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The business value of best practice process mineralogy

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ABSTRACT

Modern Process Mineralogy has been making significant advances in methodology and data interpretation since it was assembled in the mid-1980s as a multi-disciplined team approach to obtaining mineralogical information from drill core and plant samples so as to infer the metallurgical processing requirements of that ore. This hybrid discipline consists of teams that include geologists, mineralogists, samplers, mineral processors and often others, working together. The degree of cross-training, communication and trust dictates the potential capacity of the team and it is possible to develop technical capabilities that surpass those of conventional teams. A pivotal tool for technically efficient and plant-oriented process mineralogy is, of course, the use of modern, automated laboratory technology. In these cases, process mineralogy, though associated with some capital investment, is a valuable risk reduction tool and an operations optimization tool for any mining company, not only in terms of finances but also in terms of human and intellectual capital. However, if the teams are dysfunctional and information is not interpreted correctly due to limited experience in the team or less than best practice, or it is not implemented or used, much of the value can be lost. Process Mineralogy can then be regarded as 'time consuming and expensive'. In this paper, the business value of best practice Process Mineralogy is outlined and discussed. Case studies that include 'green fields' new design applications and 'brown fields' interventions to mature operations have been selected to demonstrate the tremendous financial value that can be achieved are presented, along with those where costly disasters could have been averted. The list is not intended to be exhaustive or complete, and the reader is referred to the extensive literature available. Examples are selected for this publication specifically to illustrate the delicate balance between generating additional business value through potentially expensive mineralogical analyses and the lost opportunities of underperforming flowsheets, unanticipated losses due to high feed variance, inadequate liberation or deleterious minerals, over-reagentised circuits, or extra costs of unnecessary or underutilised equipment.

1. Introduction

1.1. Best practice process mineralogy

'*Process mineralogy*' can be defined as the practical study of minerals associated with the processing of ores, concentrates and smelter products for the development and optimization of metallurgical flowsheets, including the waste and environmental management considerations or as (Henley, 1983; Jones, 1987; Petruk, 2000) put it more simply 'the application of mineralogy in making processes more effective' (Becker et al., 2016). This hybrid discipline consists of teams that include geologists, mineralogists, samplers, mineral processors and often others, working together. The degree of cross-training, communication and trust dictates the potential capacity of the team and where an appropriate work dynamic is fostered, in which relationships flourish as much as does the ethic of technical excellence, it is possible to develop technical capabilities that surpass those of conventional teams.

Current best practice of Process Mineralogy is the cumulative product of several teams across the world working at developing this platform by way of new equipment, associated software, methods and associated quality controls over several decades (Lotter, 2011; Bradshaw, 2014). Although modern laboratory technology in concert with powerful software offers fast and large-scale generation of data, our industry has observed a considerable deficiency in training of succession mineralogists. The reasons for this situation are manifold and need to be addressed in discussions on strategic business planning.

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In as much as the equipment has seen a great deal of advancement, the value potential of the data arising therefrom is only deliverable through a well-trained and experienced team.

It has been shown by several of these teams that a key part of the successful use of the toolbox is high-quality training, both within-discipline and intra-disciplinary. The latter takes longer, and works best through the medium of projects being executed, with group discussions mutually interpreting the data to hand. Several generations of team members balance the experience of the team well, with the older members mentoring and guiding the younger ones, at the same time as learning new skills from the latter. It is highly preferable that most of the team members have several years of operations experience before being assigned to this multi-disciplined team. The intra-disciplinary training generally takes two years to attain a core level of multi-discipline expertise, but the learning never stops. For example, the habit of reading new publications on the subject, attending conferences and having discussions with the presenting authors, and networking with other practitioners, all add considerably to the learning and skill development.

This mentoring dynamic leads the efficient interpretation of the large volumes of data that arise from the modern practice into the specific process implications. These large data sets potentially threaten the project unless they are analysed, interpreted and summarised before being presented to the end-user. Provided this process is in operation, the reports and recommendations presented to clients in operations are summarised, readable and practical for the end-user at the operation. The key skill to develop in these teams is the ability to assess a project and to define the correct and appropriate selection of tools and equipment to complete the job effectively and efficiently. Cross-checks using common sense instead of a default setting of "the computer is always right" are critical.

The reputation of the Process Mineralogy team thus builds in the mining company or commercial laboratory as a result of the interactive, synergistic and focussed approach in project work, delivering financial value. This enables the executive to continue supporting the team across the metals business cycle.

Gaudin's first liberation model of 1939 presented a penetrating analysis of the problem. His work was followed for decades by geometrical probability models, for example Bodziony (1965) who showed that the techniques of integral geometry could accommodate the problems associated with the indeterminate nature of the geometrical mineralogical structure. Mathematical liberation models were written in the 1970s and 1980s as a lead into the definition of the grinding requirements of an ore for flotation (King, 1979, 1989, for example).

The connection between mineralogy and metallurgical performance in a plant was recognised long ago (Gaudin, 1939; Petruk, 1976; Petruk and Hughson, 1977; Cabri, 1981; Petruk and Schnarr, 1981; Peyerl, 1983; Baum et al., 1989) for example) as was the need to provide diagnostic sampling techniques of a plant (Restarick, 1976) and to improve the statistical reliability of mineralogical and process measurements (Henley, 1983; Lotter, 1995, 2005).

The development of Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEM ∗ SEM) (and the second generation QEMSCAN) (Grant et al., 1976; Barbery et al., 1979; Sutherland, 1993; Gottlieb et al., 2000), and the later development of the Mineral Liberation Analyser (MLA) (Gu, 2003; Fandrich et al., 2007) as well as of the Tescan Integrated Mineral Analyser (TIMA) (Gottlieb and Thorpe, 2016) formed the breakthrough platforms into what is now known as Modern Process Mineralogy. At Falconbridge Limited, for example, this vision was taken into a project to develop the opportunity and deliver value into operations using this new integrated approach, in which an internal rate of return of 92% p.a. was shown for the investment in the laboratory equipment, sampling, and cost of plant modifications (Lotter et al., 2002). In this case, the Process Mineralogy platform was designed using geology, sampling, mineralogy and mineral processing. The later addition of applied statistics to the interpretation of flotation tests and plant scale trials further enhanced this development.

The re-tooling of mineralogical laboratories with automated instrumentation such as X-ray Diffraction (XRD) Rietveld, Fourier Transform Near Infrared (FT-NIR), Automated Mineral Analyzers and other equipment can reduce these metallurgical risks and provide high-throughput and fast-turnaround mineralogical data (Baum, 2009, 2014a, 2014b; Baum and Ausburn, 2014; Baum et al., 2014).

Geometallurgical units (Lotter et al., 2003; Fragomeni et al., 2005) can be defined as an ore type or group of ore types that possess a unique set of textural and compositional properties from which it can be predicted they will have similar metallurgical performance. Sampling of an orebody based on geometallurgical units will define metallurgical variability and allow process engineers to design more robust flowsheet options. This variability can be muted when samples from different geometallurgical units are blended and tested as one sample. Composites are created by ensuring grade and grade distributions from a specific area defining the geometallurgical unit within a resource are maintained. The method used to divide an orebody into geometallurgical units is based on a review of geological data including host rock, alteration, grain sizes, texture, structural geology, grade, sulphide mineralogy and metal ratios with focus on characteristics which are known to affect metallurgical performance (Lotter et al., 2003; McKay et al., 2007). The foregoing list is, however, not complete and also uses hardness testing and the grade/recovery curve as characterising parameters (Fragomeni et al., 2005, for example). Statistical analysis is often used to help define preliminary units. In addition, it is recommended that a variability program based on smaller samples from throughout a geometallurgical unit is completed prior to finalising the divisions between geometallurgical units. This approach will quantify the range in performance that can be expected from within a unit, and provides a cross check that the geometallurgical unit definition is robust Additionally the sampling requirements are less demanding when the orebody is sampled at the individual geomet unit level instead of as a run-of-mine mixture, when expressed as minimum sample mass (Lotter, 2010). Early predictions of likely grinding requirements of an ore using the sulphide grain size data obtained from a series of polished thin sections measured by QEMSCAN were proposed by Fragomeni et al. (2005). Earlier, equivalent work at Mount Isa Mines, Queensland, identified ranges of textures and associated grain sizes, leading to the concept of staged grinding and flotation (Bojcevski et al., 1998). Recently, an initiative to model geometallurgical units in terms of texture, predicted grind size and liberation behaviour from drill core using scanning electron microscopy was reported by Bonnici et al. (2009). Recently, this practice was advanced to a position whereby geometallurgical units may be populated with estimated recovery values of paymetals (Evans, 2010).

The synergy between sampling, mineralogy and mineral processing in modern process mineralogy is shown in Fig. 1. Starting from representative sample material (Gy, 1979), the mineralogical characterization of the sample material develops powerful information as to the type, size and quantity of minerals present. From this information, metallurgical processing implications are developed and communicated to the mineral processing team, who work on flowsheet development strategies. This cuts down on the mineral processing resource and schedule considerably compared to the older conventional mineral processing approach.

The foundation of good chemical, mineralogical and metallurgical data is a statistically sound, robust sampling approach. Carrasco et al. (2004) and Lotter and Laplante (2007a, 2007b) have documented these issues. As illustrated by Carrasco et al. (2004), inadequate sampling in a copper operation had resulted in hidden losses of a considerable magnitude over a 20-year period, i.e. probably more than US $ 2 billion. Laboratory automation – from sample preparation through chemical and mineralogical labs – is a pivotal addition to good sampling as it minimizes sample preparation errors and provides the better data platform for continuous process adjustments (Best et al., 2007).