

**INCREASING SAG MILL CAPACITY AT THE COPPER MOUNTAIN MINE THROUGH THE
ADDITION OF A PRE-CRUSHING CIRCUIT**

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ABSTRACT

Copper Mountain's concentrator was commissioned in May 2011. The circuit consists of a 34' x 20' EGL SAG mill, a Raptor 900 pebble crusher and two 24' x 39'6" ball mills. Each mill is equipped with a 2 x 8500 HP dual pinion drive system. The plant was designed to process 1585 mtph of SAG feed. From startup, the mill struggled to meet the required production rates. Over time, a major initiative that involved blasting and fragmentation, optimization of the SAG mill in terms of discharge grates, ball size and slurry density, and operation of up to three mobile pre-crushing plants resulted in significant increases in throughput. In parallel, a number of modeling tools, including JK SimMet, were run based on plant benchmarking exercises. Samples collected at the mine site during ramp up confirmed the very competent nature of the ore with drop weight - A*b values of less than 24 being recorded on a variety of plant feeds and lithologies. After due consideration including demonstration of proof of concept, a new pre-crushing circuit incorporating an XL2000 cone crusher and associated screening equipment was designed, constructed and commissioned at the site in August 2014. This paper reviews the history of the original circuit design, the various optimization steps taken and impacts, together with the final pre-crushing circuit and net results.

KEYWORDS

SAG mills, ball mills, pre-crushers, plant design, pre-crushing

INTRODUCTION

The Copper Mountain Mine is located approximately 20 km south of Princeton, British Columbia, Canada (refer to Figure 1). The region has a long history of copper mining dating back to 1923. The Copper Mountain camp occurs in the 'eastern volcanic belt' of the Nicola Group (Monger, 1989). It is an alkali copper-gold deposit in which the volcanic strata are intruded by early Jurassic dykes, sills, irregular plugs and zoned plutons (Woodsworth et al., 1992). The stratified rocks are relatively fresh with slight metamorphism in the local contact regions.

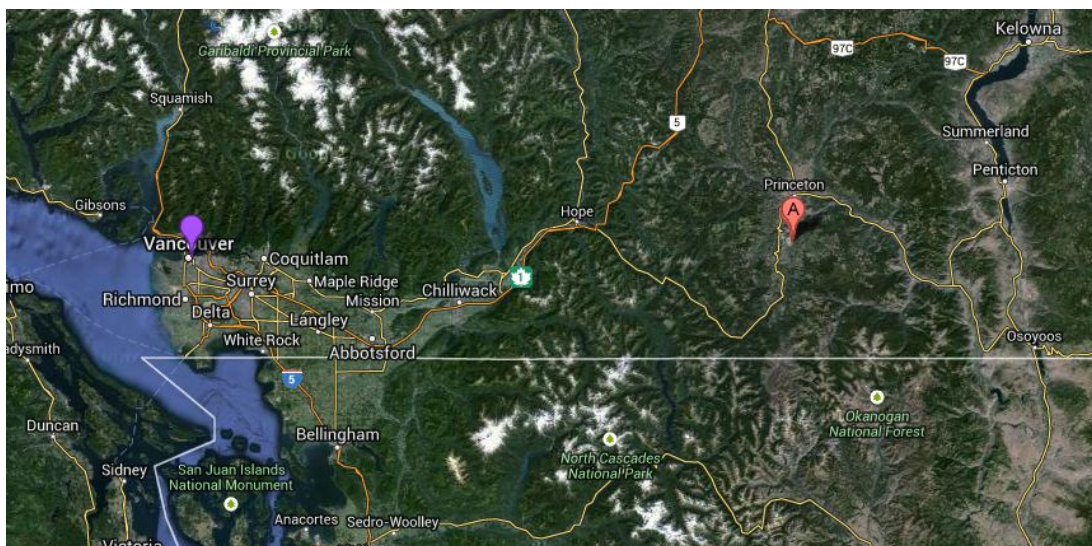


Figure 1 - Project location

In 2007, Copper Mountain acquired the property rights to the current mine site and started a 44,000 m drilling program. Drilling continued in 2008 with an additional 60,000 m program. The mine feasibility report was also completed in 2008 with a proven reserve of 5 billion pounds of copper.

With financing secured and engineering complete, Copper Mountain started construction in 2009. The project construction and commissioning was completed in 2011 on schedule and within the \$438 million CAD budget.

The plant design was based on a 35,000 tpd comminution circuit followed by a rougher-regrind-cleaner-scavenger flotation plant. Ore grades averaged 0.33% Cu with a copper recovery of approximately 82%. Copper concentrate production in 2013 was 66.2 million pounds containing over 21,000 oz gold and 320,000 oz of silver. 2014 production was 81 million pounds of copper, 22,600 oz gold and 443,700 oz silver from 11.1 million tons of ore at an average feed grade of 0.40% Cu.

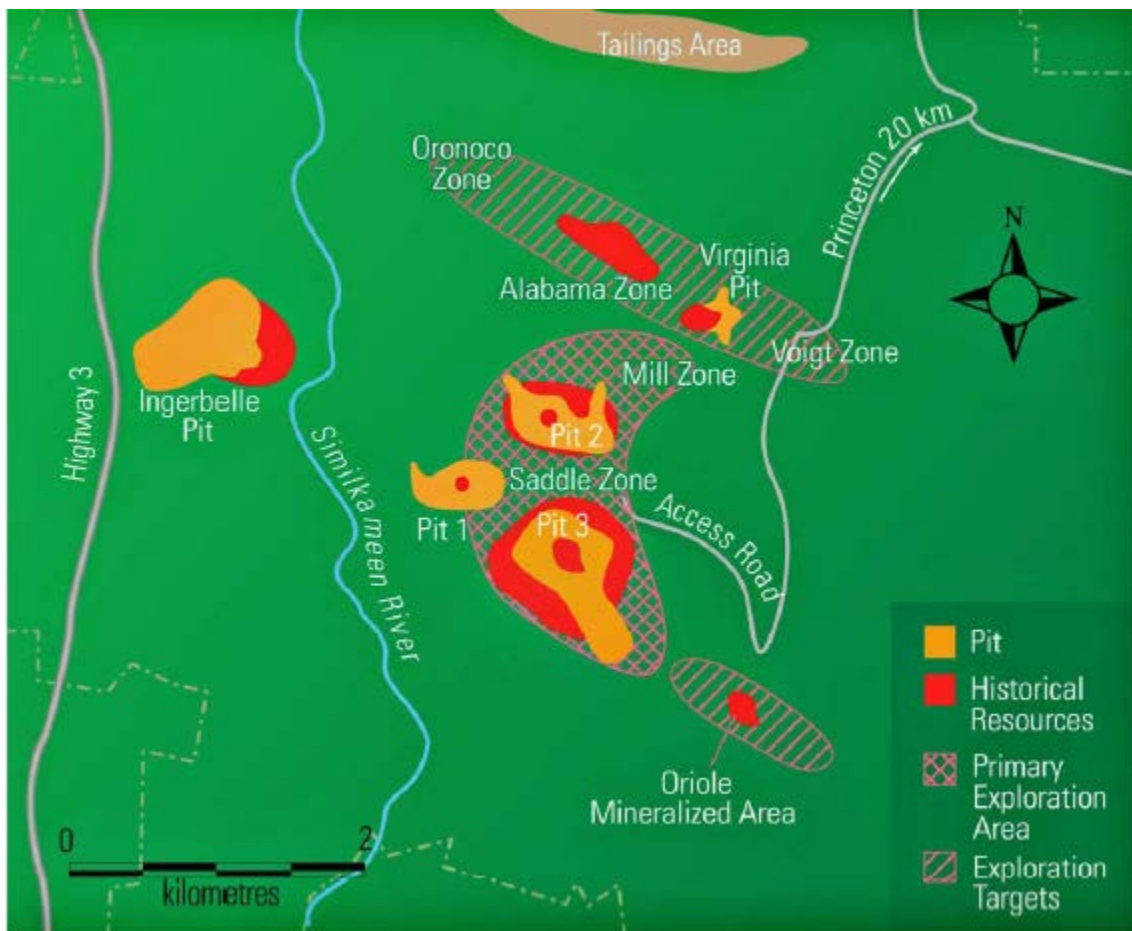


Figure 2 - Overall mine site including pit locations and mill site

GEOLOGY, MINERALOGY AND MINING

Geological Description

The Copper Mountain deposit is classified as an alkali porphyry copper deposit with associated gold and silver credits. Porphyry copper-molybdenum deposits provide more than 50% of the world's copper from more than 100 producing mines. The alkalic mineral deposits of British Columbia occur in zones of intense faulting, fracturing, brecciation and hydrothermal alteration. Hypogene sulfide minerals, which formed contemporaneously with the hydrothermal alteration of host rocks, include pyrite, chalcopyrite, bornite, chalcocite and pyrrhotite in decreasing order of abundance. Molybdenite may be present in trace amounts but gold and silver are usually economically significant.

The alkalic porphyry classification for Copper Mountain is applicable as the copper-gold-silver deposits are bulk mineable deposits with grades typical of porphyry copper deposits, mineralization is associated with complex intrusive activity localized along a regional structure with a skarn-like appearance of the alteration and mineralization zones. The Copper Mountain deposits do display some unusual alteration and structural characteristics which are not typical of the porphyry copper model. The Copper Mountain deposit shows strong structural control on mineralization, an association of copper-gold mineralization with magnetite veins, pervasive sodic and potassic alteration and an abundance of carbonate and calc-silicate minerals.

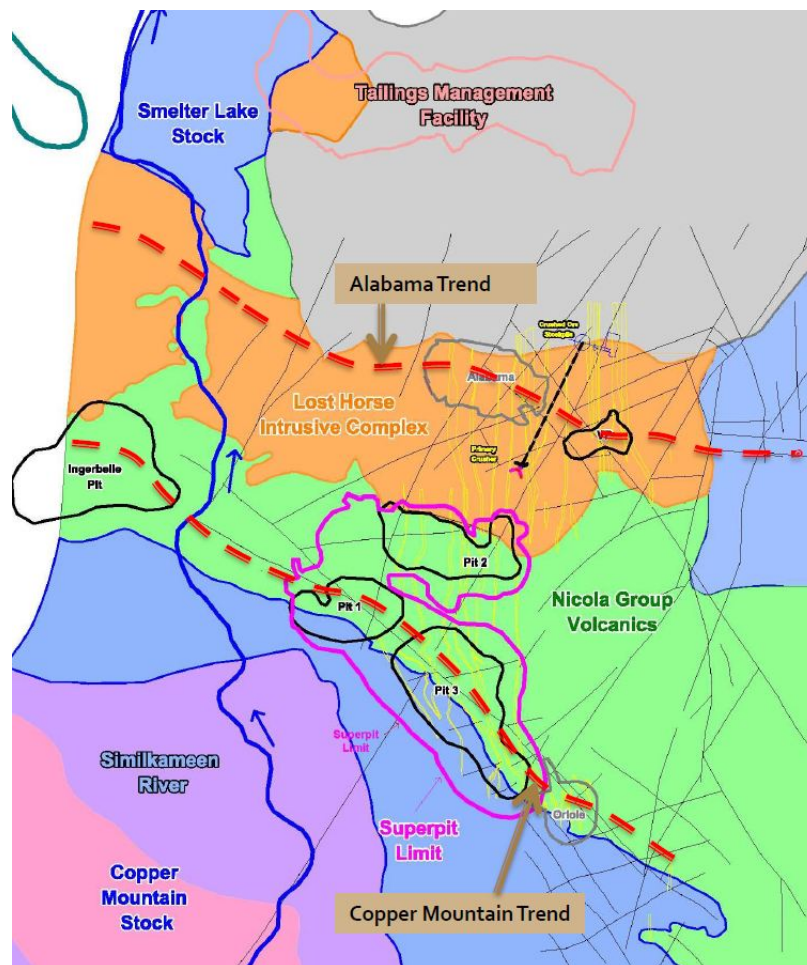


Figure 3 - Copper Mountain geological groups

Mineralogy

The Copper Mountain deposit, described in a broad simplification, consists of structurally controlled, multi-directional veins and vein stockworks. In 1972, Preto subdivided the mineralization into four types:

1. Disseminated and stockwork chalcopyrite, bornite, chalcocite and pyrite in altered Nicola and LHIC rocks,
2. Hematite-magnetite-chalcopyrite replacements and/or veins,
3. Bornite-chalcocite-chalcopyrite associated with pegmatite type veins and
4. Magnetite breccias.

All mineralization types are found in all the mining areas, but the content of each varies in each pit. Currently, there are two main ore sources for Copper Mountain, Pit 2 and Pit 3. Other ore sources have existed, but have been mined out.

Pit 2 is predominantly chalcopyrite for a copper species and contains more disseminated mineralization. Dykes are present in the pit superimposed on existing mineralization and alteration. The magnetite breccia mineralogy is also present in Pit 2, sometimes present as appendages in the pit wall that appear similar to dyke material. Pit 3 contains stockwork veins and breccia zones. Disseminated sulphide mineralization and the breccia cones constitute most of the ore mined by open-pit. Chalcopyrite is the dominant economic copper mineralization.

Mining

Copper Mountain mining operations operate in open-pits utilizing three hydraulic shovels and twenty-two haul trucks supported by four production drills and other mine operations equipment. The mine operations have a 2:1 LOM strip ratio, but the current strip ratio is higher than that and will taper down as the mine continues to develop. Mine life is currently expected to be 17 years.

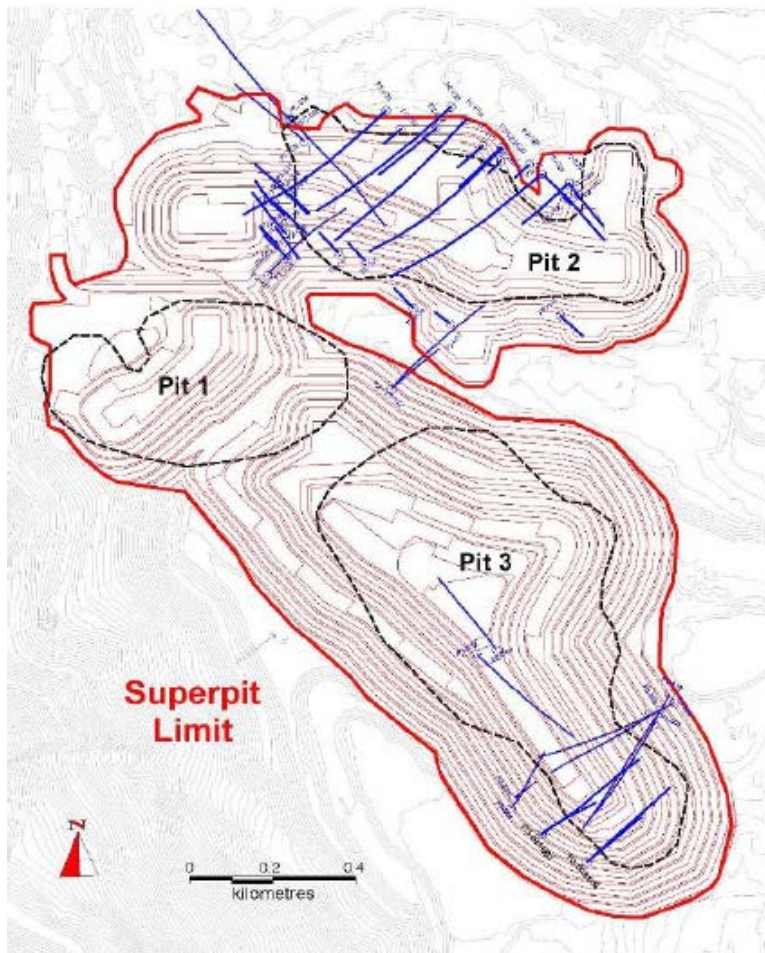


Figure 4 - Relative open pit locations and limits

PROCESS PLANT FLOWSHEET

The Copper Mountain Flowsheet is a traditional configuration with a SABC circuit followed by a rougher flotation circuit, regrind, cleaner and cleaner scavenger flotation. Final copper concentrates are pressure filtered before transport to the port site and tailings cycloned to produce coarser material for wall building, while the water and fines are deposited in the dam impoundment area.

The Copper Mountain comminution circuit originally consisted of a 34' x 20' F/F SAG mill (17,000 hp - 12,677 kW), two (2) 24' x 39'6" ball mills (17,000 hp - 12,677 kW) and a Raptor XL900 pebble crusher (900 hp - 671 kW). The comminution circuit product (cyclone overflow) feeds the rougher flotation circuit. The circuit was originally designed for 35,000 tpd capacity (1585 mtph) with a final target grind size P_{80} of 150 microns.

The flotation circuit consists of ten 160 m³ rougher flotation cells, two 3 m x 12 m cleaner column flotation cells and five 50 m³ cleaner scavenger cells. There is a regrind mill between the rougher flotation cells and the cleaner cells. In the original design, the regrind was specified as two Vertimills, but the plant was constructed with a single ball mill in this application. The regrind ball mill is a 15.5' x 29' mill with 3,600 hp (2,687 kW) installed power.

Figure 5 shows the original flowsheet at Copper Mountain.

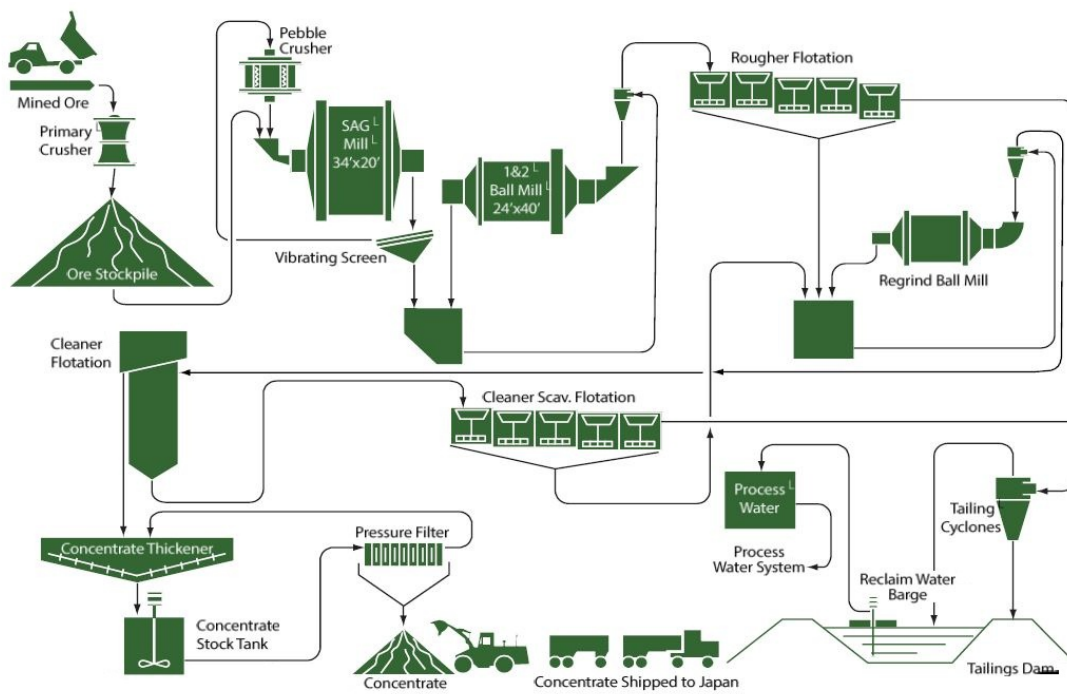


Figure 5 - Copper Mountain plant flowsheet



Figure 6 - 34' x 20' F/F SAG Mill



Figure 7 - 24' x 39'6" Ball Mills

EARLY PLANT RESULTS AND OPERATING EXPERIENCE

Copper Mountain first feed to the SAG mill occurred in late May, 2011. The circuit began ramp up in mid-June of that year, with more consistent operating run times on the SAG and Ball mills. Plant throughput in the first months was quite variable with throughput tonnage greater than 40,000 tons one day and less than 25,000 the next on some occasions.

During the early operating months, plant operators were making changes in the milling circuit as required. These included changing the SAG mill discharge grates to a larger opening size, changing the SAG mill operating speed, changing the grinding media ball supplier, increasing the grinding ball size, increasing the SAG mill discharge screen opening slot size and initiating the overall expert system into the control strategy.

Plant data through the first four months of operation showed that the milling circuit was not making the target tonnage rate (1,585 mtph) and, in fact, was peaking at just over 1,200 mtph by the end of October, 2011. The SAG mill appeared to be the bottleneck in the flowsheet as the power in the SAG was consistently high and approaching the full motor power, while the ball mills were consistently operating at less than 75% of installed power.

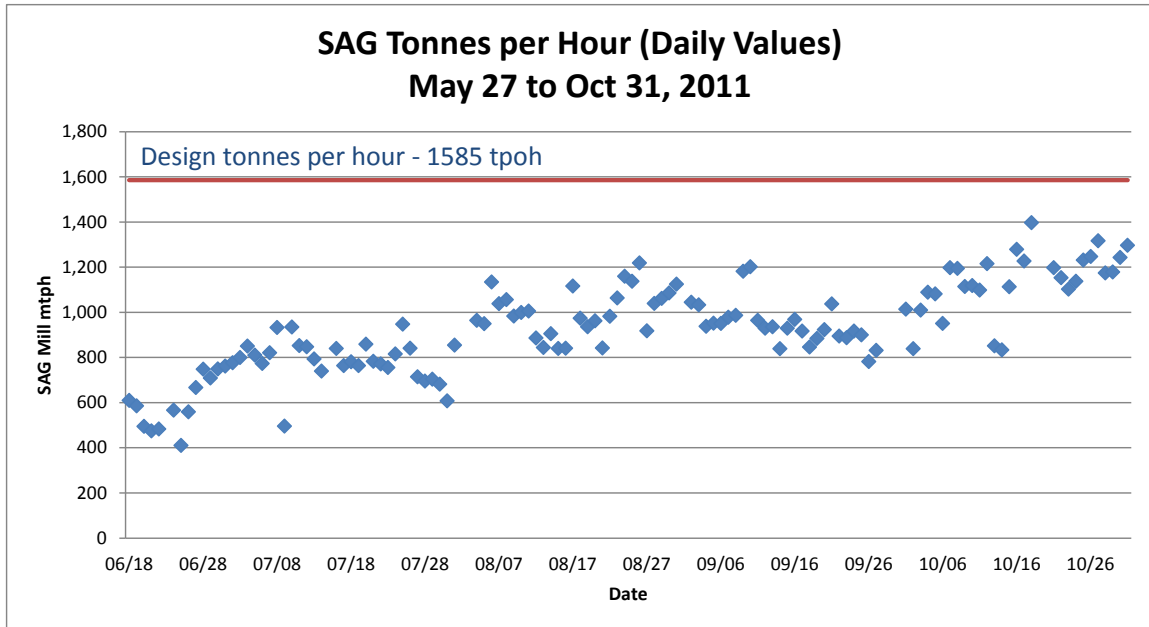


Figure 8 - SAG Mill Throughput - metric tonnes per hour

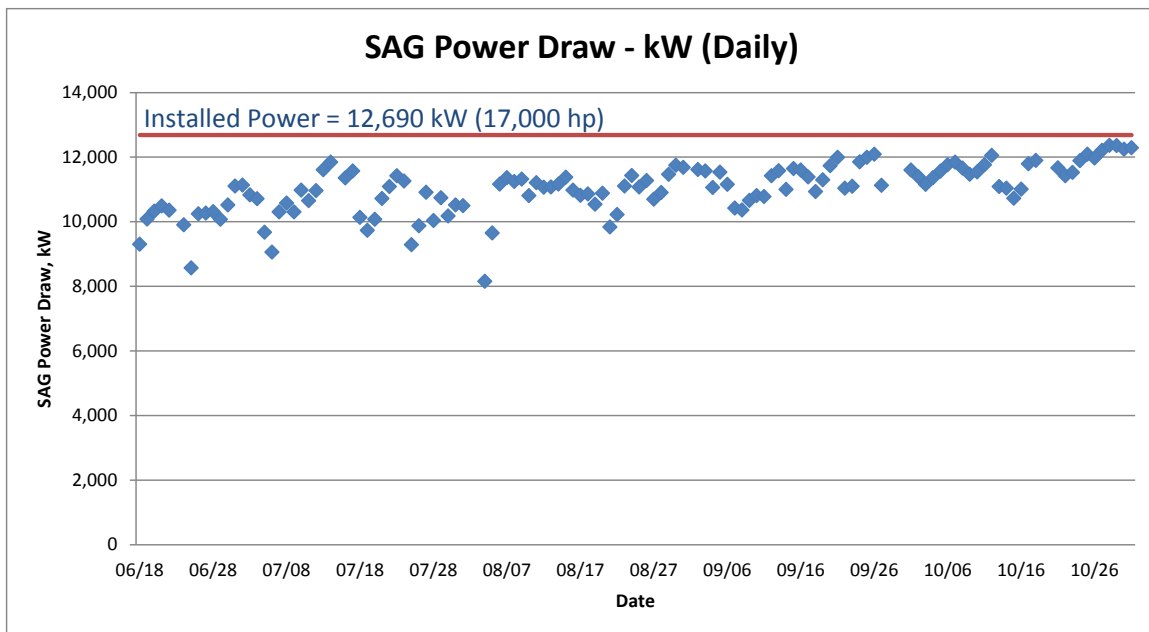


Figure 9 - SAG Mill power draw

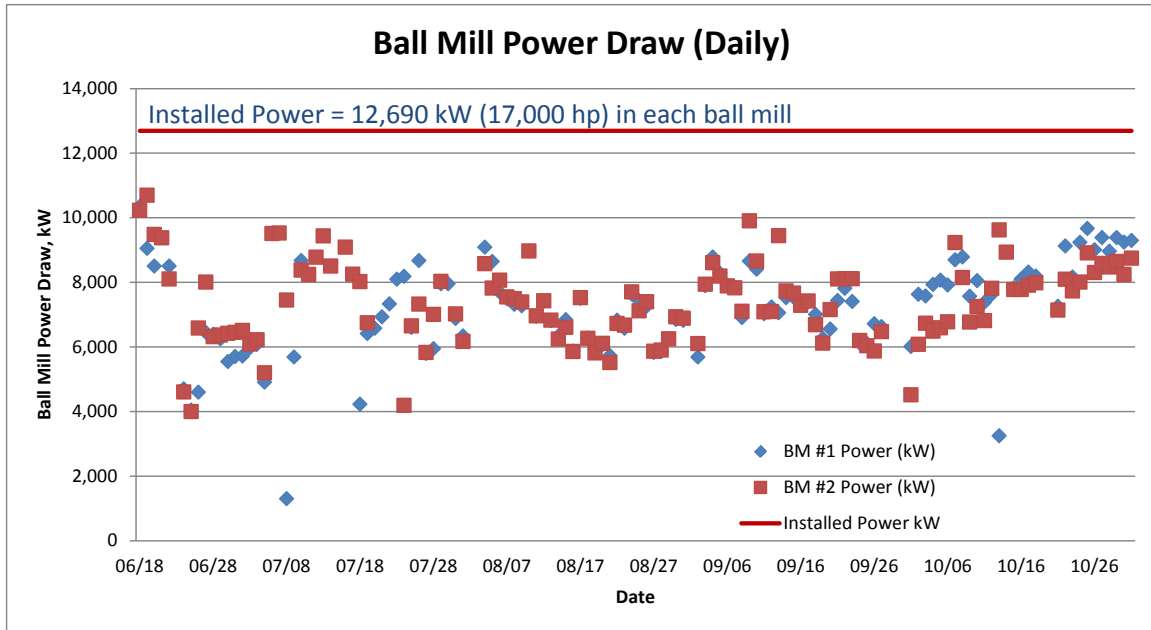


Figure 10 - Ball Mill power draw

Plant throughput rates were not much improved into 2012, so it was decided to collect a larger number of samples from the mining faces to get a better understanding of the ore that would be delivered to the plant. These samples were collected in September of 2012 and sent to the ALS Metallurgy lab in Kamloops, BC for testing. For this sampling program, all three samples were tested using standard JK drop weight tests together with other standard small scale comminution tests including bond work indices and abrasion index measurement etc. The overall results together with all the mill geometry information were finally inputted into a JKSimMet model for circuit modelling. Mark Richardson of Contract Support Services Inc conducted all the simulations with overall guidance by a team from FLSmidth and Copper Mountain. The final set up model was available to run future “what if” scenarios ahead of any plant field changes.

The JK drop weight test results for the samples showed a very hard, competent ore was present in the Copper Mountain mining areas. It was understood that the orebody contained very hard ore based on previous BBMWI testwork, but previous work had not included the JKTech procedures or JKSimMet modelling. JKTech has a significant database with results from its test procedure including reference data from operating plants to validate the model results. The A * b parameter database contained almost 3,500 samples at that time. The A * b results for the Copper Mountain ore samples placed them in the top 5% of all the samples tested to date in terms of ore hardness / competency. Combining the low A * b with the high Bond work index results provided some frame of reference when the hardness of the ores at Copper Mountain were considered.

PROOF OF CONCEPT - PORTABLE PRE-CRUSHING STATIONS

With the enhanced knowledge gained about the ore hardness and competency, the option of a pre-crusher being added to the Copper Mountain flowsheet was proposed. One of the critical factors affecting the SAG mill throughput is F_{80} to the SAG mill and a pre-crusher will reduce the feed size to the SAG mill. Modelling with the JK SimMet simulator confirmed that the SAG mill throughput could be increased with the finer feed size distribution that would result from adding the pre-crusher into the existing flowsheet. Adding the crusher was not going to be a simple task, requiring significant modifications and interfacing into the existing plant layout. These changes would ultimately include; modifying the primary crusher product conveyor and adding three conveyors, one for feeding the pre-crusher surge pile, one for feeding the pre-crusher and one for the transporting the product back to the stockpile conveyor. This was in

addition to the building required for the crusher itself, the scalping screen within the building and all associated power distribution and infrastructure for the new equipment.

Copper Mountain personnel decided to test the pre-crusher concept with the use of smaller temporary crusher plants that would crush some of the primary crusher product before it was fed to the SAG mill. In the end, there were as many as three crushing plants running at Copper Mountain crushing on up to 40% of the SAG mill feed. The plant results showed that when the crushing plants were in operation, the SAG mill throughput rates increased proportionally to the percentage of SAG mill feed that was crushed to a finer size distribution.

Figure 11 shows the trends in SAG mill throughput during the testing period with the portable pre-crushing stations. The upward trend was significant and could be related to the percentage of SAG total feed that had been run through a crushing station. The crushing stations reduced the SAG feed size which would result in higher rates through the SAG mill. Figure 12 shows the relationship between the percentages of pre-crushed feed to the SAG based on the tonnage crushed versus the total SAG feed. Note that the August 2014 data includes the first tonnage through the XL2000 crusher.

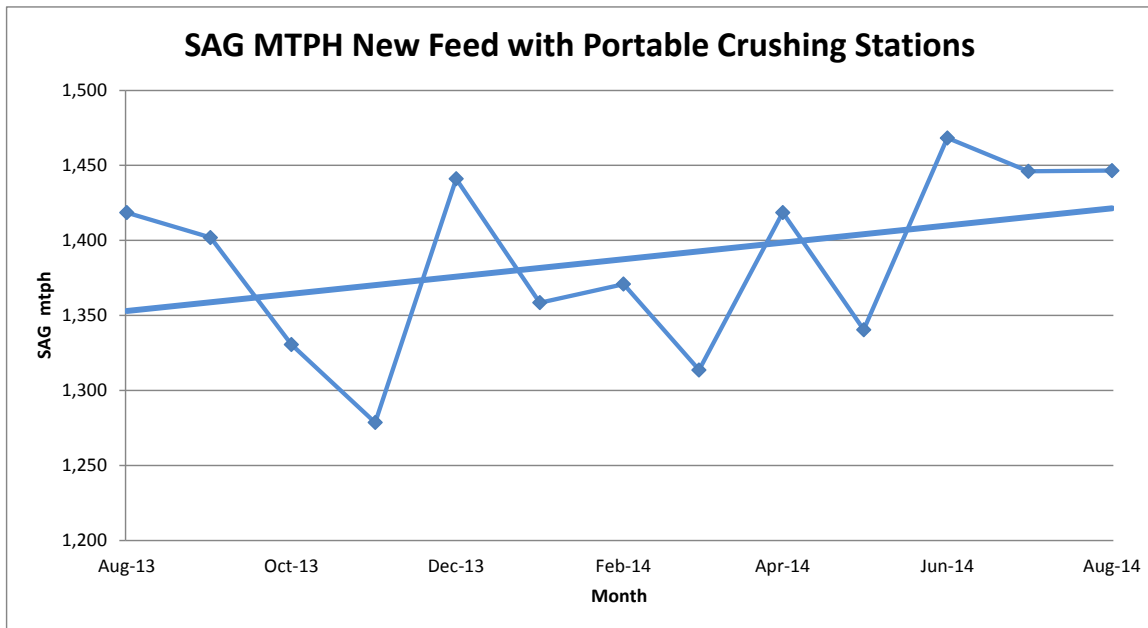


Figure 11 - SAG Mill tph with crushing stations

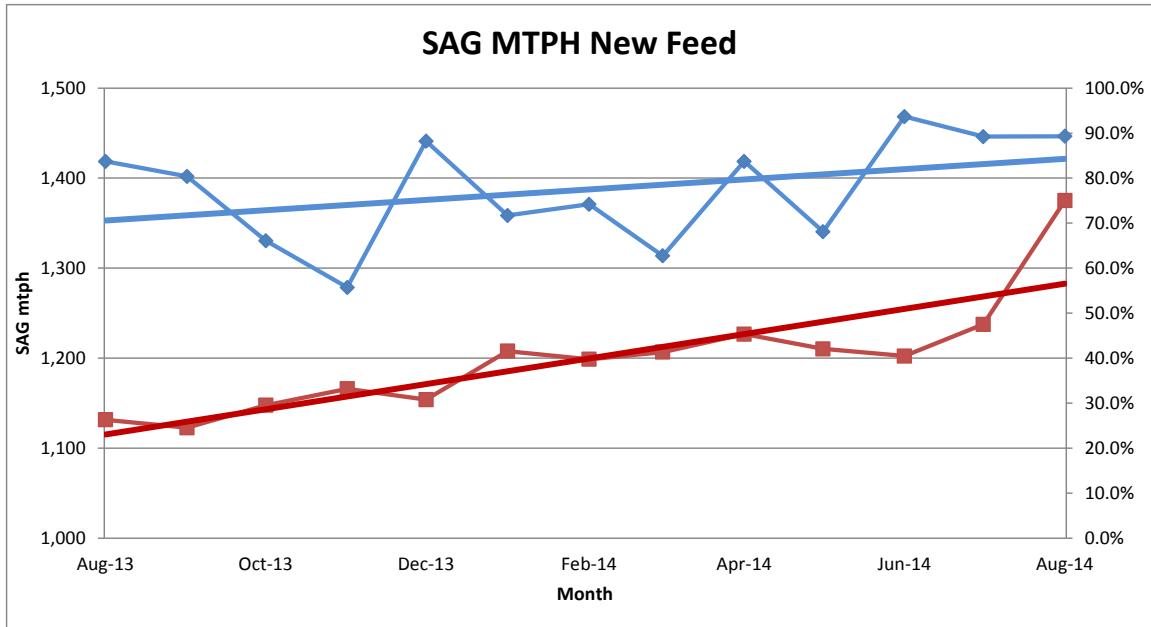


Figure 12 - SAG throughput with pre-crusher utilization

INSTALLING THE FIXED PRE-CRUSHER STATION

Based on the portable crushing station results, the Copper Mountain team decided to proceed with the pre-crusher station. In 2013 engineering was started to design the layout for the permanent pre-crusher installation. Hatch Engineering was commissioned to complete this work, which would include adding a transfer station in the existing stockpile feed conveyor which would feed a surge pile for the pre-crusher or bypass the pre-crusher altogether. The surge pile would have two feeders beneath it to control the ore to the pre-crusher station which included a scalping screen before the crusher to remove the fines from the crusher feed. Crusher product and scalping screen undersize are combined onto a product belt which returns the combined product to the transfer station and back onto the SAG feed stockpile. In December 2013, Hatch placed a purchase order for an XL2000 crusher from FLSmidth on behalf of Copper Mountain for use as the permanent pre-crusher at site.

The overall comminution circuit incorporating the pre-crusher is shown in Figure 13.

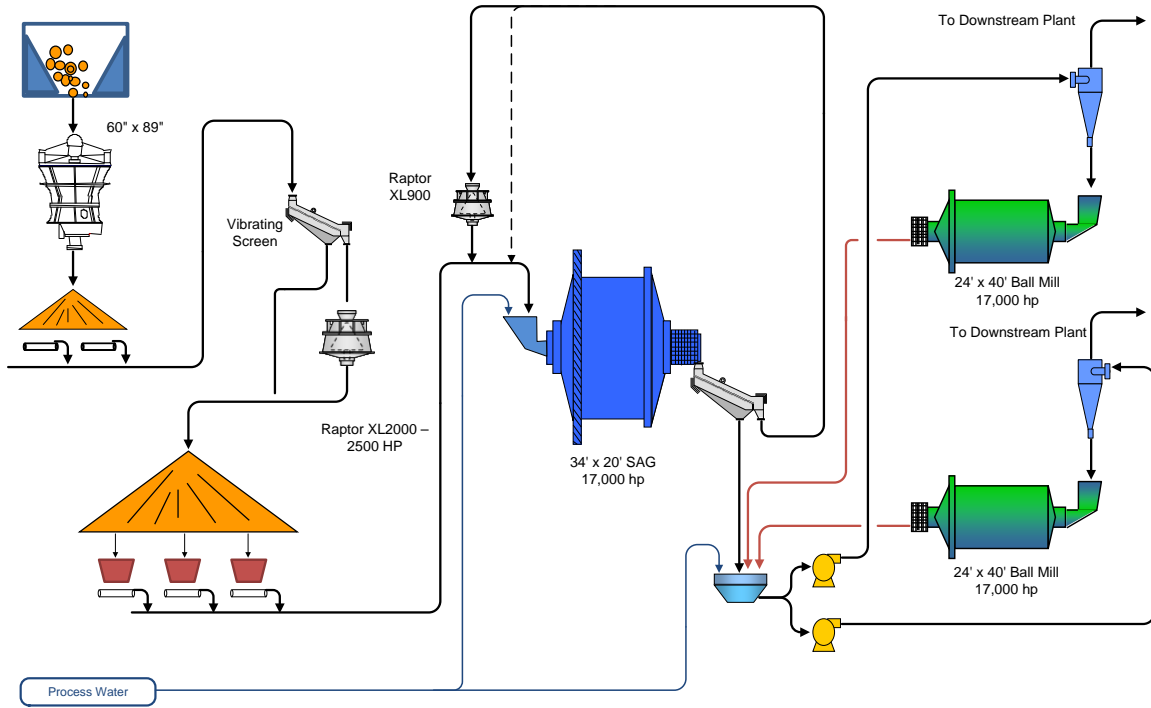


Figure 13 - Copper Mountain comminution circuit including pre-crusher



Figure 14 - Original stockpile conveyor configuration with concentrator building on far right hand side



Figure 15 - Pre-Crusher overview

Figures 14 and 15 show the changes made in the stockpile feed conveyor layouts with the addition of the pre-crusher in the circuit. In Figure 14, the conveyor follows a straight line into the stockpile. The concentrator building can be seen in the background. Figure 15 is taken from a different angle, but the surge pile is in the front of the picture, the crusher building is on the left and the stockpile and concentrator building can be seen in the background.

The pre-crusher was started with its first ore on August 4th, 2014 and commissioning the crusher began at this time. During the month of August all required start up procedures were followed with the operators and technicians from FLSmidth were also on site. In September, the crusher was effectively commissioned and operating time improved as the operating crews became more accustomed to the circuit and equipment.

With improved operating time and increased familiarity with the circuit, the benefits of working with the new pre-crusher were being realized. Tracking the SAG mill F_{80} and charting against the SAG throughput rates shows that this relationship is maintained with the mill at Copper Mountain. Figure 16 shows this trend which had also been reported from the JKTech modelling.

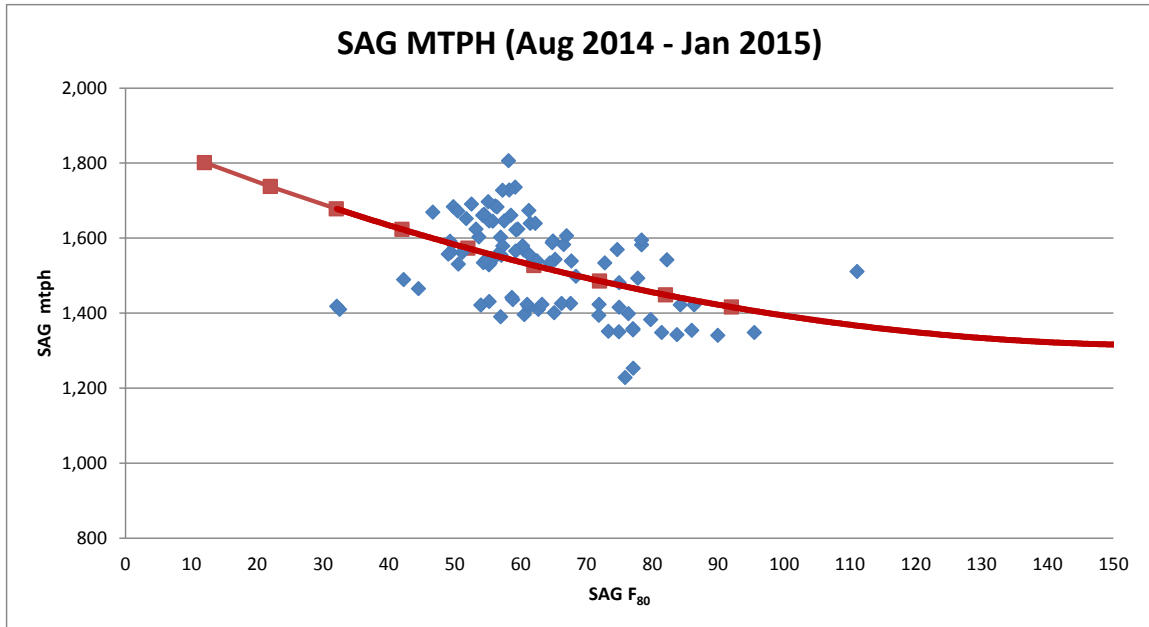


Figure 16 - SAG Mill throughput rates versus F₈₀

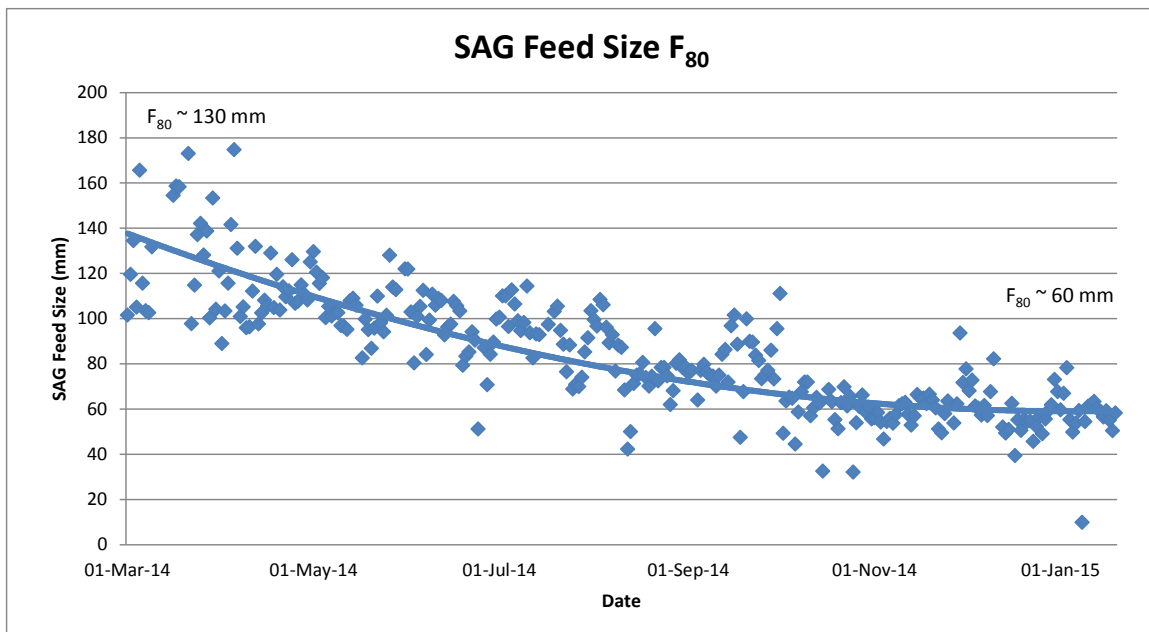


Figure 17 - SAG Mill F₈₀ trend

The SAG mill at Copper Mountain had been operating at maximum power draw since the plant started and that has not changed. With the improved tonnage rates, the SAG specific energy has decreased which results in lower power costs per tonne of ore milled. Figure 18 shows this trend.

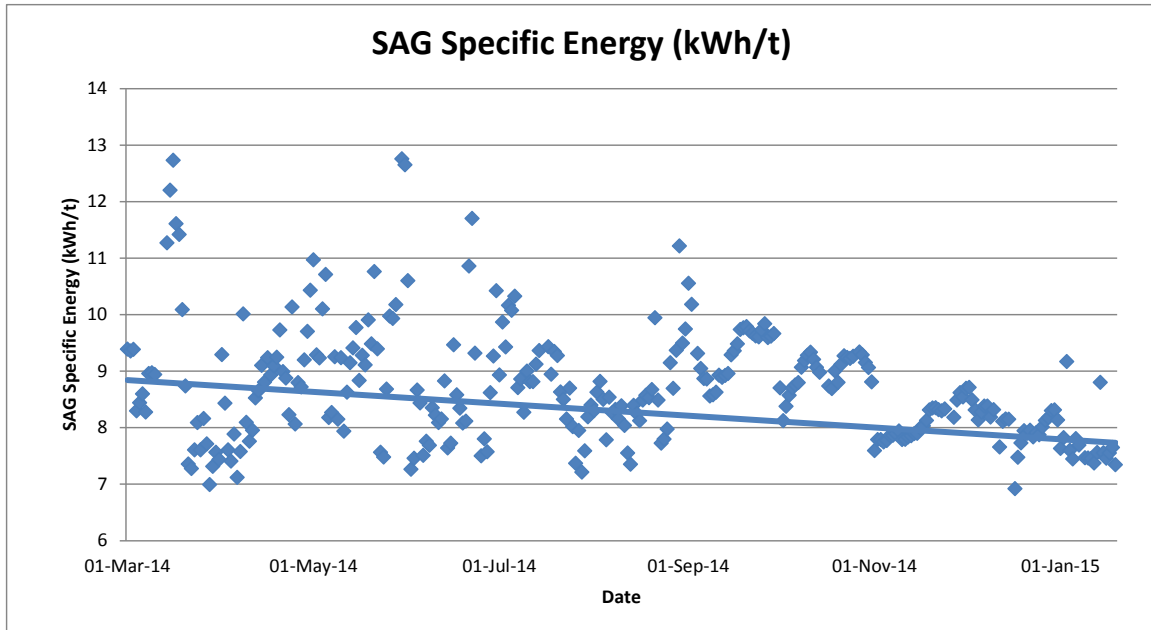


Figure 18 - SAG Mill specific energy trend

PRE-CRUSHER IMPACT ON SAG THROUGHPUT

The addition of the pre-crusher at Copper Mountain has had a significant and sustainable effect on the SAG mill throughput. The data in Table 1 and the chart in Figure 19 show the trend from 2012 indicating the time periods when there was no pre-crushing, the temporary crushing was being tested and since the commissioning of the pre-crusher into the circuit full time.

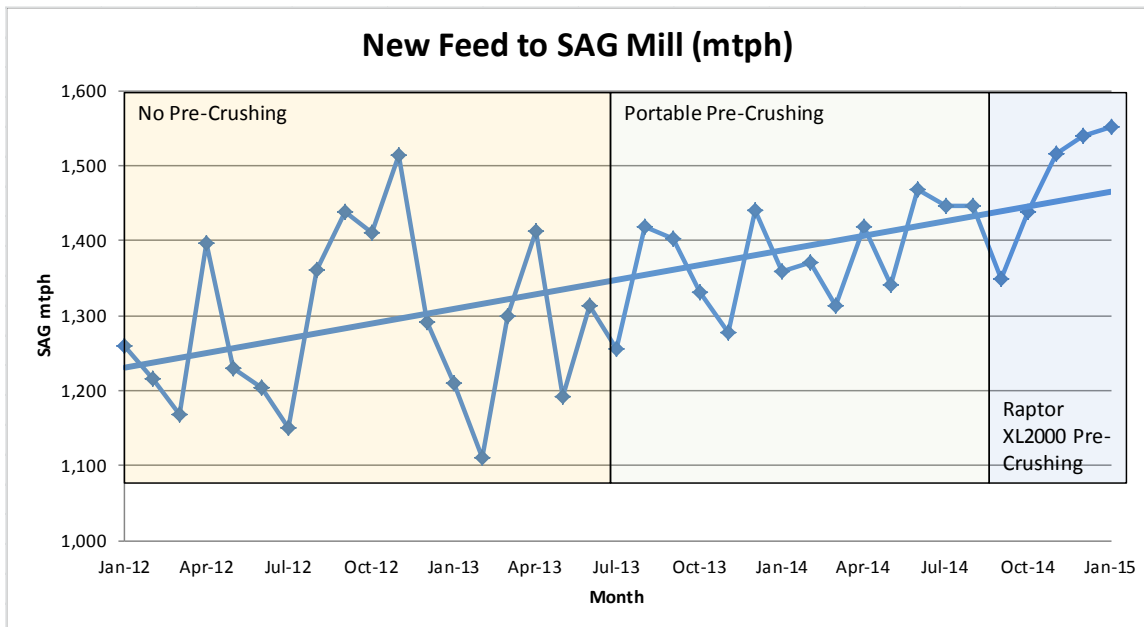


Figure 19 - SAG Mill throughput trend over time and impact of pre-crushing

The chart shows that the tonnages have been trending upwards since the plant started. In 2012, with no pre-crushing, the improved tonnage rates were accomplished by changing the mining blend. Copper Mountain had also been working on blasting fragmentation in order to generate more fines in the ore delivered to the primary crusher.

Table 1 - Copper Mountain SAG mill tph trend

	Mill Hours	Mill Tons	Pre-Crush Tons	Percent Pre-Crush ¹	SAG MTPH
Jan-12 - July-13	11,610.8	14,955,954	299,080	2.0%	1,288
Aug-13 - Aug-14	8,537.8	11,852,596	4,750,195	40.1%	1,388
Sept 2014	669.9	903,238	848,359	93.9%	1,348
Oct 2014	649.7	934,939	961,571	102.8%	1,439
Nov 2014	631.0	956,559	859,604	89.9%	1,516
Dec 2014	637.2	980,750	981,095	100.0%	1,539
Jan 2015	686.5	1,065,604	1,125,453	105.6%	1,552 ²

¹ The percent secondary crushed can vary over 100% in a given period because of the SAG feed stockpile capacity available.

² January results for the first 25 days were averaging 1642 mtph before a transformer failure required one ball mill to shut down and reducing the secondary milling capacity, resulting in cutting back on SAG mill feedrate setpoints.

SUMMARY OF OTHER BENEFITS

Other benefits have been realized by Copper Mountain after making these flowsheet changes including reduced steel consumption in the SAG mill and an expected improvement in grate and mill liner life. Table 3 shows a summary of these measurable benefits.

Table 3 - Summary of benefits realized with changes at Copper Mountain

	Before Pre-Crushing	With Pre-Crushing
SAG mill steel ball consumption	600 kg/t	375 kg/t
Ball mill steel ball consumption	600 kg/t	200 kg/t
SAG Specific Energy	9.3 kWh/t	7.9 kWh/t
SAG mill tph	1,288 mtph	1,642 mtph 1,940 mtph (max)
Grate and liner life	Grates ~ 3 months Liners ~ 6 months	Ongoing Evaluation
Copper recovery ³	80%	83%

³ - From Annual Reports 2012 - 2014

CONCLUSIONS

At the date of publication, the pre-crusher at Copper Mountain had been in operation for over six months. The impact of the pre-crusher has been seen in the SAG mill since its startup and the SAG throughput rates were still increasing with further circuit and operational changes at the site. The SAG mill had consistently achieved greater than nameplate capacity (1585 mtph) on a daily basis and had realized several daily milling rates of over 1600 mtph during the month of January 2015. Peak rates of 1940 mtph have also been achieved, which was very encouraging considering the extremely hard competent nature of the ore zones at Copper Mountain.

The use of the JKSimMet simulation tools proved invaluable to the modelling of the circuit and determining that a pre-crusher added to the circuit would be beneficial to the overall plant throughput rates. The circuit is no longer SAG mill limited and the operations are currently working towards increasing the capacity of the ball mills with various changes that can be made in the mills.

Other benefits of the pre-crusher installation have been recognized, including a significant reduction in steel ball consumption in the SAG mills amounting to several million USD savings on operating costs. The pre-crusher mantle profile is still being optimized, which ultimately will result in a longer life for the mantles and the potential to operate at a smaller CSS, which could provide further improvement in the SAG mill throughput.

Continual improvements in the operations of the crushing circuit and changes that can be included in the mills are expected to advance the SAG mill feedrates beyond 1800 mtph.

ACKNOWLEDGEMENTS

The authors would like to thank Jim O'Rourke for his permission to publish this paper and the findings within. The pre-crusher project at Copper Mountain is an example of forward thinking in our industry and Copper Mountain's success represents a good step forward in the future development of comminution circuits.

A special thank you is extended to Mike Westendorf, Renee Morrison and Cam Edwards for their invaluable contributions to this paper. Without their support and assistance with all the plant related access and data, this paper would not be able to be published.

The entire Copper Mountain team has stepped behind this project and their commitment to making the project a success is a major reason why this has been possible.

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