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Process mineralogy as a predictive tool for flowsheet design to advance the Kamoa project ☆

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ABSTRACT

The Kamoa resource, located in the Democratic Republic of the Congo, contains an array of copper sulphide minerals which are present as small grains, averaging 10–27 μm. An initial flowsheet was developed in 2011/12 for the prefeasibility study that was robust enough to handle flotation of all the copper sulphide minerals. Copper recoveries of the flowsheet were 85.4% for the hypogene ore and 83.4% for the supergene ore. Further work on the flowsheet required reduction of the SiO_2 grade of the concentrate, which at 19.1% negatively affected the downstream smelter processing, and also required improvement to copper grades and recoveries given the high grade of the ore. When new sample material became available as part of the Phase 6 drilling program, a fundamental reassessment of the ore and its flotation behaviour was conducted. Although mineralogical characterisation of the ore and liberation of the sulphides was quantified in previous phases of work, there was little understanding of the kinetics of each of the copper sulphide minerals and how they performed in the flowsheet. Comprehensive flotation kinetic tests at various primary grind sizes were performed. The corresponding timed concentrates of the three best performing grinds were characterised by QEMSCAN on a size-by-size basis to fully understand the flotation kinetics and liberation characteristics of the various copper sulphides. A simple and practical recovery model using minerals, particle size and liberation and association was developed from these data, and various flowsheet configurations were simulated. These simulations led to some robust process implications completely rearranging the flowsheet from the previous iteration into a more simple and economic configuration with better performance. The modelled data was confirmed with practically achieved data, extending the use of process mineralogy as a valid, predictive tool in process design. Additionally, the simulations using mineralogical, reduced empirical flotation testing needed to develop the new flowsheet.

1. Introduction

The utilisation of process mineralogy has been widely accepted and reviewed as an almost essential requirement in a range of scales of today's ore characterisation, projects, and operations improvement programs (Baum et al., 2002, 2004; Barns et al., 2009; Bradshaw, 2014; Lotter et al., 2002, 2014; Lotter, 2011; McKay et al., 2007; Rule and Schouwstra, 2011; Schouwstra and Smit, 2011). These more modern practices are the products of more recent studies following on from the milestone of Henley (1983). The introduction of best sampling after Gy (1979), to these programs has contributed meaningfully to the reliability of the project information produced by the laboratory programs (Lotter, 1995, 2007, 2010). From ore characterisation to flowsheet development and diagnostics, process mineralogy contributes significant and powerful information to pinpoint process challenges, streamline flowsheet development and optimise metallurgical performance. The Kamoa project has utilised process mineralogy extensively throughout ore characterisation and flowsheet development programs (Lotter et al., 2013). This paper further demonstrates the power of process mineralogy in a program that used simple flotation kinetic testing in conjunction with comprehensive size-by-size automated mineralogical data to advance the Kamoa flowsheet.

It is widely known that flotation kinetics of sulphide minerals are affected by their particle size. The particle size distribution presented to the flotation circuit by the grinding and classification circuit, influences flotation performance to a large extent (Trahar, 1981; McIvor and Finch, 1991). Economic sulphide minerals float

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fastest in the intermediate particle size range, with finer and coarser particles being slower to float. The liberation and locking of the sulphide minerals adds another layer of complexity to the understanding of the size-by-size kinetics and their behaviour through the flotation circuit (Sutherland et al., 1988; Johnson, 1987; Quinteros et al., 2015). The power of automated mineralogy techniques is that it defines flotation behaviour in relation to liberation and locking characteristics of particles and is valuable in guiding both laboratory scale testing and plant practice. From a flowsheet development perspective, an understanding of the kinetics of composite particles, allows for informed decision making regarding the setting of flotation residence times and direction of concentrates and tailings streams to further cleaning, recirculation or regrinding stages.

2. Previous work

The Kamoa resource is located 25 km west of the city of Kolwezi, in the western area of the Katanga Province, Democratic Republic of the Congo. The resource was estimated in January 2013 at 739 Mt of indicated resources grading 2.67% Cu at a cutoff grade of 1% and contains both hypogene and supergene ores. An additional 227 Mt of inferred resources have been identified at a grade of 1.96% Cu also at a 1% cutoff grade (Friedland and Johannson, 2014). The hypogene ore contains bornite and chalcopyrite as the main Cu sulphides, whilst chalcocite and bornite are the dominant Cu sulphide minerals in the supergene ore.

An initial flowsheet was developed that processed both hypogene and supergene ores and has been described by Lotter et al. (2013). The layout of the flowsheet is shown in Fig. 1, and the metallurgical performance is described in Table 1. Mineralogical measurements on several composites of both hypogene and supergene ores, from various areas of the Kamoa deposit throughout the stages of flowsheet development, show a changing distribution of Cu sulphide minerals (Fig. 2). This variation in mineralogy leads to swings in Cu head grade, expectation of mass pull to the concentrate and pulp conditions in flotation. Regardless of the Cu sulphide mineralogy all samples showed fine grained Cu sulphides, averaging 10–27 μm in size with some grains upwards of 50–75 μm.

The fine grained nature of the Cu sulphides led to the development of an MF2 (mill float mill float) based flowsheet with 75 μm and 38 μm primary and secondary grinds respectively. At the 75 μm primary grind, Cu sulphide liberation was reported at 62.5% for the hypogene ore and 53.1% for the supergene ore (Lotter et al., 2013). A mixed reagent suite was selected and refined based on the mineralogical information, which successfully floated liberated and middling Cu sulphides to the rougher and scavenger concentrates. Development on a subsequent cleaner circuit included regrinding by IsaMill of both the rougher and scavenger concentrates to improve liberation and concentrate grade. Concentrates were produced from both ore types in the flowsheet with satisfactory Cu grades and recoveries.

Three items were identified for further work at this point:

1. The grade of SiO_2 in the final concentrate is high; 19.1% for hypogene ore and 26.0% for supergene ore. Mineralogical characterisation of the final concentrate shows 50% of the SiO_2 gangue dilution is liberated and distributed to particles <3 μm in size – indicating entrainment as a significant recovery mechanism. The remainder occurs as composite particles with locked Cu sulphides despite prior regrinding of the rougher and scavenger concentrates to 15 μm and 10 μm. The high SiO_2 grade poses processing concerns for the smelter in that slag formation will be problematic and will require lime addition. The abundance of slag will also increase and likely incur proportionally higher copper losses. Further work is required to both eliminate

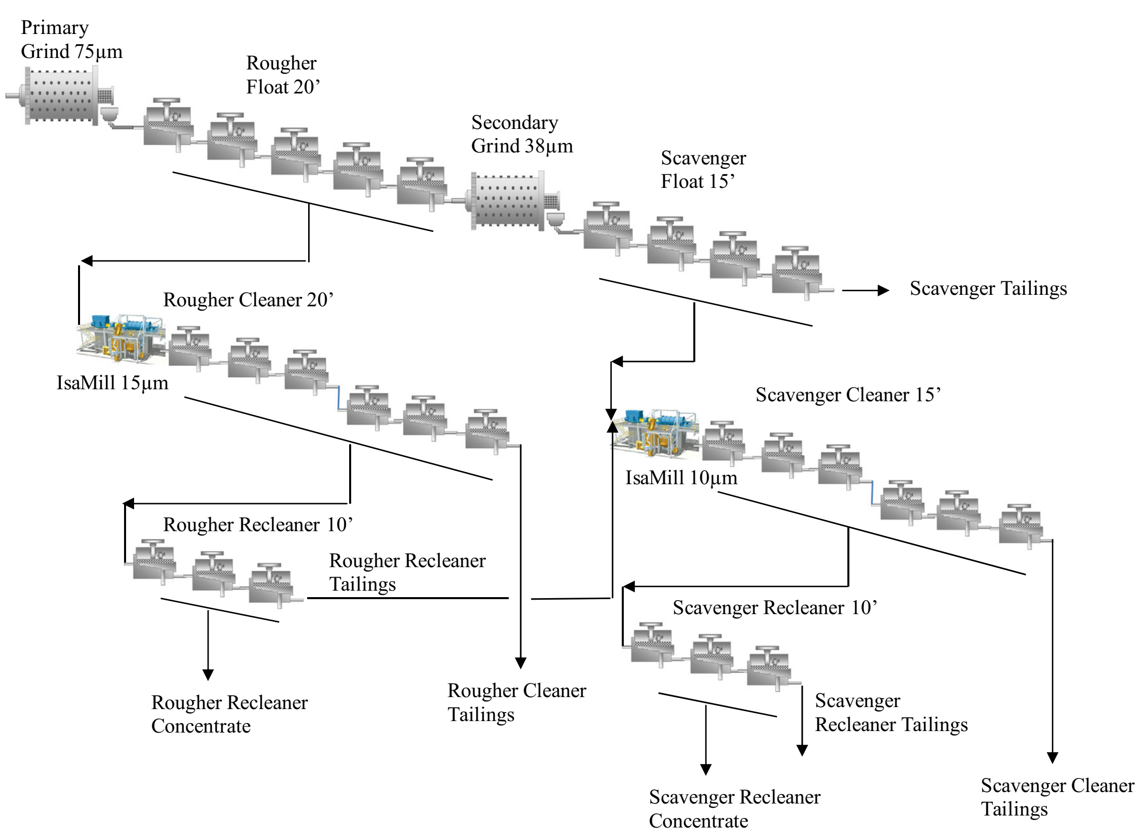

Fig. 1. Kamoa flowsheet prior to further development.