



The mechanisms of decision-making when applying geometallurgical approach to the mining industry

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Abstract

It is believed that most of the production problems in modern mining industry could be solved solely by applying technical tools such as better machinery, more accurate models or more advanced technology. Geometallurgy was initially introduced as a tool aimed to improve production performance by integrating geological and process information into a predictive model. However, the actual benefits of geometallurgy cannot be achieved without considering actors involved and strategic decisions made by the management in addition. The purpose of this paper is to introduce a framework of decision-making in which technical and managerial aspects of the geometallurgy are fully integrated. This framework is aimed to be used for improving predictability of the geometallurgical programmes.

Keywords Geometallurgy · Geometallurgical programme · Decision-making · Classification · Interview

INTRODUCTION

Modern mining industry is exposed to serious risks, including more complex geology (e.g. geometric shapes of deposits, deep-seated deposits), lower ore grades, variability in ore quality (e.g. textural complexities) and large production volumes, and as a result increased waste quantities, demands from metal producers, metal prices fluctuations and stricter environmental regulations (Bridge et al. 2014; Curry et al. 2013; Dominy and O'Connor 2016; Kojovic et al. 2010; Lund and Lamberg 2014; Williams 2013). Many of those risks could be mitigated or eliminated by applying geometallurgy. Geometallurgy is a team-based and multidisciplinary approach (Bayraktar 2014; Parian 2017) that aims at linking geological (i.e. variability in the feed) and mineral processing parts (i.e. variability of the ore performance in the process) of the mining value chain, to build a model for production

management—a geometallurgical model (Dunham and Vann 2007; Kittler et al. 2011; Lamberg 2011; Lund and Lamberg 2014; McQuiston and Bechaud 1968; Navarra et al. 2018; Vann et al. 2011). While the approach is not new, recent advances in automated mineralogy, data processing and metallurgical testing have made it feasible in practice (Lamberg and Lund 2012; Schouwstra et al. 2013). A geometallurgical model aims to provide quantitative prediction of metallurgical performance, i.e. quality of concentrates and tailings, recoveries, throughput, environmental impact (such as fresh water consumption for a treated ton of ore) and overall economical fluctuations of the project. A geometallurgical model can also be oriented at solving problems as a black box (the entire processing plant in a single model), by processing sections (e.g. comminution, concentration, leaching, dewatering etc.) or with only one processing unit (e.g. crusher, mill, flotation cell etc.). The ultimate goal of geometallurgy is a spatial predictive model (Dunham and Vann 2007; Lund and Lamberg 2014; Vann et al. 2011). The process of creating, maintaining and utilising a geometallurgical model is called a geometallurgical programme. Within a geometallurgical programme, geometallurgical models define the use of geological data, sampling strategy, testing methods and simulation outcome.

Geometallurgy is claimed to help in optimisation of mineral resource utilisation (Philander and Rozendaal 2013). According to Dunham and Vann (2007) geometallurgy can

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give increased total metal recovery and improved asset utilisation. In addition, Lamberg (2011) listed in his review that geometallurgy has potential to bring benefits, such as better controlled ore deposit utilization, higher flexibility in introduction of new technological solutions, lower operational risks and wider access to economical optimisation of the full operation. Introduction of geometallurgy at early stages of the project can decrease the level of uncertainty in future project stages and consequently in production (Baumgartner et al. 2011).

Actively used geometallurgical models can be applied to identify, correct or prevent current processing issues, preventing future problems, or in a more holistic approach to optimise the full production chain based on ore variability. While correcting can be contained within a single processing unit, e.g. mine, comminution, concentration or dewatering, preventing must always involve several processing units or processing unit parts. In this, the geometallurgical programme offers invaluable benefits by providing relevant information and connecting the terminology for all relevant parties.

Applications of geometallurgy are not limited to process problems but may include mine stability and blasting (Bridge et al. 2014; Hunt and Berry 2017). Additional benefits from applying geometallurgy are widely discussed in literature and include: reduced energy consumption, optimised water consumption and process control, ensuring product quality (Beniscelli 2011; Bridge et al. 2014; Coward et al. 2009)

Establishing geometallurgy in a mine and developing a geometallurgical programme is associated with risks of getting either low or no benefits from it due to low predictability. Predictability issues may be caused by complexity of the process, low agility of the geometallurgical programme, lack of collaboration between players or even insufficient automation. Predictability, as a term, occurs often in the literature when discussing the quality of the geometallurgical models, although it lacks own definition in a geometallurgical context. The nearest definition of predictability was found in Mckee (2013), stating that correctly implemented geometallurgy (aka Mine-to-Mill) will provide “Improved predictability and hence consistency of both mining and processing performance by providing performance benchmarks for the range of ore types present in every mining operation. Such predictability allows operations to identify when performance slips below benchmarks and promptly initiate corrective action”. Predictability is believed to be in balance with available data and business’ tolerance for complex models (Everett and Howard 2011). The need for improvement in predictability of metal grades for maximising the throughput and recovery was emphasised by Esper et al. (2013). Moreover, the predictability improvement from the perspective of product grade and yields in iron ore by applying multivariate statistics was discussed by Vatandoost et al. (2013). Many other scholars use the term predictability in their research in connection with

geometallurgy, e.g. Minz et al. (2015); Chetty (2018); Seaman et al. (2016); Vatandoost (2010).

The aim of this paper is to show that the efficiency of a geometallurgical programme can be improved by enhancing the predictability of geometallurgical programme. The predictability can be enhanced by identifying gaps in the methods applied in geometallurgy. Knowing those gaps will show areas where development to improve predictability is needed. More detailed geometallurgical data and more advanced usage of the data may lead to increased predictability after answering the following questions:

- What type of geometallurgical data is used for the modelling and how can this data be generated, considering three major approaches: elemental, proxy and mineralogical?
- How is geometallurgical data used in production at seven different application levels ranging from no application to managing production scenarios on the level of higher managerial decision making?
- Additionally, an attempt is made to identify the players and their roles in geometallurgy depending on the application level.

Methodology

Geometallurgical programme aims at the development and use of geometallurgical models. Geometallurgical models should provide reliable forecast for the variation in production performance by linking it to the variability in the upstream processes. Knowing the magnitude and implications from the variations in production allows for informed decision-making at managerial level regarding the actions required for better production planning. However, all mines are different and consequently the commodity, the process, the working culture, the local environmental regulations etc. will differ in different mines. Accordingly, each mine represents a unique case that is likely to require customised geometallurgical solution for the production problems. The aim of the classification is therefore to investigate different application levels of geometallurgy and different approaches to data collection in order to identify gaps in the applied methods with the overall purpose of finding ways to increase the predictability of the process, and thus indicate areas where development is called for. Filling in gaps allows to measure and model the impact of geological variability in the feed on the variability in the process performance, when such impact is significant. Possible gaps are as follows: (1) less costly and simpler mineralogical characterisation techniques, (2) geometallurgical tests which would allow to capture the variability in the process (i.e. new tools for conducting tests or a new testwork routine for measuring desirable parameters), (3) process models which could

explain the behaviour of the ore in a particular part of the process; (4) process simulation with relevant models implemented in a simulation software and (5) spatial modelling methods adequate for the reviewed case.

Collecting information on industrial practices of geometallurgy

This paper is based on cross-disciplinary research, involving an extensive literature review (38 cases) as well as semi-structured interviews (14 cases) and a cross-sectional survey (Lishchuk 2016) to validate the notion of geometallurgical programme. A total of 52 case studies (Lishchuk 2016) were reviewed to develop an analytical framework for the assessment of geometallurgical programmes. The cases were selected on the basis of the (alleged) existence of geometallurgical activities. The selection of interviewees and survey participants was based on personal contacts. The survey serves the purpose of structuring the geometallurgical data (sampling, models and simulations) in a way which would facilitate identifying the gaps in available technologies (e.g. mineralogical characterisation, geometallurgical tests, process models). Identifying those gaps will show where the development is needed for constructing a geometallurgical programme. An online questionnaire form (Lishchuk 2016) linked to the database was developed in Google Forms. The questionnaire form was grouped by the following seven chapters:

1. Respondent information, i.e. information about the person who was filling the form;
2. General information on the mine project;
3. Production information to collect data about the most common production parameters, i.e. ore type, main product etc.;
4. Deposit model to cover availability and potential for application of the geological and geotechnical data for geometallurgical modelling;
5. Geometallurgy level to obtain existing information regarding the geometallurgical purposes;
6. Implementation of geometallurgical information in order to collect answers regarding the information depth of application of geometallurgy;
7. Application of geometallurgical approach. Self-evaluation. The purpose of this section was to double check results by asking questions in a graphical way.

The survey included 14 participants (mining and mineral processing engineers, process mineralogists, researchers, trainees, master students) at companies in Europe (Sweden, Poland, Finland, Russia), Americas (Canada, USA, Brazil) and Africa (Namibia, and one unspecified country in Africa). The participants have in-depth knowledge of the mine production, processing, production planning, the level of

implementation of geometallurgy at their companies and were, therefore, suitable to validate the notion of geometallurgical programme. The interaction with the respondents for the cases Mine-1, Mine-2, Mine-3 and Mine-4 was via face-to-face communication, and interaction with other respondents was via mail, or social networks (e.g. Facebook).

Information treatment

The information collected was used to classify the case studies according to the respective approaches, i.e. traditional, proxy or mineralogical and levels of applications (Fig. 1).

While it is necessary to more clearly define the notion of geometallurgical programmes, there is a risk of misinterpreting the collected information. Some of the main challenges (sources of possible errors) of the survey include difference in terminology used in different geographical locations and different meanings for the same term applied in different areas (e.g. recovery in mining means proportion of the ore extracted after accounting for mining losses, while recovery in mineral is the percentage of the total metal contained in the ore that is recovered to the concentrate).

Classifying according to approaches

The type of approach is defined by the data used in the geometallurgical programme (Fig. 2). Three different geometallurgical approaches could be distinguished: traditional (elemental), proxy and mineralogical.

The classification of the approach is based on the traceable component, e.g. chemical composition, metallurgical response and mineralogy, and is thus affected by the methods for sampling and analysis. The sampling frequency and types of tests used for defining metallurgical responses also varied between the identified geometallurgical approaches. Therefore, the case studies were classified into the *traditional approach* if they were using chemical (chemical composition)

		Level of technological advance (approach) →		
		TRADITIONAL	PROXY	MINERALOGICAL
Depth of geometallurgical program (application) ↓	PASSIVE USE:	<ul style="list-style-type: none"> • None • Data collecting • Visualization • Forecasting 		
	SEMI-ACTIVE USE:	<ul style="list-style-type: none"> • Changing process 		
	ACTIVE USE:	<ul style="list-style-type: none"> • Constraining • Production planning • Managing production scenarios 		

Fig. 1 Classification matrix of the geometallurgical programmes

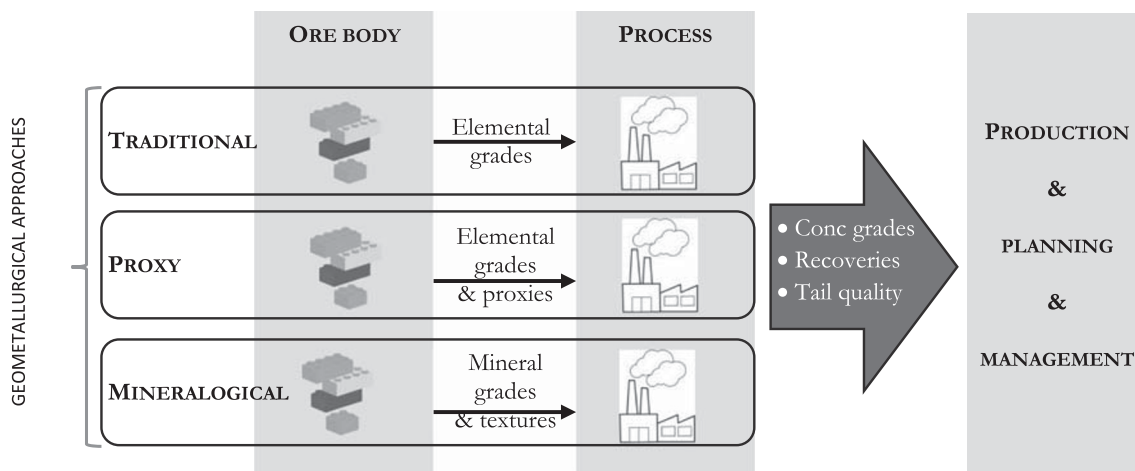


Fig. 2 Linkage between geology and process via geometallurgical approaches

and qualitative mineralogical (list of minerals) information. The case studies which used quantitative mineralogical (modal mineralogy) information were classified into the *mineralogical approach*. Finally, case studies, where geometallurgical tests were combined with chemical (chemical composition) and qualitative mineralogical (list of minerals) information, were classified into the *proxy approach*.

Traditional approach

In the traditional approach, chemical assays and chemical compositions of the ore form the basis of the programme. Metallurgical response is calculated from the chemical composition of the ore collected by chemical assays of samples. Simple recovery functions are used for this purpose, i.e. elemental recovery is a function of the elemental content in the ore. The functions are developed by using metallurgical testing and statistical analysis to define the correlation between the metallurgical response and feed properties, i.e. chemical composition. Traditional approach is common for commodity types where ore grades are high. It is also a common method for the early stages of the mining projects, i.e. conceptual study stage and pre-feasibility study. Often the development of geometallurgical programme starts from traditional approach.

Proxy approach

The proxy approach uses geometallurgical tests or other indirect measurements of metallurgical response to characterise the metallurgical behaviour of ore for large number of samples in different processing stages. The geometallurgical test is a small-scale test which indirectly measures the metallurgical response. Normally, the geometallurgical test results must be converted with certain correction factors (often called scale up factors) to give estimate of the metallurgical results at the plant. Examples of geometallurgical tests are Davis tube

(Niiranen and Böhm 2012) and semi-autogenous grinding (SAG) power index (Kosick et al. 2002). Geometallurgical tests need to be applied early in the ore characterisation in order to collect information on the ore variability (Mwanga et al. 2015). Such tests are cheap and rapid, in comparison with laboratory scale metallurgical tests, and usually require special equipment. They can be performed on samples of a small size and should correlate reasonably well with conventional tests and metallurgical results of the plant (Chauhan et al. 2013). It is the application of geometallurgical tests in connection with elemental grades and without connection to mineral-related behaviour of the ore, which distinguishes proxy approach from the mineralogical one.

Mineralogical approach

The mineralogical approach refers to geometallurgical programmes where a geometallurgical model, i.e. deposit and process model, is built based primarily on quantitative mineralogical information. The process simulation in the mineralogical approach must be capable of handling unit process models at the particle level (Parian 2017). This often means that accurate information on modal mineralogy is needed for the whole ore body (Lamberg et al. 2013). Thus, mineralogical data has to be quantitative, and the collection of information has to be continuous throughout the life of the mine (Hunt and Berry 2017) and systematic. Lund (2013) and Lamberg (2011) demonstrate how a geological model and a process model can be linked using mineralogical information. Bonnici et al. (2008) highlight the implications of mineralogical information (textural attributes) for processing behaviours such as comminution, liberation and recovery.

Classifying according to applications

To become an industrial geometallurgical programme, the geometallurgical model has to be used in production. The

Table 1 Application levels of geometallurgical programme

Level	Name	Geological database	Metallurgical testing	Model	Simulation	Actions	Players	Mapping	Continuity
0	None	X				None	None	No	No
1	Data collecting	X	X	Y*			geologist and mineral processing engineers	No	
2	Visualization	X	X						
3	Forecasting	X	X	X					
4	Changing process	X	X	X		Corrective			
5	Constraining	X	X	X		Preventive	and mining engineer and economist, maintenance, automation engineers	Yes	Yes
6	Production planning	X	X	X	Y*			Yes	
7	Managing production scenarios	X	X	X	X		and QEHS** engineer, environmentalists, sellers of concentrate, product buyers, metallurgists, shareholders		

* Y is not obligatory

** QEHS, Quality, Environmental, Health and Safety

depth of the applicability of the programme is defined by how geometallurgical data may be used in production management. The depth of the geometallurgy application shows the level of geometallurgy involvement in production management decisions and is divided into passive, semi-active and active level of use. This depends on the sophistication of the model, the depth of its use, the main involved players at the site, the complexity of managerial tasks involved and if a corrective or preventive approach is used to solve production issues. The conditions for placing the case study on a certain level of application of geometallurgical programme are listed in Table 1. Fulfilling more technical requirements from the list in Table 1 (e.g. creating geological database, conducting metallurgical tests, building process models, continuity of the programme etc.) does not necessary lead to a more advanced level of application, but creates such a possibility. The number of participants involved in the geometallurgical programme changes with the depth of the programme. A deeper (more advanced) level of geometallurgy corresponds to deeper integration and cooperation between the involved parts of the mineral production chain, i.e. geology (exploration and production), mining, production maintenance, sales etc.

Level 0: none

Level 0—none means that no geometallurgical data is collected and neither a geometallurgical programme nor a geometallurgical model exist. This is the starting level of every geometallurgical programme.

Level 1: data collecting

At the level 1, geometallurgical data is collected systematically but is not used for any production planning purposes or visualization of the information. Collecting geometallurgical data requires collaboration between the geologist and the processing engineer. At this level, the ore has to be tested for either a feed-forward effect on the variability in metallurgical response in laboratory conditions or for feedback connection between variability in metallurgical response at the plant that can be consciously linked to the geological variability. The latter can be optionally achieved by thorough empirical plant observations in operating mines. The basis for the future geometallurgical model is created at this level. The existence of geometallurgy at this stage does not lead to any noticeable actions.

Level 2: visualization

At level 2, the variability within the ore body is visualised based on the collected geometallurgical data. The data is stored in numerical form; thus, special software has to be used. The data is used by visualising the variability in presentations,

meetings and discussions. At this level, also people outside processing and geology should have access to it. A geometallurgical model may exist at this stage, but it is not used for any production-related purposes. Besides that, geometallurgical programme at this stage inherits all the features of the level 1 “Data collecting”.

Level 3: forecasting

Level 3 uses geometallurgical data to forecast production. The information is used to raise awareness amongst other players without any active actions for production. Information may be used in tailings management and concentrate marketing and shipping, i.e. information is taken but no actions exist to change mining, ore blending or processing. Commonly, the geologist and the processing engineer remain the only active participants of the geometallurgical programme.

Level 4: changing process

At level 4, information on the variability in feed quality is used to make changes to the process. At this stage, only corrective but no preventive actions are taken. Corrections may be planned beforehand; however, they impact only a limited part of the process (a section) and involve a limited number of people. Level 4 is a transitional stage between passive and active application of geometallurgy.

Level 5: constraining

At level 5, data is used to define feed quality constraints and production limitations of the process. This is the lowest level of active use of geometallurgy including typically some preventive actions. It is also the first level on which geometallurgical programme has to be continuous and is often also constantly improved. Typically, this level includes limitations on the feed properties, e.g. titanium grade must be below 0.9 wt% in the feed; the mass proportion of talc bearing country rock must be lower than 4% of the feed. Therefore, changes are typically made on mining side or in feed blending to mitigate the negative impact of the problematic components in the downstream process. Changes include such actions as ore blending, selective mining and small changes in production flowsheet. Level 5 requires a larger group of participants with obligatory involvement of mining engineers and production planners, besides geologist and metallurgist.

Level 6: production planning

At level 6, the production plan is based on geometallurgical data. Wide range of players, including (besides geologist, metallurgist and mining engineer) maintenance and automation engineers, and also economists benefit from the

geometallurgical results and actively contribute to the utilisation and development of the geometallurgical programme. At this level, often both geological variables and geometallurgical indices are included in block model (3D). Therefore, a block model is continuously maintained and updated. In some cases, simulations of alternative scenarios are done, although not on a regular basis. Effective application of geometallurgy at this level requires advanced online measurement tools (e.g. measurement while drilling system) and real-time update of the geometallurgical model, block model and mine production plan. Both geological and processing simulations are utilised. Involvement of economists and finance specialists allows for production benefit estimation in terms of cash flow and projected cash flows, including both discounted cash flow and net present value (NPV).

Level 7 : managing production scenarios

At the highest level 7, managing production and geometallurgical data form a vital basis of the decision making, e.g. investments, selection of alternative technologies, production interruptions (or production speed-ups), merging of companies, expansion and investments. Such flexibility is achieved through active use of simulation and active involvement of wide range of players. Both upstream and downstream processes are affected by geometallurgy. Effective application of geometallurgy at this level requires advanced online measurement tools and real-time update of geometallurgical model, block model and mine production plan.

Results and discussions

According to the reviewed literature, establishing geometallurgical programmes is assumed to be beneficial for certain types of deposits. The theoretical gap in research is the lack of tools and methods for planning geometallurgical programmes in an efficient way, which in turn would ensure predictability.

This study aims to provide a new framework for doing geometallurgy with better predictability. Predictability should be introduced into geometallurgical programmes early, preferably by planning how much geometallurgy is needed.

The organisational and interdisciplinary aspects of geometallurgy have received less attention than the technical aspects (Jackson et al. 2011). This paper aspires to address this gap. The recommendations to enhance the decision-making in geometallurgy presented here are based on the literature review, and on interviews with geometallurgy specialists within the mining sector. The main usage of the developed classification is linking geological information with metallurgical responses and identifying gaps where improvement is needed

for better predictability. The main difference between the previous systems for structuring geometallurgical programmes presented by others (i.e. Bridge et al. (2014); Dunham et al. (2011); Jackson et al. (2011); Sola and Harbort (2012); Vann et al. (2011)) and the one presented in this paper is the classification under traditional, mineralogical and proxy approaches, which clarifies how to collect and use the geological and process information for further planning. Such a classification allows for the investigation of the more practical issues related to the geometallurgical programmes: which analytical instruments (e.g. XRF or XRD) and process tests should be used (e.g. Davis tube, Wet Low Intensity Magnetic Separation, flotation); how the geometallurgical model can be applied in production; which actors have to be involved in the @@geometallurgical programme; etc.?

The full list of the reviewed cases and detailed information about geometallurgical programmes is listed in Lishchuk (2019). The classification system developed here (Fig. 3) has two dimensions: the first dimension is the type of geometallurgical approach and the second dimension is the

depth of application of geometallurgy. In most cases, geometallurgy was applied to predict ore behaviour in comminution (mainly throughput in grinding and work index) and separation (mainly recovery of valuable metals in flotation and magnetic separation). Only one case (Silinjärvi mine—case) reported usage of geometallurgy in dewatering. Few cases (Olympic Dam, case 24; Radomiro Tomic, case 26; Morro do Ouro, case 47; and Dutwa, case 48) reported usage of geometallurgy for hydrometallurgical purposes. Only one case was found, where geometallurgy was applied for environmental purposes for observing acid rock drainage in waste rock (Canahuire, case 30).

Approaches

The classification system shown in Fig. 3 is essential for the identification of different ways to connect geological information and ore performance in the process. Three geometallurgical approaches were systematised to classify the case studies shown in Fig. 3: traditional (12 cases), proxy

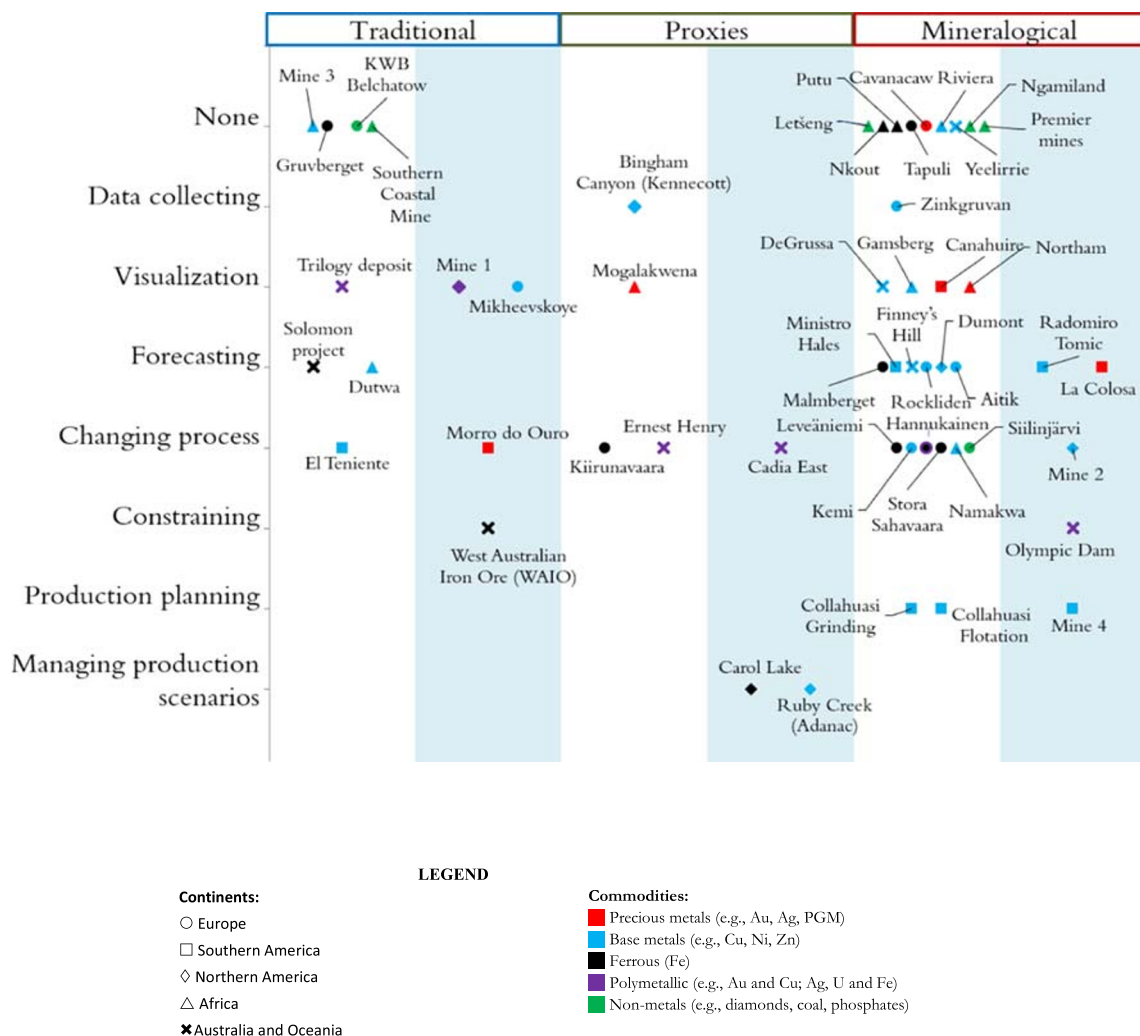


Fig. 3 Selected mines arranged in classification matrix (based on Lishchuk et al. 2015)

(7 cases) and mineralogical (33 cases). Each geometallurgical approach is divided into the following two sub-approaches: domained and global. The domaining sub-approach implies a more advanced use of a block model, while a global sub-approach does not require a block model at all. In other words, mines that follow the domained geometallurgical approach in Fig. 3 generally have more capabilities towards developing a more advanced geometallurgical programme.

Applications

The depth of the geometallurgy application, described in Fig. 3, shows the level of geometallurgy involvement in production management for the selected case studies. The practical use of this classification system becomes obvious when there is a need to either change a geometallurgical approach (e.g. from traditional to proxies or from proxies to mineralogical) or to go to a more advanced level of the geometallurgy application. The following eight levels of application were identified (Fig. 3 and cf. Table 1) in the order of increasing involvement in production management ranging from the simplest (level 0) to the more advanced (level 7): (0) none, 13 cases; (1) data collecting, 2 cases; (2) visualization, 8 cases; (3) forecasting, 10 cases; (4) changing process, 12 cases; (5) constraining, 2 cases; (6) production planning, 3 cases; and (7) managing production scenarios, 2 cases. Normally, more advanced level includes all features of the lower levels.

Trends and key findings

Based on the data collected on different geometallurgical programmes, a trend was identified that the more advanced levels of geometallurgical programmes tend to use a mineralogical approach. The traditional elemental approach is used more in the less advanced levels of geometallurgical programmes, and the proxy approach is applied in between these levels. The explanation is that the development of a geometallurgical programme usually starts with a systematic collection of numerical data—chemical assays from the drill core samples—with high data collection frequency. This information is often defective for the purposes of metallurgical model development, because a metallurgical response is likely to be more dependent on mineralogy than on the chemical composition of the ore. Thus, once the geometallurgical programme goes to a more advanced level, the use of mineralogical information increases.

A large number of geometallurgical programmes, where geometallurgy is claimed to exist, have been classified as cases with no application of geometallurgy (4 programmes with traditional approach and 9 programmes with mineralogical approach). Most of these (9 programmes) use a mineralogical approach in their work. This suggests that the term geometallurgy may have been incorrectly used as a synonym

for mineralogical and chemical characterisation of the ore properties in the deposit. No cases with “None” application of geometallurgy were found in the “Proxies” approach. Proxies require usage of special proxy tools to predict ore performance in the process, which makes process data available at the lowest application level. Therefore, “data collection” is the lowest application level available for proxies approach (see Table 1 for the minimum requirements for each application level).

No geometallurgical programmes corresponding to the most advanced application within the traditional approach were found. Both the mineralogical and the proxies approach, on the other hand, had cases within the advanced level of application. Process models based on elemental properties of ore tend to have lower accuracy than models based on mineralogical properties. This is because the mineral concentrate, but not pure elements, is the final product of the mineral processing. For the same reason, there are more geometallurgical cases reported for the mineralogical approach than for other approaches.

In the paper, geometallurgy is viewed as a paradigm change in mining industry from just problem solving to a holistic variability management and problem prevention. This shift has prompted the inclusion into geometallurgy of a wide range of disciplines, i.e. spatial modelling, economical modelling and a dispersion of responsibilities across a wider range of actors.

Conclusions

The predictability of the geometallurgical programme was enhanced by developing a two-dimensional classification system for geometallurgical approaches which enables the following:

- Identifying different ways to link geological information with metallurgical responses: mineralogical, traditional, proxy approaches.
- Suggesting areas where the development for the improved predictability of the geometallurgical programme is needed.
- Assigning key players to the geometallurgical programme based on the aimed application level of geometallurgy.

The methodology developed here can be used in the implementation of geometallurgical programmes in a more predictable way by considering the planning of the programme with the classification system. More detailed studies are suggested for the future, including studies of the various actors involved in the process; how to determine whose interests are more important than others and if they are adequately represented in geometallurgical context. Here it would be necessary to

identify the roles of the actors, their power in relation to e.g. the deposit and the process types, as well as production issues, geographic location of the mine, cultural differences and other aspects which might be difficult to foresee.

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