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Variability of samples from various drilling and sampling methods

Jay Horton, Lisa Butler
Norwest Corporation, Vancouver, Canada
Daniel D. Overton, Denise Garcia
Engineering Analytics, Inc., Fort Collins, USA

ABSTRACT
A series of supplementary geotechnical investigations were conducted at the Questa Mine Site in 2013 and 2014 to collect additional information regarding the waste rock piles located on the site. These investigations highlighted the effects that different drilling and sampling methods can have on soil samples and the associated geotechnical laboratory characterization testing. Samples were collected from a series of collocated Becker borings and test pits and particle size distributions were determined for the samples collected from the two different investigation and sampling methods. The Becker samples had 3 percent more material passing the number 200 sieve and 11 percent more material passing the number 4 sieve than the test pit samples. Additionally two sets of Becker and sonic companion holes were drilled through the waste rock piles, with the Becker samples taken from a split spoon sampler and the sonic samples taken from the sonic core. The average fines content of the sonic core was found to be similar to that of the samples taken from the Becker split spoon sampler. However, the sonic drilling method resulted in significant zones of drill induced breakage and creation of rock flour in zones of dry gravel and/or cobbles within the rock pile. These drill induced breakage zones resulted in core with much higher fines content than the corresponding zones sampled from the Becker drilling. An analysis of shear strength test results on many Questa rock pile samples showed a relationship of decreasing friction angle with an increase in the percentage of fines. The higher fines contents of the Becker and sonic samples versus test pit or in situ samples needs to be considered when selecting appropriate shear strength parameters based on laboratory testing.

Key Words: becker drilling, sonic drilling, test pit samples, drill induced breakage, friction angle versus fines, sampling and site investigation

1 INTRODUCTION

The Chevron Questa Mine (Questa Mine) is a molybdenum mine owned by Chevron Mining, Inc. (CMI) located near the Village of Questa in Taos County, New Mexico. Mining began in 1919 with a number of underground workings. Large-scale open pit mining began in 1965 and continued until 1977. Large-scale underground mining began after the open pit was closed. Waste rock from the open pit (and a limited amount from the underground mining) was placed in several waste rock piles around the mine. The placement was mostly completed by 1985. Throughout the operational history of the Questa Mine site, numerous geotechnical investigations have been performed for various reasons. These investigations included soil sampling and laboratory testing.

In 2000, the mine and tailings facility were proposed as a National Priority Listed (NPL) Superfund site and listed as a NPL Superfund site in 2011. On June 2, 2014 CMI decided to permanently close the mine which triggered closure requirements under State permits issued by the Mining and Minerals Division (MMD) of the Energy, Minerals and Natural Resources Department (EMNRD) and the New Mexico Environment Department (NMED). The Environmental Protection Agency (EPA) mandated cleanup will continue in coordination with the State Agencies and as outlined in the December 20, 2010 EPA Record of Decision (ROD). The EPA issued an Administrative Settlement Agreement and Order on Consent (AOC) for Early Design Actions for the Questa Mine on June 13, 2012. The AOC contains a statement of work (SOW) which details the Early Design Actions that CMI will implement. Supplemental

geotechnical investigations were performed in 2013 (ARCADIS, 2014) and 2014 (Norwest, 2014) as part of the Early Design Actions for remediation of the waste rock piles located at the site. These geotechnical investigation programs included soil sampling and laboratory testing of the waste rock piles in locations where previous grain size information had been obtained by other methods, or where two sample collection methods were undertaken in the new program. Results from these most recent geotechnical investigation programs have highlighted the effects of drilling and sampling methods on soil samples and resulting geotechnical laboratory testing results. Some significant insights are discussed below.

2 PRIMARY FACTORS IMPACTING REPRESENTATIVENESS OF GRAIN SIZE SAMPLES

There are two primary factors impacting the representativeness of the samples intended for grain size testing of the Questa mine waste rock. The first factor is a selection bias in the choosing of samples and the second factor is alteration of the grain size due to the sampling method.

Selection bias can be overcome to some extent by taking regular samples according to a sample protocol such as specifying a 3 meter (10') long sample every 6 meters (20') of depth. Quantifying the impact of the sampling method itself on sample gradation can be more challenging. The samples can be altered by both exclusion due to size (i.e. rock fragments larger than the sampling tool would not be collected) or by breakdown of the larger particles through interaction with the sampling tool (such as the drill bit breaking down rock fragments while obtaining core). Both of these factors are present to some extent in the programs discussed in this paper, though efforts were made to reduce the selection bias as discussed below.

3 PARTICLE SIZE DISTRIBUTION – TEST PITS AND BECKER CUTTINGS

In 2013, ARCADIS completed a geotechnical investigation that included excavation of six test pits and drilling of six 23 cm (9") outside diameter (OD) Becker Hammer boreholes through the waste rock at Spring Gulch (SG). The test pits were collocated with the boreholes to the extent possible, typically offset by approximately 4.6 meters (15') or less. Two locations were offset by more than 4.6 meters (15') due to physical obstructions and/or access for drilling rig support trucks. Bulk samples were collected from the test pits and Becker cuttings were collected from the boreholes for various laboratory tests including particle size distribution.

Particle size distribution testing was completed on the test pit samples and Becker cuttings for the depth intervals of 0-0.6 meters (0-2') and 2.4-3.0 meters (8-10') for comparison. The consistent sampling depths were intended to remove any significant impact of selection bias. Figures 1 and 2 show the results of the particle size distribution testing for the test pits and boreholes at each depth interval. In general, testing from the Becker cuttings displayed a finer particle size distribution than the samples collected in the test pits. No material larger than 3.8 to 5.1 cm (1.5 to 2") was found in the Becker samples. Larger materials (about 20% according to test pit results) are apparently reduced in size due to the drilling process. Table 1 summarizes the findings. This information is also presented graphically in Figure 3 showing a consistent increase in fines (#200 mesh) content.

Table 1. Summary of Particle Size Distribution Testing from Test Pit and Becker Cutting Samples

	Test Pit Samples	**Becker Cutting Samples**
Fines (passing #200)		
Average	7%	10%
Standard Deviation	3%	2%
Gravel+ (retained on #4)		
Average	68%	57%
Standard Deviation	13%	6%

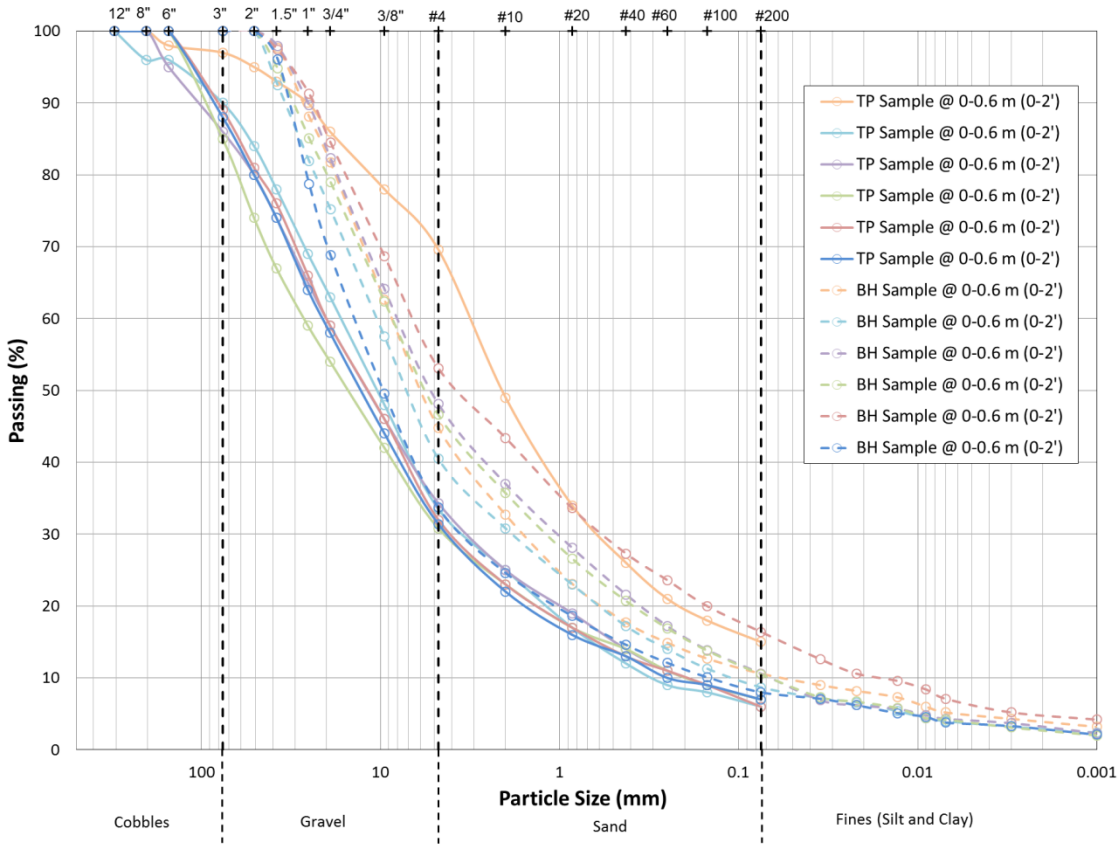

Figure 1. Test Pit and Borehole (0-0.6 meters (0-2') samples) Particle Size Distribution Plot

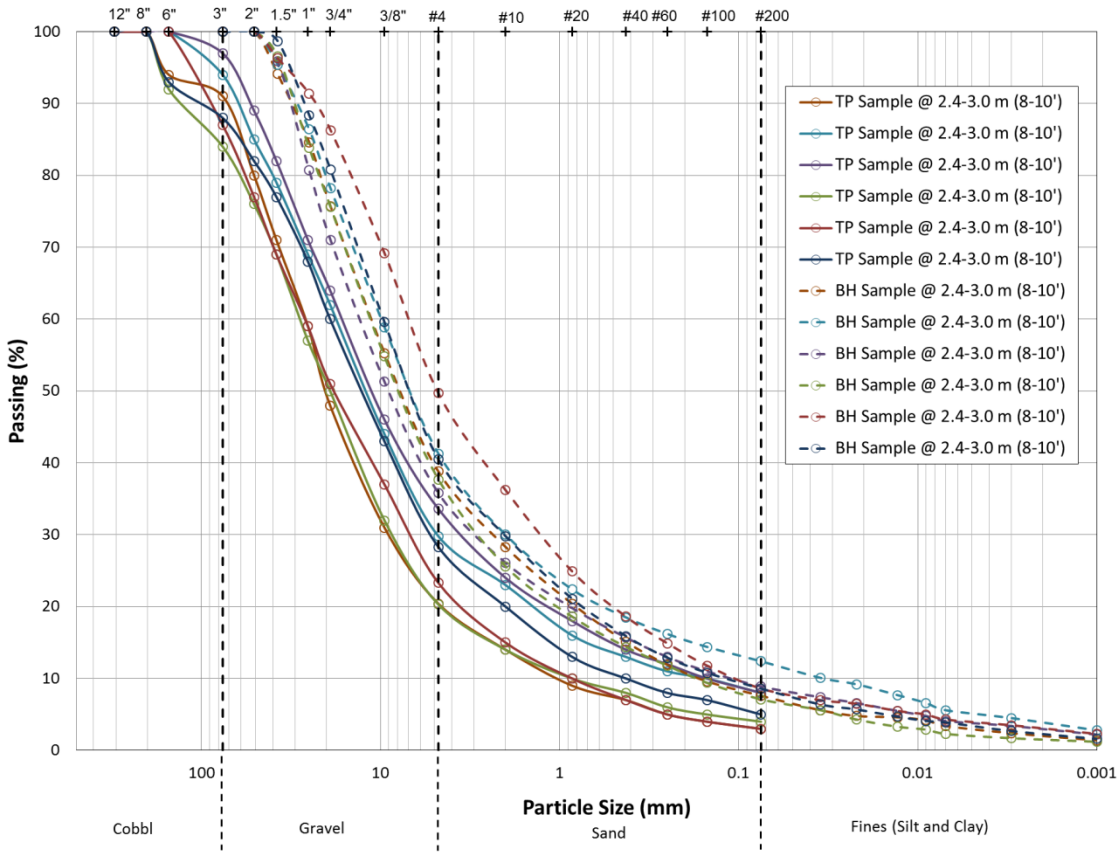

Figure 2. Test Pit and Borehole (2.4-3.0 meters (8-10') samples) Particle Size Distribution Plot

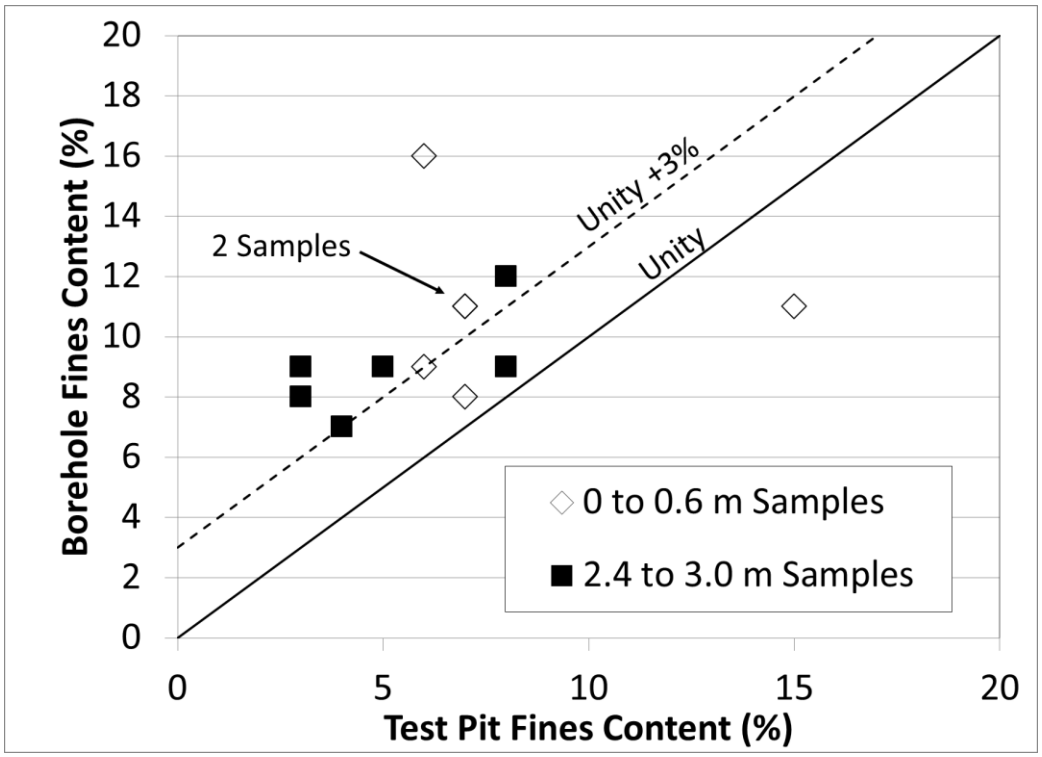

Figure 3. Comparison of Percent Fines Content for Becker Cuttings and Test Pit Samples

4 FINES CONTENT - BECKER SPLIT SPOON SAMPLES AND SONIC CORE SAMPLES

In 2002, URS drilled borehole SI-6 on the 8650 bench of the Sulphur Gulch South (SGS) waste rock pile. In 2004, Norwest drilled borehole SI-50 on the 8650 bench of the Sugar Shack South (SSS) waste rock pile. Both of these boreholes were drilled with a Becker Hammer drill. Split spoon samples were collected of the waste rock ahead of the drill bit with the intent of minimizing any breakdown due to drilling, although this results in limiting the recovery of coarser material and in less sample volume. In 2014, Norwest drilled two more boreholes (SSSBH-2 and SGSBH-6) in close proximity to the previously drilled SI-50 and SI-6 boreholes at the SSS and SGS waste rock piles, respectively. These boreholes were drilled with a sonic drill rig with a 12.7 cm (5”) or 9.5 cm (3.75”) inside diameter (ID) bit and sonic core of the waste rock was collected for laboratory testing.

The split spoon samples from SI-50 and SI-6 and the sonic core samples from SSSBH-2 and SGSBH-6 were tested in the laboratory for fines content (percent passing the No. 200 sieve). Figures 4 and 5 show the fines content results versus depth for each waste rock pile and sample type.

As shown on Figures 4 and 5, the fines content is generally similar between the sonic core samples and the Becker split spoon samples down to a depth of approximately 46 meters (150’). The average fines content for the sonic core was 18% for SSSBH-2 and 20% for SGSBH-6 (standard deviations of 4 and 6 percent) while the average fines content for the Becker split spoon samples from the companion holes was 17% for SI-50 and 16% for SI-6 (standard deviation of 5 percent). Below 46 meters (150’) in SGS, there does appear to be a difference where the sonic drill is returning samples with approximately 10% higher (25% vs 15%) fines content. Figure 4 also shows a zone of strong continuous sonic drill induced breakage which is discussed in the following section.

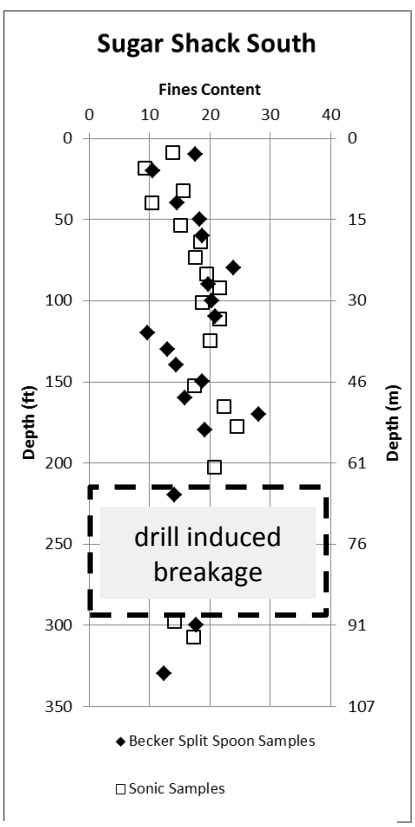

Figure 4: SSS Fines Content versus Depth

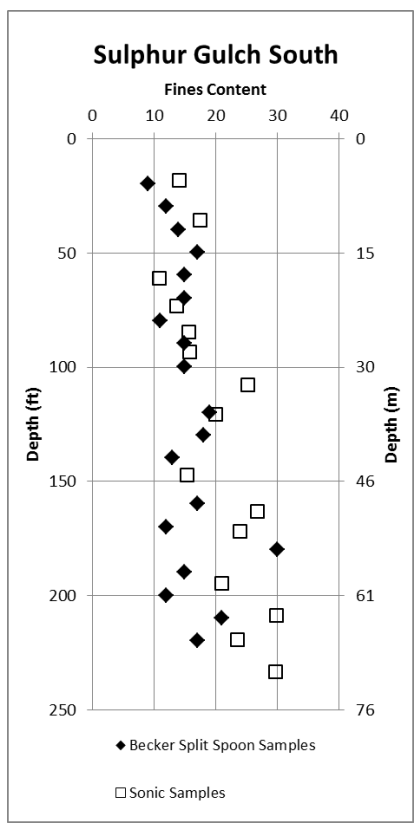

Figure 5: SGS Fines Content versus Depth

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As part of the 2014 supplemental geotechnical investigation discussed above, Norwest excavated seven test pits and drilled seven boreholes at the SSS, SGS, and Middle waste rock piles (termed Roadside Waste Rock Piles) (Norwest, 2014). During the logging of the boreholes, several locations were identified where it appeared that the in situ particles had been broken down by the drilling method resulting in finer material and rock flour. The locations ranged from small zones less than 3 meters (10') to large zones greater than 10 meters (10s of feet) and from minor impact (some rock flour) to strongly impacted (sample completely disaggregated). These locations were identified in the logs as disturbed (dis) and attributed to drill induced breakage (DIB). The DIB zones were visually identified based on the changed character of the core which appeared finer and contained rock flour, which was not typical of the bulk of the material previously observed. These DIB zones are described in four classes: Bedrock Drilling DIB, Discrete DIB, Weak DIB, and Continuous Strong DIB.

Bedrock Drilling DIB: The bedrock drilling DIB occurs when the sonic drill comes into contact with bedrock, resulting in a sorted material, or a gravel with a rock flour matrix depending on the exact drilling methodology used. Figure 6a shows an example of bedrock DIB. Figure 6b shows a core sample obtained from adjacent diamond drilling as a comparison. One reference sample was taken from this sonic core sample which reported 28% fines.

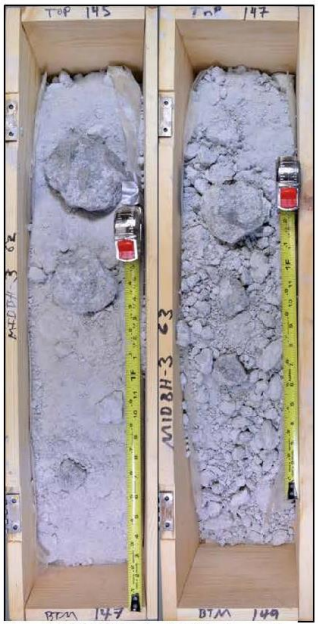

Figure 6a: Sonic core from Boring MIDBH-3 from 44.2-45.4 meters (145-149') resulting in rock flour and gravel

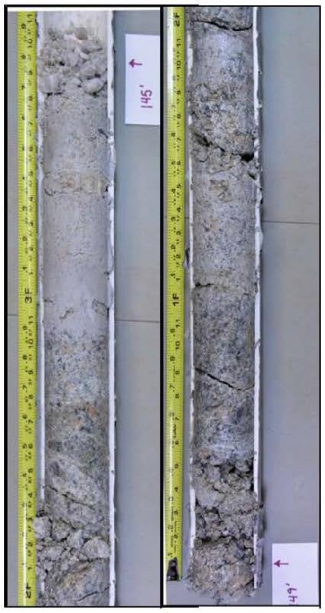

Figure 6b: Diamond Core from Boring MIDBH-3A from 44.2-45.4 meters (145-149') resulting in competent fractured and jointed core.

Discrete DIB: This type of DIB is believed to occur when the sonic drill comes into contact with a boulder or cobbles within the rock pile, resulting in discrete zones less than 0.9 meters (3') of visually finer material including rock flour. One sample was taken from this DIB type which reported 39% fines but with a plasticity index (PI) similar to the waste rock average. The shape of the grain size curve is very similar to that of the Bedrock Drilling DIB.

Weak DIB: Throughout the 427 meters (1400') of drill core acquired in waste rock in 2014 a substantial portion (27%) was observed to have at least a small amount of DIB. Of this, less than 12% of the total was deemed "strong" as described below. The remainder had limited

occurrence of rock flour either spread throughout the run or in very discrete zones up to 10 cm (3.9”). Most of the sonic core also showed a thin “rind” of finer material around the perimeter of the core where the core was intact. Excluding both the continuous strong DIB and the discrete DIB, the remaining DIB is referred to as weak DIB. While this may result in slightly higher fines contents reported, it is not believed that the difference would be greater in magnitude than the difference seen between other sampling methods and was not obvious in the test results received.

Continuous Strong DIB: Continuous intervals of DIB which exceeded 15 meters (10s of feet) occur when the sonic drill comes into contact with a drier zone of boulders and large gravels within the rock pile. Continuous strong DIB amounted to about 12% of the core length drilled in 2014 and was characterized by continuous zones of visually finer material including rock flour. These zones are particularly prevalent in the lower half of SSSBH-2. This zone in SSSBH-2 is also characterized by low water contents (0.5 to 2%) but with plasticity indices typical of the rock pile material. These zones also tended to correlate with higher incidences of SPT refusal in previous programs. Visual comparison of the DIB samples from this zone and a typical coarse sample, showed noticeable differences (Fig. 7a and 7b) before undergoing grain size testing, yet yielded similar grain size curves (Fig. 8). This is likely due to the disaggregation effects of the sonic drill being replicated by the screening process of a grain size analysis. While there is also likely some contribution from broken down boulders as in the Discrete DIB, their relative proportion is impossible to quantify. It is probable that the samples taken from this zone have an overstated fines content, but not by as much as might be expected from observation of the samples before screening.

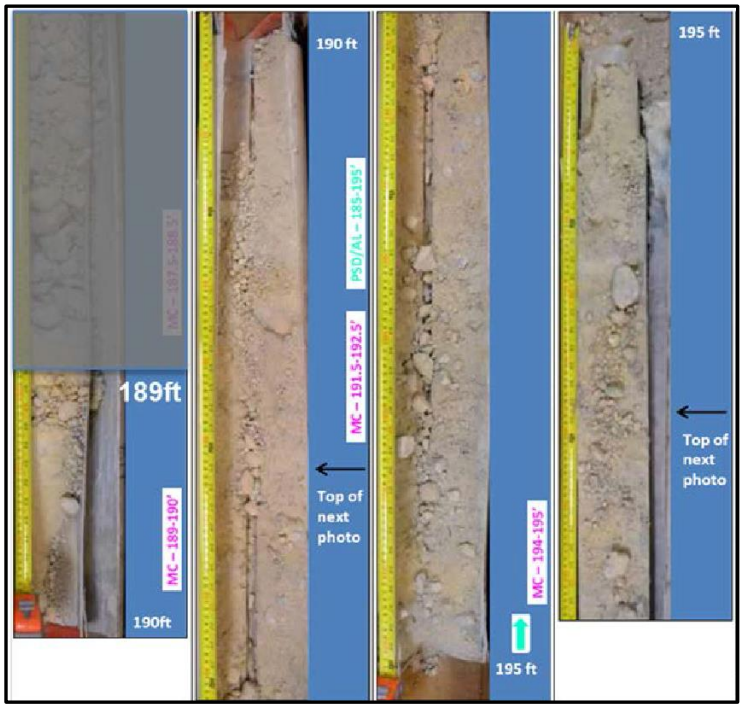

Figure 7a: DIB Sample

Figure 7b: Typical Sample

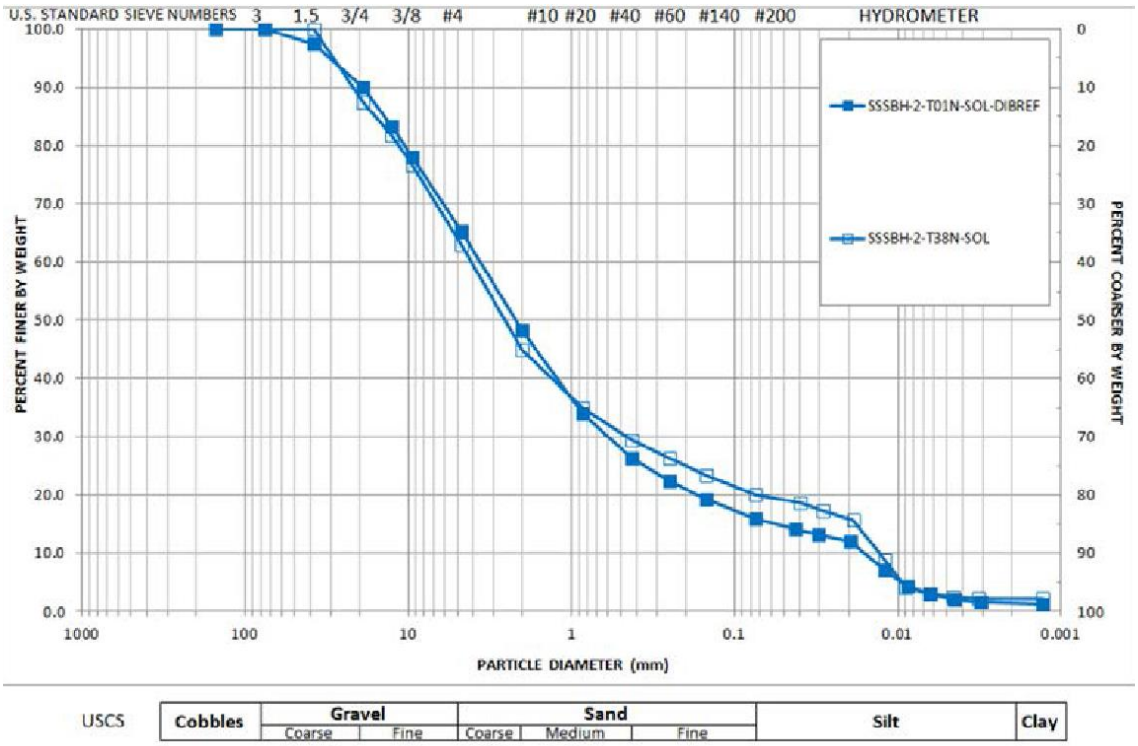

Figure 8: DIB Sample versus Typical Sample

Drill induced breakage appears to have affected much of the sonic drilling, to at least some degree. The occurrence of DIB appears to be governed by the presence of coarser material and associated lower moisture contents. While the tested fines content appear elevated in the discrete DIB zones, the PI values are consistent with the larger data set. It should also be noted that few large boulders were observed to have been cut by the sonic drill unless they were of more durable rock types such as some of the dikes. It appears that when boulders of lesser durability are encountered by the sonic drill, they are broken down to rock fragments and rock flour and spread through a core run. The observed discrete DIB zones are believed to be a single large boulder or zone of smaller boulders or cobbles broken down by the drill. The continuous strong DIB zones are made up of a larger zone of boulders or cobbles. The weak DIB zones are likely to contain the occasional boulder susceptible to being broken down by the drill.

5 IMPACTS OF SAMPLE SIZE AND PARTICLE SIZE DISTRIBUTION ON SHEAR STRENGTH

The discussions above highlighted differences in particle size distribution that result from the type of soil sampling that is used for a geotechnical investigation program. Particle size plays an important role in mine waste rock characterization. Mine waste rock exists in a wide range of particle sizes, varying from microns to over one meter (3') in diameter. Testing of waste rock requires consideration of the sample size ratio (SSR), which is the ratio of the sample diameter to the maximum particle size of the sample, as discussed in Stoeber (2012). Typically a minimum SSR of 6 is used for testing granular materials. Several large-scale triaxial apparati have been built for use in academic research with test chamber diameters ranging from 260 to 1,000 mm (10 to 39") (Marsal 1973), which are capable of testing waste rock with a maximum particle size ranging from about 40 to 160 mm (1.6 to 6.0"). However, commercially available testing apparati are generally limited to 300 mm (11.8"), and result in the testing of maximum particle sizes of only about 50 mm (2.0"). Varadarajan et al. (2003) concluded that samples scaled with parallel gradations, which maintain a constant ratio between particle sizes at a given percent passing, accurately represent the friction angles found in situ. However, industry often

relies on removal of the larger particle sizes (scalping) because of its simplicity, which results in a finer grained sample for laboratory testing.

Kara et. al. (2013) found that the peak friction angle increases when the size of the particles increases and that there is a relationship between the grain size and the peak friction angle. Koustuvee (2014) also found that the friction angle significantly increases with an increase in the size of the grain fractions. Wang (1994) found that the friction angle generally increases with increasing median particle diameter and gravel content. Van Zyl (2011) summarized geotechnical characterization results obtained during the Questa Rock Pile Weathering and Stability Project. His study concludes that the peak friction angle of samples containing larger diameter particles is higher than that for samples containing smaller particles. Analyses of the data presented on Tables 9 and 10 of Van Zyl (2011) indicated that the friction angle of air dried waste rock was 38 degrees for results obtained using a 60 mm (2.4”) direct shear box, and 48 degrees for results obtained using a 300 mm (11.8”) direct shear box. Additionally, the friction angle for saturated waste rock was 34 degrees and 40 degrees for the 60 mm (2.4”) and 300 mm (11.8”) direct shear boxes, respectively.

The analyses conducted for this study show a relationship between the friction angle and the percent fines for Questa waste rock samples. As shown in Figure 9, samples show a decreasing trend in friction angle with an increase in fines. This difference in friction angle is a result of varying fines content and has significant implications in determining the selection of sample method and the interpretation of geotechnical laboratory results with respect to geotechnical characterization of in situ properties. A decrease of the particle size and an increase in the fines content, as a result of the sampling method, will result in a reduced laboratory shear strength value as compared to in situ conditions.

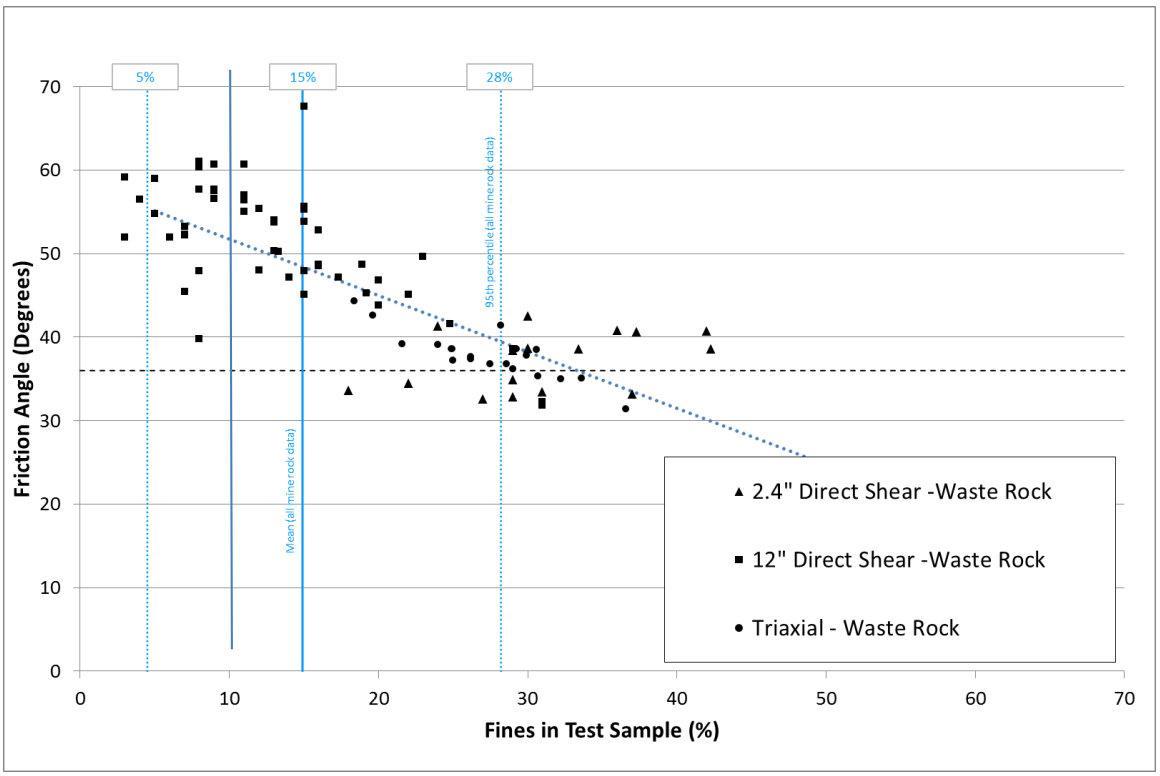

Figure 9. Fines Content versus Friction Angle

6 CONCLUSIONS

Six paired test pits and Becker holes were excavated and the soil samples tested for comparison of the two investigation and sampling methods. The samples of the Becker cuttings had on average three percent more (10% vs 7%) material passing the number 200 sieve and 11 percent more (43% vs 32%) material passing the number 4 sieve than the test pit samples. There is an obvious effect on the reduction of particle size due to the Becker drilling method.

The average fines content of the sonic core samples was generally similar to samples taken with the Becker split spoon, with some zones of higher fines in the sonic core.

The sonic core resulted in significant drill induced breakage and creation of rock flour in zones of dry gravel/cobbles or bedrock. This breakage results in a significant increase of fines versus in situ conditions but this is likely only significant in specific materials.

For the Questa waste rock there are appears to be some general trends in the representativeness of grain size samples using the various methods:

Test Pits:

- Large samples can be taken covering the entire range of particle sizes
- Limited breakage of particles occurs during sampling

Becker – Cuttings

- Fragments greater the 3.8-5.1cm (1.5-2”) may be broken down, resulting is a higher fines content in the soil sample versus in situ conditions (3% higher fines content observed, 10% vs 7% in test pits)
- Large samples can be taken but the drilling process homogenizes the sample over meters

Becker – Split Spoon

- Small sample volume
- Sampling is unlikely to significantly break down particles
- Sampler is not able to recover larger coarse materials
- Sampler advance may be refused in coarser material preventing sampling
- Where sampling has been successful, it appears reliable, but may bias to higher fines contents overall as coarser materials are not sampled

Sonic Drilling

- Variable breakage of particles. In silts, sands, and fine gravels, or in wetter materials (>2% water content), the sonic drill does not appear to be breaking down particles
- In coarser, drier or more friable materials the breakage appears to be significant
- Large samples can be obtained

The higher fines content of the Becker cuttings, Becker split spoon, and sonic core samples versus test pit or in situ samples is important to understand with respect to the friction angle reported by the laboratory shear strength testing of these samples. The impact from sampling will result in higher fines content samples used in strength testing than that which exists in situ The percentage of fines has a direct effect on the friction angle of the material. A large number of shear strength tests have been performed as part of this additional geotechnical analyses, which show that a 5% increase in tested fines (#200 mesh) will produce a friction angle approximately 4 degrees lower. The in situ material will have less fines, and thus a higher friction angle, than that suggested by laboratory testing performed on soil samples obtained from Becker cuttings, Becker split spoon samples, or sonic core. This higher friction angle of the in situ material may have a significant impact on the selection of appropriate geotechnical parameters and subsequent analytical results if not accounted for appropriately.

7 REFERENCES

ARCADIS US, Inc. 2014. Early Design Action: Pre-Design Borrow Characterization of Spring Gulch Waste Rock and Toxicity Review – Final Report. To Chevron Environmental Management Company. December 12.

Kara, E. M., Meghachou, M., and Aboubekr, N. 2013. Contribution of particles size ranges to sand friction. *Engineering, Technology and Applied Science Research* 3.4: 497-501.

Koustuvee, K., Sridharan, A., and Chetia, M. 2015. An investigation on the influence of grain shape and size on shear strength of cohesionless soils. *Proceedings of Geo-Congress*, Georgia, Atlanta. Web. August 10.

Marsal, R. J. 1973. Mechanical properties of rockfill. *Embankment-dam Engineering*, John Wiley & Sons: New York.

Norwest Corporation. 2014. Roadside Waste Rock Piles Supplemental Geotechnical Investigation Report. Report to Chevron Environmental Management Company. August 5.

Stoeber, J. N., Fox, Z. P., Abshire, M. S., and Overton, D. D. 2012. Evaluating the shear strength of mine waste rock. *Proceedings. of Tailings and Mine Waste 2012*, Keystone, Colorado.

Van Zyl, D. 2011. Questa Rock-pile Weathering Study: Geotechnical Characterization. *Proceedings of the 15th International Conference on Tailings and Mine Waste*, Vancouver, BC, Canada, pp. 439-453.

Varadarajan, A., Sharma, K. G., Venkatachalam, K., Gupta, A. K. 2003. Testing and modeling two rockfill materials. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 129, No. 3, 206-218.

Wang, J.J., Zhang, H.P., Tang, S.C., and Liang Y. 2013. Effects of particle size distribution on shear strength of accumulation soil. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 139, No. 11, 1994-997.