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Geotechnical model making: steps and stories of how LKAB started geotechnical modelling

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Abstract

In recent years LKAB systematically built a system of geotechnical data collection and competency across its four major mine sites and associated sub-projects. While technological advances are rare in geotechnical logging and modelling, this paper aims to provide more efficient geotechnical data collection team set-up with goals of contributing towards automation. By describing the process of in-house team set-up, the use of contractors, and the selection of expert guidance and consultancy competencies, the geotechnical department's time and effort may be reduced for high-volume drill programs. Here we discuss topics on problems encountered when inserting teams into existing workflows, and practices for data collection and modelling. Also LKAB's experiences are shared, i.e. the problems and solutions, with steps to make a geotechnical model and how to add (not remove) value to projects.

LKAB's deep mass mine designs are now dependent on geology and geotechnical model improvements to develop current understanding of design criteria, plan for high stresses at depth and optimise extraction sequences, while the current mine planning team grapples with these same incipient issues across a wide mining front. Kiruna's recent sterilisation of 90 Mt of ore within the Block 22 pillar has sharpened the senses across LKAB.

1 Introduction

LKAB, the Swedish state's mining company (www.lkab.com), has mined iron ore from Sweden's arctic region since 1890 (Viklund et al. 2015). However, only in 2020 did the need for a geotechnical model became a top priority. Establishing a need for the geotechnical model is the first step but how does LKAB, with four operating mine sites and combined resources and reserves of 4.6 billion tonnes (Bt) of iron ore (www.lkab.com), implement the systems needed for geotechnical modelling?

While many mining companies rely on consultancy work programs or use existing in-house expertise, this paper is for companies that quickly require a geotechnical model while currently operating without one. The scope of the paper is to document how LKAB made sustainable, systematic changes to its long-established work patterns, and how it managed the relationships of industry experts and consultancies. It is hoped the paper can be a blueprint for companies to provide a more efficient set-up of sustainable geotechnical data collection and modelling.

2 Background

Mining method and mine design are based on orebody shape and geotechnical hazards identified in a geotechnical model. A geotechnical model consists of input from separate geological, structural, rock mass and hydrogeological models (Read & Stacey 2009). At LKAB the geotechnical models are a matrix of raw data, processed data and interpretation. The maximum value of a geotechnical model is attained by the model's segmentation, domaining and characterisation of the rock mass (Read & Stacey 2009), and, where spatial coverage is sufficient, is often summarised as orebody knowledge.

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Mining innovation can be considered as increasing productivity and decreasing waste, and it may relate to a productive procedure (Sanchez & Hartlieb 2020). In this case a productive procedure is the selection of efficient tools, procedural efficiency and maintaining a minimal workforce. By selecting workflows that automate geotechnical core data-handling processes and use existing facilities and teams within a department or group, a company avoids waste, reduces costs and attains a lean model.

As a sector, mining is often considered conservative. Furthermore, orebody depth and associated high stresses require industry innovation and investment in research and development (R&D). LKAB's R&D department – Gruvteknik – is continuing with procedural innovation and automation to maximise productivity and assist in the exploitation of deep orebodies.

3 LKAB's system for geotechnical data and modelling

New geotechnical logging and modelling processes are normally established to solve an epistemic problem. An epistemic issue in the mine may be knowledge gaps, which can hinder efforts to have a geotechnically led mine design process, or – at a technical study stage – to have geotechnical study input when converting resources to reserves. Both positions are common but mine planning requires geotechnical data ahead of time; not by weeks or months but by years.

LKAB developed detailed geotechnical data collecting at four different sites, in unison, without breaking the company's budget, and here is how (current as of May 2024).

The steps taken to deliver the geotechnical model were as follows:

Plan

- Step 1: creation of log routines
  - Part a – what drillcore attributes are needed to be logged and why? (consultancy review)
  - Part b – communicate with internal departments to assist in buy-in

Implement

- Step 2: creation of logging team
  - Part a – externally led team
  - Part b – contract – per metre basis
  - Part c – training – consultancy review
  - Part d – quality assurance, quality control (QAQC)
  - Part e – tools for the job
- Step 3: insert team with routines into exploration and operations programs
  - Part a – core piggybacking
  - Part b – share existing facilities

Deliver

- Step 4: modelling and model use
  - Part a: modelling team – one project geotech per site
  - Part b: routines for all data-handling functions
  - Part c: global block models for mine design use
  - Part d: project-specific feedback

The planning stage aims to streamline the decision of which rock mass classification system is best applied in consideration of the project's probable mine design and the 'core table' time available. If mine design is not decided then the logging teams collect more drillcore attributes, such as Q parameters and mining rock mass rating (MRMR) (Laubscher & Jakubec 2001). At this first step the importance of geotechnical data must be stated to interdepartmental working groups such as mine operations and exploration. Geotechnical data collection will mean the core is on logging tables for longer (1.5 to 3 times as long) and unless the reasons for the added time are reasonably explained, conflict is sure to occur. Routines to guide the logging team are the glue that binds the planning stage to the implementation stage. Have a first draft of the routines, trial these and share them with the other geology groups. Without guidance, the planning step may take up to six months; with guidance and advice this timeline may be greatly reduced.

At the implementation step a contractor is recommended for executing the logging and sampling. A logging contractor specialises in advertising, recruitment, onboarding, training (according to the specifications outlined in the routines), staffing levels, payroll, client meetings, data handling, QAQC, and billing. Detailed planning meetings are necessary to ramp up and ramp down according to the drill plans. Weekly (at the minimum) meetings should be held, at which short-term plans are exchanged between the contractor and client. LKAB sees huge advantages in this employment model, such as reduced administration tasks for its human resources department and small geotechnical team, and continues to utilise logging contractors. LKAB logging and transport facilities are used for the contractor's logging teams, as for the in-house geology groups. Hardware and software tools are bought, contracted and set to 'live'. LKAB's tools for logging and modelling include: measure tapes, scratch pens, acid drops, chinagraph logging pencils, Canon SLR cameras, Manfrotto camera arms, arm clamps, Reflex IQ loggers, Lenovo laptops, and software (IMDEX, Imago, Leapfrog^{TM} Central, acQuire^{TM}, MS office). Implementation is the most sensitive of all the stages as without facility owner commitment, this stage could be seriously delayed.

Data handling of past drill programs can be a significant issue. LKAB's 'historic' data is defined as data that deviates significantly from a new standard of data collection. Past drill programs expanded their geotechnical data collection due to increasing awareness of geotechnical data (Table 1). For any historic dataset, this data curation is essential. An assessment is needed of past programs, and this may be assigned to an external consultancy.

Table 1 LKAB's major drill programs for the Per Geijer deposit

Geotechnical dataset	Drill program year (phase)	Borehole prefix	Purpose	Boreholes	
				Total length (m)	Number of holes
No geotechnical data	1959 to 1976, 1980 to 1982	10-, 11-, 12-14-,	Shallow and deep delineation drilling	121,804	510
RQD only	2013, 2015	81-, PYK-	Surface and deep resource drilling — some wedging	34,830	43
RQD + Q' only	1982, 2011, 2013	14-, 81-, 88-	Shallow surface targets and two deep holes	10,199	25
RQD + Q' + IRS	2020 onwards	PTK-, PYK-	Deep resource drilling and geotechnical	3,391	3
RQD + Q' + IRS + IRMR	2011, 2020 onwards	88-, PTK-, PXK-, PYK-	Exploration, resource and geotechnical drilling	82,236	77

Lastly, the deliverables must be achieved. The data chain of custody from the contractor to the client includes QAQC-flagged intervals and editing, overseen by one company geotechnical geologist per site. The company geotechnical geologist manages all data processing functions using Visual Basic for Applications (VBA) and for calculations within the modelling software, Leapfrog. Processing and data handling is stipulated in individual routines and checklists which include those for model domaining and validation. A geotechnical block model is the final deliverable.

These steps may be summarised as a workflow diagram (Figure 1).

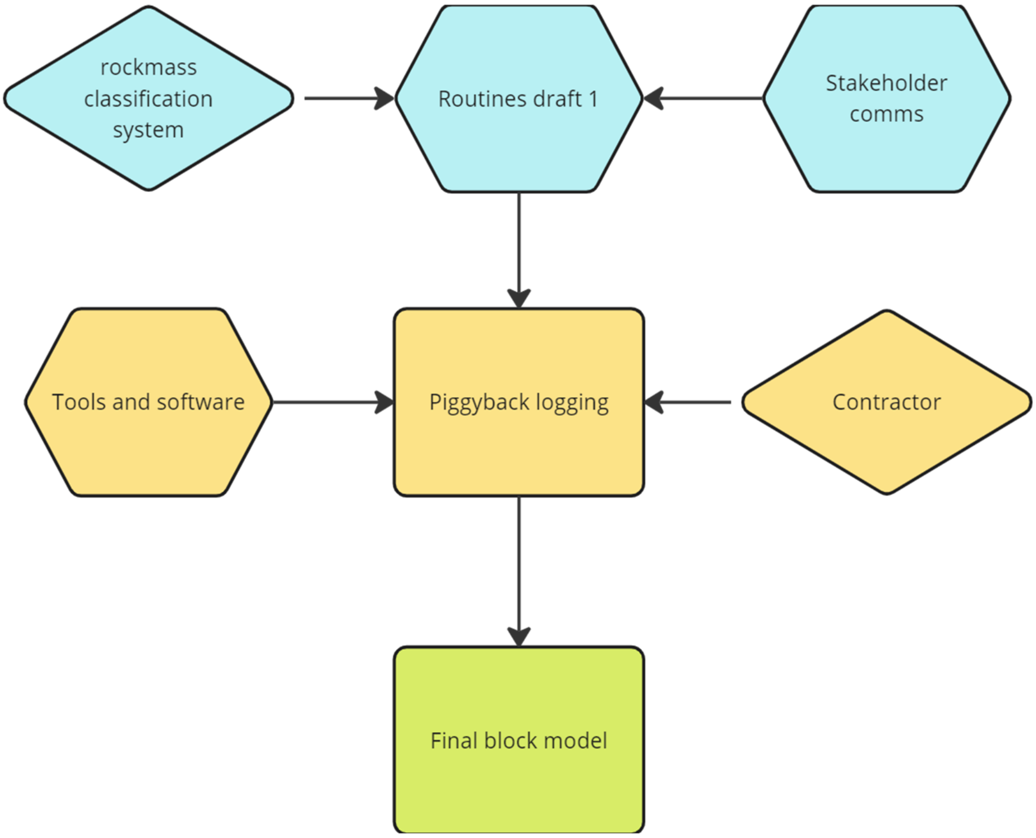

Figure 1 **LKAB workflow diagram used for geotechnical drillcore logging**

The final block model deliverable and the components needed to achieve it may be presented as an equation termed the geotechnical success equation:

$$Geotechnical\ model\ success = \frac{data\ x\ experience\ x\ routines}{time\ x\ budget\ x\ interpretation\ factor} \tag{1}$$

where:

data = any geotechnical data, logged or inherited, and QAQC.

experience = competency in logging, data handling and modelling.

routines = good guides to log, process data and model.

time = drilling and logging timelines.

budget = cost of drilling, the geotechnical contract and to build a team.

interpretation factor = aleatory risk, and incorrect interpretation or systems.

Project geotechnical geologists want to maximise the equation's top half and minimise the bottom half. Firstly, geotechnical data can be subjective and strewn with errors. To decrease subjectivity in the geotechnical logging clear and concise logging protocols or logging routines are needed (Read & Stacey 2009). Across different deposits, mines and companies there may be thousands of different geological logging routines. However, geotechnical routines allow a more systematic approach. A geotechnical logging routine's structure will be based around the logging and database systems; in LKAB's case, both use the licensed software product acQuire^{TM} (acQuire Technology Solutions Pty Ltd 2023). Any routine must be well structured, with explanations of the background concepts in brief and links to full explanations or long-form training material. The individual steps needed to complete the logging process must be described to enable trained geotechnical geologists to log efficiently and effectively.

At LKAB, logged data resides in the database. While these data may be verified, a process of QAQC is applied. The QAQC process uses a combination of calculations run in the modelling software (Leapfrog [Seequent 2024]) followed by an export-import into a VBA script. Data for an appropriate data range (e.g. the previous month's logging) are analysed for QAQC, and data that fail QAQC are returned to the logging contractor. The contractor then assesses failed QAQC data against the photographs and the database, searching for reasons why these data are flagged. Calculations and the VBA-coded script identify two types of error: concrete errors, such as nulls (blanks and missing values), and soft errors, such as data contradictions. In the same interval, logged contradictions can occur between the different rock mass classification systems such as Q and MRMR. However, these contradictions may be justified due to different logging of the rock mass classification attributes and resolved on analysis by the contractor. Interval data that are genuinely incorrect are kept, and a new, lower-priority number is assigned to the interval. Any new interval data are prioritised, thereby retaining original logged data and connecting, through the 3D software, to the correct data.

Competency in logging, data handling and modelling experience are sought after competencies are gained through training and the application of training through delegation and doing. When a new team is being set up there can be a gap in knowledge. To resolve the gap, consultancy expertise or subject matter experts must be used (Mawson et al. 2024). Consultancy expertise may be applied in many formats according to client needs. LKAB's experience showed that consultants worked the most intensively and participated best during the early start-up phase. Early and intense involvement delivered quick results and built confidence within the Gruvteknik team. Consultants contributed at many stages and, as regards geotech, their best use involved log routine development, geotechnical data auditing, model auditing, and onsite training and expertise.

In collaboration with consultancies, LKAB first developed log routines, and later in-house routines, for each process of data handling and modelling. The routines are steps which are implemented across LKAB's mines and they allow for a standard method application to the data with the aim of building and delivering models. Routine steps for some data-handling functions, e.g. classification of the type of geotechnical data present or not present for boreholes, are straightforward. Other routines, e.g. modelling, are complicated. These complicated routines are based on the functionality of the modelling software (in LKAB's case, Leapfrog), the rock mass classification systems used (Barton 2015; Laubscher & Jakubec 2001) and the components of a geotechnical model (Read & Stacey 2009). Collectively these routines make up a standard operating procedure.

To minimise the lower half of the geotechnical success equation one must decrease the time taken to log and model, minimise the costs and narrow the aleatory risk, whether in interpretation or in the system's whole. These are all disadvantages due to implementation.

The last component of the geotechnical success equation is uncertainty. Aleatory risk in the systems themselves, the training and implementation or the interpretation must be addressed. Without robust routines in place, the opportunity for most error may be in data collection (Read & Stacey 2009), followed by data processing and the modelling of data. At LKAB an annual consultancy audit of geotechnical data provides continuity and an ongoing collaborative approach with the consultancy.

4 Lessons and discussion

The paper's scope is to discuss a geotechnical team set-up across large underground mine operations with high drill and logging rates, and big teams. Several elements are transposable to smaller operations and the steps above may be selected à la cart. In this section, discussion points are expanded and overarching lessons presented.

Time logging may be time well spent but for LKAB, drilling and logging geotechnical holes using in-house teams across three tier one deposits with a combined running total of 4.6 Bt of iron ore would be prohibitively expensive. Thus LKAB's Gruvteknik department planned to box clever. Geotechnical data may be collected from the exploration department, operation's infill programs and ad hoc geotechnical drilling. During each of the past three years, LKAB's contractor achieved around 200,000 m of geotechnical logging. This volume of drillcore logging requires significant working space, staff and staff training; each of which must be slotted into the LKAB geology department's existing drilling and logging workflows. These demands are achieved by using a piggyback relationship with the existing teams at LKAB. Geotechnical logging is completed immediately after the geology logging, exploration holes are extended hundreds of metres to cover mine design development, and existing core facilities are used to minimise administration tasks and to maximise cross-pollination with the geologists. Piggybacking requires that staff be super flexible, and able to communicate their needs and requirements effectively. A piggyback approach is a lean approach to maximise the resources while minimising capex and opex costs.

When confronted by the inevitable obstacles, be super flexible. Established teams may exhibit unwillingness to accommodate and integrate new teams, which may be due to time pressures or inexperience. Likewise, inserting a team into existing working groups or workflows will have unanticipated consequences and reactions. For instance, acceptance from the in-house geologists is a complex and underestimated factor that can develop into feelings of inferiority within the external team. Whether inferiority feelings are real or not, they are perceived. When dealing with groups, the Gruvteknik department never criticises. It start trials, presents updates regularly, and communicates when stages and objectives are achieved. Finally, with existing interdepartmental teams, needs must be communicated from the start: which geological, structural and resource models are needed, what are the dates on which to share these models and how any models should be shared are questions that need to be discussed and explained to mutual benefit.

As competency develops and teams mature, geotechnical analysis and practices should remove the focus of orebody bias – inevitable from the piggyback method – and target any epistemic situations. Important structural features, rock strength testing and joint conditions can be modelled. Conceptual hydrogeological models, stress models and temperature models can be based on *a priori* reasoning.

The final deliverable is a block model: a format that allows reliable modelling processes and regular updates (Sewnun et al. 2019). At LKAB, routines for data handling and modelling allow standardisation across the three major deposits of Kiruna, Per Geijer and Malmberget, and application to Svappavaara (an open pit deposit). However, the block model's data and categories must be explained along with its uncertainties.

Hopefully what is clear is that LKAB has a long history of mining, and many datasets may be selected with which to base a geotechnical model on. A small in-house team may decide what to log and how to log it based on the mine engineer's needs and company strategy, with consultancy review. Review assistance may be intense at an early stage. New routines and workflows created must have a trial period and be shared among the teams already logging in advance of any geotechnical team being inserted. On maturity of the logging process and teams, annual consultancy review is recommended.

5 Conclusion

For optimal mine design, industry acknowledges the need for a geotechnical model, but there are mining companies in operation without a good working knowledge of their geotechnical attributes. Starting the process of geotechnical competency is a difficult task requiring time and investment. This paper seeks to highlight an efficient model to establish geotechnical teams on high-volume drill programs.

The logging team, whether in-house or external, is the engine of data collection. A distinct advantage of LKAB's use of a contractor is that all the administrative jobs in establishing and running a logging team are handled by the contractor. The symbiotic nature of the client-contractor relationship needs handling from a position of understanding and flexibility.

Shared drillcore and the facilities in which to log the core are the source of many obstacles. Establishing and inserting a logging team is done by piggybacking. Piggybacking is a lean model when addressing how to systematically log core. Advantages of piggybacking are that no drilling budget is required (at least to start with, until a picture of the geotechnical spatial coverage is gathered), a logging and laboratory sampling budget is more affordable, no administration time is spent on facilities and, consequently, a smaller and more productive workforce can be focused on geotechnical issues. However, downsides include a lack of control, and that data are captured from core that you or your team had little to no input in the planning of (drill method, drill direction, drill targets). This model, while suffering from the disadvantages of drill program control, is highly efficient in gathering geotechnical data from the implementation.

Mining innovation can be procedural. Past arguments that geotechnical data is too expensive to obtain and takes too long no longer hold true if a piggyback method of data capture is instigated. Geotechnical data capture and logging have the potential to be objective, and may be applied across geology and deposit types in a standardised format. During the past four years LKAB developed geotechnical models systematically across its deposits and acknowledges it still has far to go.

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