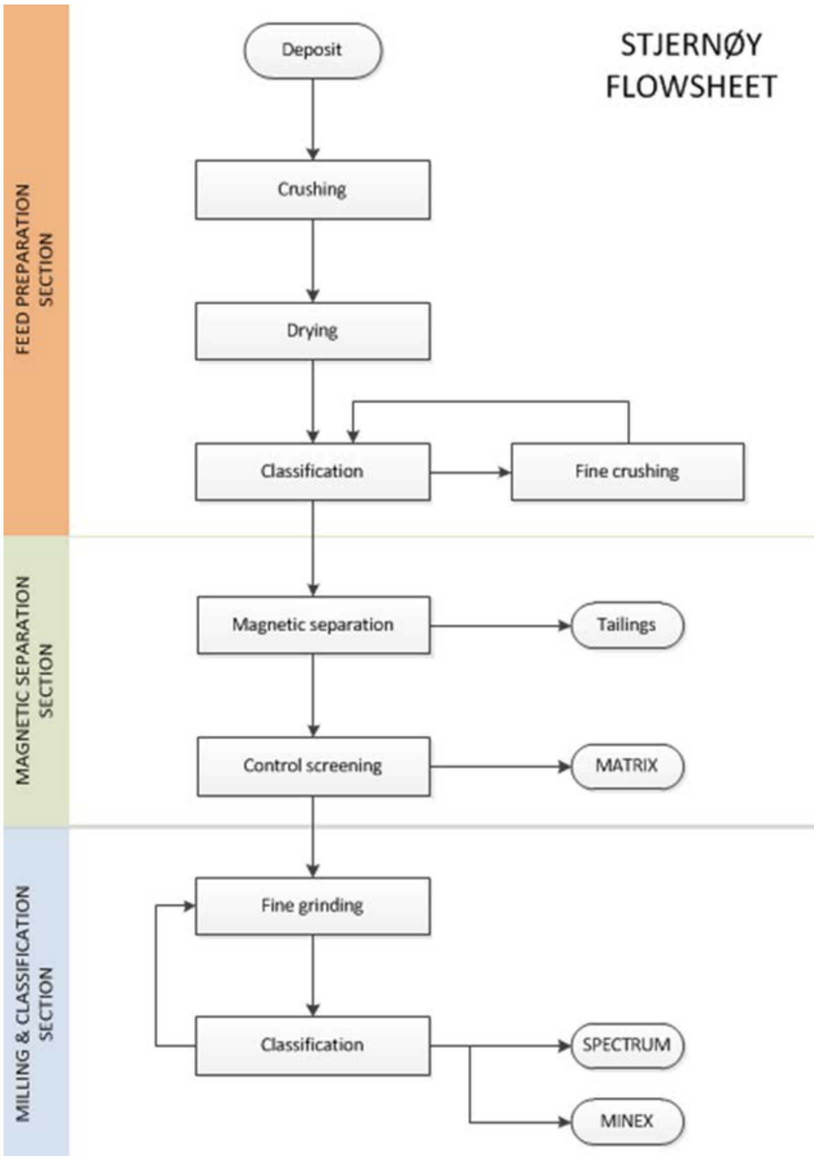


Figure 1. Stjernøy flowsheet summary

3. PROJECT OBJECTIVES

The first objective of this project is an extensive characterization of different zones within the deposit and material flow-streams in the plant for a definitive discretization between material types based on theory and experimental investigation, finalizing in a possible future operation implementation. This objective will be achieved by means of:

- Material description regarding mineralogical, textural, grain and particle sizing, chemical composition, etc. using different instruments and techniques such as: sieving, SEM imaging, XRD, XRF, EPMA, etc.
- Processing response evaluation of different material types (blend-ability) at lab scale using similar plant operational conditions, with possibilities for up-scaling testing in case results suggest it. This will be carried on mainly using sieving, magnetic separation, and crushing equipment.
- Predictive processing response modeling (if possible) aiming to match lab testing with plant performance as part of the geometallurgical concept implementation and future implementation of them in operations and mine planning.

The second objective of the research corresponds to investigation regarding sampling practices and theory, in addition to a geological background checking associated to the deposit, for better understanding of the troubleshoots and/or drawbacks of current practices, and possible suggestions for implementation and optimization. In order to achieve this objective, the following points are required:

- Review on representative sampling theory and state-of-art (for material from pit and processing plant) based on classic and current literature, including benchmarking if such information is available.
- Laboratory and sampling procedures evaluation to determine matching degree with processing plant operation and general inconsistencies on current practices. This point will be strictly based on the outcome of the previous point.
- Geological literature review on nepheline syenite and any relevant subject associated with characterization and processing of this type of deposit, based mainly on available literature associated to this type of deposits.

4. METHODOLOGY

The overall research method to be used in the present work are experimental trials in different scales (mainly lab scale), microscopic observations for the characterization and image processing for further data acquisition, sampling trials in the relevant sampling points of the processing chain, and finally literature review.

In relation to the whole research theoretical background (i.e. geometallurgy, sampling, geology, mineral processing, characterization concepts) extensive literature research has to be done in order to define the current state-of-art on the corresponding concepts, in addition to a review on the current mining industry practices.

The characterization of the material will be carried mainly out by the means available at NTNU, such as: optical microscopes with both illumination modes (transmitted and reflected), scanning electron microscopes with the relevant detectors (BSD, EDS, EBSD, etc.), x-ray diffractometer (with copper cathode) and x-ray spectrometer (portable and stationary options), additionally electron probe micro-analysis (WDS) can be used if further information regarding characterization is needed. The use of the instruments will depend on their availability and the research progress.

Regarding lab work, there are various equipment available at NTNU with flexible settings allowing multiple configurations (sieving, magnetic separation, crushing, grinding, etc.). The scale of the devices is also flexible being up-gradable towards pilot plant scale for short circuits testing, if the results support it. In case the industrial partner suggest that some tests have to be done there, Stjernøy facilities also provide equipment but with a much restricted variety. Plant facilities can also be used if a detailed work plan in agreement with a matching plant schedule are presented to the industrial partner allowing the possibility to run plant scale testing. The generic procedure for lab work will be as explained next:

- General sieving
- Oversize grinding
- Sieving of the recently ground material
- Discard remaining oversize
- Magnetic separation of the material
- Further characterization of the resulting fractions

The data obtained will be treated using different software with a valid license at NTNU, mainly using Microsoft Excel and Matlab for treating data and image analysis, LeapFrog and ioGAS for treating geological data, and the corresponding software associated to the instruments previously mentioned. If additional software is required, their use will be restricted to availability at NTNU.

5. EXPECTED RESULTS

Mineralogical data will be unveiled by the future research, information that will substantially help to understand the behavior of the material treated, allowing the proposal of solutions or at least explanations to what happens within the plant and mine. This information will also give deeper knowledge of the material and therefore open the possibility for the implementation of a full geometallurgical plan with behavior forecasting and therefore improving the resources usage and availability in the deposit. In addition, geometallurgical planning would improve mine lifetime and also the way it is exploited giving a dramatic boost to the reserves and the industrial partner value.

Regarding mineralogical characterization outcomes, plant settings can be adjusted if previously unnoticed features are detected such as the degree of liberation of dark minerals, which is expected to influence directly on magnetic separation efficiency, and therefore final product quality. It is expected an improvement of the current raw material quality definition, by taking in count additional material information (e.g. mineralogical data) which might lead to a better and more suitable quality definition. Major improvements for production can be achieved if the information obtained suggests it.

Among the other possible outcomes, reliable and fast mineral differentiation would be of most relevance for the industrial partner which nowadays counts only on chemical data for decision making. Expectations are focused on finding a way to determine the ratio between nepheline and feldspar, major phases present in the deposit, which until now are not known by the industrial partner. It is expected that the definition of this ratio might reveal new rock characteristic for the industrial partner to work with.

Regarding sampling studies, better and more reliable practices are expected taking in count theory and the applicability of it within the chain e.g. improvement on sampling point selection, sampling procedures and tools, etc. Also a review with the current sampling techniques status, benchmarking and contrast with good practices is expected. From this part it is expected to develop a way to define material quantities and time required during sampling campaigns, and the design of updated sampling practices and laboratory procedures linked to them.

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REFERENCES

Aasly, K., & Ellefmo, S. (2014). Geometallurgy applied to industrial minerals operations. Mineralproduksjon, 5, 21–34.

Boesche, N., Rogass, C., Mielke, C., Herrmann, S., Körting, F., Papenfuß, A., … Tonn, S. (2016). HYPERSPECTRAL RARE EARTH ELEMENT MAPPING OF THREE OUTCROPS AT THE FEN COMPLEX, NORWAY: CALCITIC, DOLOMITIC, AND ANKERITIC CARBONATITES. In I. Borges de Lima & W. Leal Filho (Eds.), Rare Earths Industry (pp. 235–265). Elsevier Ltd. http://doi.org/10.1016/B978-0-12-802328-0.00016-4

Bolger, R. (1995). Feldspar & nepheline syenite - Turkish delight in export sales. Industrial Minerals, 25–45.

Brough, C., Warrender, R., Bowell, R., Barnes, A., & Parbhakar-Fox, A. (2013). The process mineralogy of mine wastes. Minerals Engineering, 52, 125–135. http://doi.org/10.1016/j.mineng.2013.05.003

Butcher, A. (2012). Geometallurgy: An Exciting Professional Area of Activity. 11th Freiberg Short Course in Economic Geology Notes.

Dunham, S., & Vann, J. (2007). Geometallurgy, geostatistics and project value – does your block model tell you what you need to know? In Project Evaluation (pp. 189–196).

Edraki, M., Baumgartl, T., Manlapig, E., Bradshaw, D., Franks, D., & Moran, C. (2014). Designing mine tailings for better environmental , social and economic outcomes : a review of alternative approaches. Journal of Cleaner Production, 84, 411–420. http://doi.org/10.1016/j.jclepro.2014.04.079

Fandrich, R., Gu, Y., Burrows, D., & Moeller, K. (2007). Modern SEM-based mineral liberation analysis. International Journal of Mineral Processing, 84(1–4), 310–320. http://doi.org/10.1016/j.minpro.2006.07.018

François-Bongarçon, D. (2004). Theory of sampling and geostatistics: An intimate link. Chemometrics and Intelligent Laboratory Systems, 74(1), 143–148. http://doi.org/10.1016/j.chemolab.2004.03.015

François-Bongarçon, D., & Gy, P. (2002). The most common error in applying Gy's Formula in the theory of mineral sampling, and the history of the liberation factor. Journal of the South African Institute of Mining and Metallurgy, 102(8), 475–479. Retrieved from https://noppa.aalto.fi/noppa/kurssi/yhd-33.3600/materiaali/Yhd-33_3600_gold_liberation_2.pdf\npapers2://publication/uuid/F5FC5720-E8EC-4B88-91CC-A559B826BCDF

Geis, H. P. (1979). Nepheline Syenite on Stjernøy, Northern Norway. Economic Geology, 74, 1286–1295.

Goodall, W., & Cropp, A. (2013). Integrating Mineralogy into Everyday Solutions.

Gu, Y. (2003). Automated scanning electron microscope based liberation analysis. Journal of Minerals and Materials Characterization and Engineering, 2(1), 33–41.

Gy, P. (1976). The sampling of particulate materials - a general theory. International Journal of Mineral Processing, 3, 289–312. http://doi.org/10.1016/0301-7516(76)90020-X

Gy, P. (1979). SAMPLING OF PARTICULATE MATERIALS: THEORY AND PRACTICE. Elsevier Scientific Publishing Company.

Heier, K. S. (1961). Layered gabbro, hornblendite, carbonatite and nepheline syenite on Stjernøy, North Norway. Norsk Geologisk Tidsskrift, 41, 155–190.

Hestnes, K., & Sørensen, B. (2012). Evaluation of quantitative X-ray diffraction for possible use in the quality control of granitic pegmatite in mineral production. Minerals Engineering, 39, 239–247. http://doi.org/10.1016/j.mineng.2012.06.006

Hoal, K. (2008). Getting the Geo into Geomet. Society of Economic Geologists, 73.

Hoal, K., McNulty, T., & Schmidt, R. (2006). Metallurgical advances and their impact on material exploration and mining. Society of Economic Geologists, 12, 243–261.

Kendrick, M., Baum, W., Thompson, P., Gilkie, G., & Gottleib, P. (2003). The use of QEM-SCAN automated mineral analyzer at the Candelaria Concentrator. Mineral Processing, III, 415–430.

Li, X. (2013). Alkaline Magmatism , Water-Rock Interaction and Multiple Metamorphism in the Seiland Igneous Province , Northern Norway. Freiburg University.

Lund, C., & Lamberg, P. (2014). Geometallurgy: A tool for better resource efficiency. European Geologist, 37, 39–43.

Lund, C., Lamberg, P., & Lindberg, T. (2015). Development of a geometallurgical framework to quantify mineral textures for process prediction. Minerals Engineering, 82, 61–77. http://doi.org/10.1016/j.mineng.2015.04.004

Mclemore, V. T. (2006). Nepheline Syenite. In J. E. Kogel, N. C. Trivedi, J. M. Barker, & S. T. Krukowski (Eds.), Industrial Minerals and Rocks - Commodities, Markets, and Uses (7th ed., pp. 653–670). Society for Mining, Metallurgy, and Exploration.

Minkkinen, P. (2004). Practical applications of sampling theory. Chemometrics and Intelligent Laboratory Systems, 74(1), 85–94. http://doi.org/10.1016/j.chemolab.2004.03.013

Minkkinen, P., & Esbensen, K. (2009). Grab vs. composite sampling of particulate materials with significant spatial heterogeneity — A simulation study of “ correct sampling errors .” Analytica Chimica Acta, 653, 59–70. http://doi.org/10.1016/j.aca.2009.08.039

Mwanga, A., Rosenkranz, J., & Lamberg, P. (2015). Testing of Ore Comminution Behavior in the Geometallurgical Context—A Review. Minerals, 5(2), 276–297. http://doi.org/10.3390/min5020276

Parian, M., Lamberg, P., Möckel, R., & Rosenkranz, J. (2015). Analysis of mineral grades for geometallurgy: Combined element-to-mineral conversion and quantitative X-ray diffraction. Minerals Engineering, 82, 25–35. http://doi.org/10.1016/j.mineng.2015.04.023

Payne, J. G., & Shaw, D. M. (1967). K-Rb RELATIONS IN THE BLUE MOUNTAIN EPHELINE SYENITE. Earth and Planetary Science Letters, 2, 290–292.

Petruk, W. (2000). Applied Mineralogy in the Mining Industry (First Ed.). Elsevier Science B.V.

Pitard, F. . (2009). An Introduction to the Theory of Sampling: An Essential Part of Total Quality Management. Comprehensive Chemometrics, 1–16. http://doi.org/10.1016/B978-044452701-1.00089-2

Raaness, A. M. (2003). Mineralbalansen i prosessanlegget til North Cape Minerals på Stjernøy. NTNU.

Salvo, L., Cloetens, P., Maire, E., Zabler, S., Blandin, J., Ludwig, W., … Josserond, C. (2003). X-ray micro-tomography an attractive characterisation technique in materials science, 200, 273–286.

Schneider, S., Murphy, R., & Melkumyan, A. (2014). Evaluating the performance of a new classifier – the GP-OAD : A comparison with existing methods for classifying rock type and mineralogy from hyperspectral imagery. ISPRS Journal of Photogrammetry and Remote Sensing, 98, 145–156. http://doi.org/10.1016/j.isprsjprs.2014.09.016

Suazo, C., Kracht, W., & Alruiz, O. (2010). Geometallurgical modelling of the Collahuasi flotation circuit. Minerals Engineering, 23(2), 137–142. http://doi.org/10.1016/j.mineng.2009.11.005

Sørensen, B. E. (2016). Mineralogical investigation of nepheline syenite from Stjernøy. Trondheim.

Tungpalan, K., Manlapig, E., Andrusiewicz, M., Keeney, L., Wightman, E., & Edraki, M. (2015). T An integrated approach of predicting metallurgical performance relating to variability in deposit characteristics. Minerals Engineering, 71, 49–54. http://doi.org/10.1016/j.mineng.2014.10.004

Williams, S., & Richardson, J. (2004). Geometallurgical mapping: a new approach that reduces technical risk geometallurgical mapping. Sgs Minerals Services, 1–13.