Investigating particle size distribution of blasthole samples in an openpit copper mine and its relationship with grade

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Abstract

Blasthole sampling practices were investigated at the Erdenet copper and molybdenum mine in Mongolia to address grade reconciliation issues. The goal of the study was to determine if the particle size distribution (PSD) of blasthole cuttings was accurately reflected in the samples. The study additionally examined if the measured grade was related to the particle size of samples. Using a sector sampler specifically designed to collect samples for the study, six large samples were collected from three blocks following a specialized protocol. Each sample was split into nine size fractions, ranging from larger than 12 mm to smaller than 63 μm. Copper and molybdenum grades were determined for each of the size fractions. For comparison, nine samples were collected from the same blocks following the standard mine sampling protocol. These samples were also split into the same nine size fractions. As with the other samples, grades were determined for each of the size fractions. The results showed that the PSD in the samples collected following the standard operating procedure varied significantly from sample to sample. This variation was much lower for the samples collected following the specialized protocol. Loss of fines was also indicated in the standard mine sampling process. These observations suggest that the standard sampling protocol did not consistently capture the PSD. The copper and molybdenum grades increased as particle size decreased, regardless of the sampling protocol used. This observation underscores the importance of the PSD of a sample being representative of the true PSD. Given the low number of samples in the study, it is not a strong conclusion that the standard sampling protocol captures the PSD inconsistently. However, it could be taken as a caution. On the other hand, the grade versus PSD relationship is more certain, given that it was observed regardless of the sampling method used.


Introduction

Erdenet Mining Corp. (EMC), a Mongolian-Russian joint venture company, operates in one of Asia’s largest deposits of copper ore, in the Orkhon province of Mongolia (Erdenet Mining Corp., 2016). The orebody, located in the Erdenet-in-Ovoo region, is 25 km (16 miles) long and 1.5 to 3 km (1 to 2 miles) wide. The mine produces more than 500 kt (550,000 st) of copper concentrate annually after processing about 26 Mt (28 million st) of ore. It also produces around 4.5 kt/a (4,960 spy) of molybdenum concentrates.

As with many other mines, grade reconciliation between the mine and the mill has been an issue. Correct blasthole sampling is challenging, as noted by Pitard (2008), Francois-Bongarcon (2010) and McArthur et al. (2010). Therefore, a study was conducted to investigate if blasthole sampling was a contributor to the problem. A specific concern at the time was that the blasthole samples collected using the current sampling protocol may not be capturing the true particle size distribution (PSD) of the blasthole cuttings. Chieregati, Delboni and Costa (2008) stated that sample bias is often caused by particle-size-related problems, so the study investigated if the blasthole samples captured the true PSD of blasthole cuttings. The study also examined the relationship between the particle size of samples with measured grade.

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About the mine

The copper-molybdenum deposit consists of various copper and molybdenum sulfide and oxide minerals including chalcosine, chalcopryite, bornite, bronchatite, azurite, tenorite and molybdenite. The 15-m (50-ft) benches are drilled using Russian drills with diameter of 215 mm (8.5 in.).

The blasthole sampling protocol used by the mine is as follows:

- Each blasthole in an ore block is sampled for grade.
- Before a hole is drilled, the drill operator places a sample collector about 1.5 to 2 m (5 to 6.6 ft) from the drill hole (Fig. 1a). When drilling starts, the collector starts to fill with cuttings as cuttings fall into it.
- A plastic sheet is placed at some distance from the hole. The collector is emptied onto the sheet at the end of 7.5 m (25 ft) and 15 m (50 ft) of drilling, twice per hole. The total weight of the sample dumped into the plastic sheet is between 10 and 20 kg (22 and 44 lb) (Fig. 1b).
- Approximately 10 to 20 days later, a separate crew collects about 1 kg (2.2 lb) of sample from the plastic sheet for laboratory analysis. Before the sample is collected, the sample pile is mixed with a sample scoop.

The drills use an air blower (Fig. 1a) that has an impact on sampling. Compressed air is blown at the drill rod parallel to the ground and about 0.25 m (10 in.) above the hole collar (Fig. 2). The feature was probably designed to minimize dust blowing into the operator’s cabin. This dust is actually the fines component of the sample and, therefore, a bias is created when it is blown away. Loss of fines is a concern everywhere, though it should be minimized (Chieragati and Pitard, 2009). Two other issues with the sampling protocol are (1) the location of the sample collector and (2) the length of time the sample is exposed to the elements before it is collected from the mine site. The larger particles may not make it to the sample collector, while the smaller particles may go past it. This may or may not have an impact on the grade estimate. What will have an impact on the grade is the physical contamination of the sample as it lays on the plastic, exposed to the elements, for days. Vehicles, people and drill cable will occasionally make accidental physical contact with the samples, while wind, rain and snow can wash or blow them away or contaminate them.

Sector sampler

A sampling protocol was developed to determine the true nature of the cuttings, in terms of the PSD and the relationship between particle size and grade. The 15-m (50-ft) height of the bench combined with the large diameter of the drill results in a large amount of cuttings, approximately 2 t (2.2 st). As that amount of cuttings is difficult to handle in a reasonable amount of time in a typical laboratory, it was decided that the cuttings from a hole be sampled instead of being collected entirely. A sector sampler was therefore designed for the given particle size and drill. A sector or radial sampling bucket is considered to be an appropriate way to collect blasthole samples (Pitard, 2008; Chieragati and Pitard, 2009). The sector sampler had two parts: one went on the outside of the drill while the other went under it in the opposite direction (Fig. 3). Each part had a 25-mm (1-in.) opening in the front, as shown in Fig. 4. The sector sampler was manufactured in the mine machine shop. Figure 5 shows the cuttings inside the sector sampler immediately after the drill was moved. The weight of the cuttings inside the sector sampler averaged 195 kg (430 lb).

Test protocol

A total of six samples were collected using the sector sampler over a two-week period, from three drill blocks being drilled at the time with two samples per block. Because the air blower disperses the fines, it was turned off when
these locations were being drilled. The designed method of sampling was termed the University of Alaska Fairbanks method (UAFM). Each UAFM sample underwent the following protocol after being collected:

- The sample was dried at 90 °C (194 °F) for 24 h.
- After being mixed thoroughly, it was split by a riffle splitter to reduce it to under 10 kg (22 lb).
- Gilson sieves were used to split the sample into the following size fractions: larger than 12 mm (0.5 in.); smaller than 12 mm (0.5 in.) and larger than 6.3 mm (0.25 in.); smaller than 6.3 mm (0.25 in.) and larger than 1.7 mm (0.07 in.); smaller than 1.7 mm (0.07 in.).
- Using RoTap sieves (W.S. Tyler, Mentor, OH), the smaller than 1.7 mm (0.07 in.) size fraction was further split into the following six size fractions: smaller than 1.7 mm (0.07 in.) and larger than 1 mm (0.04 in.); smaller than 1 mm (0.04 in.) and larger than 425 μm; smaller than 425 μm and larger than 250 μm; smaller than 250 μm and larger than 125 μm; smaller than 125 μm and larger than 63 μm; smaller than 63 μm.
- The PSDs of the nine size fractions were determined.
- Each size fraction was analyzed for copper and molybdenum grades.

The laboratory work was conducted at the Institute of Technology facilities, a branch of the Mongolian University of Science and Technology. This process took several weeks because each of the 54 samples — six samples each split into nine size fractions — had to be ground before the EMC laboratory accepted them for analysis.

For comparison with the UAFM samples, a total of nine samples were collected from the same three blocks using the normal EMC method (EMCM). The plastic sheet at each drill hole contained about 10 to 20 kg (22 to 44 lb) of cuttings. After the geology department took its 1-kg (2.2-lb) sample as part of normal operations, the remainder was used for this research. Each sample was split and reduced to under 10 kg (22 lb) in weight before being analyzed. Note that comparative samples could not be taken for the holes drilled using the UAFM because the air blower was off. Some UAFM samples were rejected because they failed quality control checks, resulting in a slightly lower number of samples.
The EMCM samples underwent size classification into nine size fractions following a protocol similar to that for the UAFM samples.

Results

Figures 6a and 6b show the PSDs of the UAFM and EMCM samples, respectively. The trend for individual samples seems similar across the board. The most mass appears to be in the smaller than 6.3 mm (0.25 in.) and larger than 1.7 mm (0.07 in.) size fraction, followed by the smaller than 1 mm and larger than 425 μm size fraction. An interesting observation is that the range of mass proportions within a given size fraction is much higher for the EMCM samples. For example, while one EMCM sample only has 20 percent of its mass in the smaller than 6.3 mm (0.25 in.) and larger than 1.7 mm (0.07 in.) size fraction, another has more than 50 percent, yielding a range of 30 percent. Range here is defined as the difference between the highest and the lowest mass proportions in a size fraction for a sampling method. For example, the range for the smaller than 1.7 mm and larger than 1.0 mm size fraction is approximately 9 percentage points, or 20 minus 11 percent, for the EMCM samples and 5 percentage points, or 13 minus 8 percent, for the UAFM samples. Figure 7 compares the ranges seen within each size fraction for the two sampling methods.

Differences were seen in the ranges in the coarse size fractions (Fig. 7), and as shown in Fig. 8 the median mass proportions in the larger and smaller sizes are lower for the EMCM than the UAFM. Some variance in the PSD is to be expected between samples regardless of the method followed, but a high variance may suggest flaws in the EMCM. Because the EMC collector is located some distance away from the drill hole, there may have been a size bias caused by larger particles not making it to the bucket and smaller particles flying past the bucket. Also, inconsistent results may have occurred from the sample being left open to the elements for 10 days or more. More importantly, the direction and distance between the drill hole and the EMC sample collector is not consistent between holes.

Figures 9a-9d show the relationships between particle size and grade for copper and molybdenum. The trends are the same for the two methods, with the grades at the finer sizes generally higher than the grades at the coarser sizes. As the two methods sampled different holes, the grades are not expected to be identical. In Fig. 9a, the grade for sample B4 is plotted on the secondary axis because it was considerably higher than the other samples. The high value was later reconfirmed by checking it with the mine sample that was taken independently at the same hole. In the figures, molybdenum shows a curious trend, with the highest grade for some samples at the finer sizes but not at the finest size. Regardless, both copper and molybdenum grades generally went up as particle size decreased, pointing to the importance of ensuring that the PSD of blasthole samples is representative of the true PSD. If a sample is shown to contain more coarse particles than it actually does, the grade will appear to be lower, and vice versa. This will have a significant impact on economics, as holes deemed poor may be sent to the waste dump, resulting in loss of revenue.

The impact of the air blower, which was operated for the EMCM samples, is manifested in the data for the smaller than 63 μm size fraction. Six of the nine EMCM samples reported mass percentages below 7 percent for the smaller than 63 μm size fraction, while only one out of six UAFM samples reported the same. This confirms what is visible: fines do get blown away by the air blower in the EMCM to a noticeable extent. Given the relationship between PSD and grade, this observation is worthy of note. It is interesting to compare this observation with two samples taken by the EMC except without the blower. Both samples reported mass percentages above 7 percent for the smaller than 63 μm size fraction. The loss of fines — fines contribute to higher grade — may be somewhat compensated by another aspect of the EMCM: the 1.5 to 2 m (5 to 6.6 ft) distance between the EMC sample collector and the blast hole. Larger particles — these contribute to lower grade — do not make it to the collector because of the distance. However, particles that are larger than 12 mm (0.47 in.) make up less than 1 percent of sample mass, with medians of 0.8 and 0.2 percent for the UAFM and EMCM, respectively, so the overall effect may be only a slight underreporting of the grade.
Particle size distribution (PSD) versus grade relationships for the various samples: (a) PSD versus copper grade, UAFM samples, (b) PSD versus molybdenum grade, UAFM samples, (c) PSD versus copper grade, EMCM samples, and (d) PSD versus molybdenum grade, EMCM samples.

Conclusions
Six large samples were collected following a proper and tightly controlled sampling technique, using a sector sampler that was designed and manufactured for this purpose. Nine samples were collected following the standard operating procedure. The nine samples revealed that the standard operating procedure resulted in blasthole samples with inconsistent particle size distribution. Both larger and smaller particles appear to be underrepresented in the samples. Loss of fines is also indicated in the standard mine sampling process.

The two sampling procedures demonstrated similar particle size to grade relationships, with grades generally increasing as particle size got smaller. The sampling procedure followed by the mine is problematic given this relationship.

Six samples is not a large sample size. Therefore, the conclusions on inconsistency in representation of true PSD in EMCM samples should be taken as a caution rather than an absolute. This conclusion should be confirmed by a larger study. The conclusion on the particle size to grade relationship is more certain, as both methods showed the trend. This adds urgency to the need to ensure that day-to-day blasthole samples be representative of the true PSD.

This paper contributes to the literature by adding knowledge on practices and data from Mongolia that is not currently available in the literature. Additionally, findings such as that on the particle size to grade relationship add to the general literature on sampling.

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