DRA-51. EXTRAPOLATION OF GEOTECHNICAL AND GEOCHEMISTRY CHARACTERIZATION INTO THE FUTURE

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1. STATEMENT OF THE PROBLEM

What are the effects of weathering on the present and future stability of the Questa mine rock piles? Changes due to weathering are of interest with respect to predicting long-term geotechnical slope stability of the rock piles at the Questa molybdenum mine. The final goal of the Questa investigation is to assess the potential for gravitational stability of existing mine rock piles over time (100 yrs and 1000 yrs) based on the physical, chemical, mineralogical, biological, and geotechnical characteristics as well as the weathering of the rocks in the rock piles.

2. PREVIOUS WORK

A wide variety of weathering indices have been proposed in the literature (McLemore et al., 2008c) using physical, geochemical, mineralogical, and geotechnical characteristics. Most of the chemical weathering indices in the literature are based only on geochemical parameters, which restrict their application to the type of environment for which they were developed. These indices typically are based on larger time scales and, in many cases, different climate and geomorphic conditions than those found at Questa. A review of literature summarized weathering on rock piles, geotechnical characterization of rock piles world-wide, failures of rock piles, and the stability of rock piles throughout the world (DRA-39; McLemore et al., 2008). The results of direct shear tests and other geotechnical data conducted by different consulting companies who studied the Questa rock-pile materials was compiled (DRA-44). Data summaries for all shear testing and other geotechnical data conducted by NMT (DRA-42) and UBC (DRA-43) was compiled. Summaries of all previous geotechnical data on samples from the site was compiled (geotechnical data summary spreadsheets).

Tamrakar et al. (2007) concluded that composition of grains, shape and sorting have little influence on mechanical and physical properties of sandstones, because the composition of the grains do not play a role in the variation of these properties. Bell (1978) also found no relationship between quartz content and strength of sandstone. Bell and Barton (1999) determined that grain interlocking was important in the strength of grains.

3. TECHNICAL APPROACH

The technical approach for examining the effect of weathering processes on slope stability involves an iterative and interactive process addressing both the geotechnical and geochemical characterization of materials. Principal features of the process include the following steps:

1. Compilation and evaluation of existing information on the construction of rock piles, characterization of rock piles, effects of weathering on rock piles, and the stability of rock piles throughout the world (DRA-39; McLemore et al., 2008a).

2. Compilation and evaluation of existing information on weathering indices and weathering of rock piles from throughout the world (DRA-27; McLemore et al., 2008c, d).
3. Formulation of an initial conceptual geological, geochemical, hydrological, and geotechnical model that can distinguish features of pre-mining hydrothermal alteration and supergene alteration from post-mining weathering in the rock piles (DRA-27; McLemore et al., 2008a, c; McLemore and the Questa Rock Pile Weathering and Stability Tam, 2008).
4. Establish and evaluate natural analogs to determine weathering products of similar rocks at a longer time scale (DRA-19, 20, 21; Graf, 2008; McLemore, 2008a, G. Ayakwah, in preparation).
5. Geochemical testing
    a. Examine chemical compositions of water samples collected from seeps, trenches, surface and underground water samples, and runoff waters (E. Osantowski, dissertation in preparation).
    b. Determine geochemical trends for fresh outcrop samples, using published and new chemical analyses of outcrop, rock pile and drill hole (representing samples from the open pit, i.e. pre-mined overburden) samples (DRA-1; McLemore et al., 2008b).
    c. Characterize weathered and unweathered boulders to understand short-term chemical effects on weathering (DRA-25, disintegration of the boulders; N. Dunbar, in preparation).
    d. Characterize the samples before and after humidity cell testing (DRA-34)
6. Formulation of an initial weathering index (Simple Weathering Index, SWI, McLemore et al., 2008a).
7. Evaluation of geochemical data and published weathering indices (McLemore et al., 2008c).
8. Formulation of the Questa Mineralogical Weathering Index (QMWI, DRA-16; McLemore et al., 2008c).
9. Detailed geotechnical testing of a subset of samples for shear strength properties for internal angle of friction and cohesion. Evaluation of geotechnical data (DRA-50; McLemore et al., 2008e).
10. Initial development of integrated models of geotechnical behavior as a function of weathering (McLemore et al., 2008e).
11. After the data sets are initially judged complete, the team will determine whether the provisional weathering index can be tied to the geotechnical data in a manner that would allow development of long-term modeling sufficient for the project requirements.

4. CONCEPTUAL MODEL(S)

The Questa rock piles were formed by blasting of the overburden (material overlying the ore deposit), transported by truck, and dumped by end-haul methods over the edge of the slope into steep valleys near the Questa open pit (URS Corporation, 2003, appendix C). End-haul dumping results in a rock pile that consists of numerous layers that are matrix supported and finer in particle size at the top of the rock pile and increase in particle size and becomes more cobble supported at the base (McLemore and the Questa Rock Pile

Weathering and Stability Team, 2008; McLemore et al., 2008a). The resulting layers locally are at, or near, the angle of repose and subparallel to the original slope angle. Detailed geologic mapping and sampling in the Goathill North (GHN) rock pile at Questa revealed that these layers could be defined as mappable geologic units in the rock pile (McLemore et al., 2008a). The overburden was fractured before blasting due to pre-mining hydrothermal activity and intrusion of granitic porphyritic and aplitic rocks, resulting in angular rock fragments when blasted (McLemore et al., 2008b). The mineralogical and chemical variations that occurred during hydrothermal alteration before mining are greater than the variations found during weathering of the rock-pile materials after mining.

Chemical weathering throughout the world is based upon the CO_2 system, where the dissolution of feldspar to form clays is the most important chemical reaction (Drever, 1997; Price, 2003). However, in the Questa rock piles, unlike most natural residual soil weathering profiles, dissolution of pyrite, calcite, and to a lesser extent chlorite, illite, and other silicate minerals are more important chemical reactions that results in 1) dissolution in water seeping from the rock piles and 2) the precipitation of gypsum, jarosite, soluble efflorescent salts, and Fe oxide/hydroxide minerals. These reactions can occur within years to hundreds of years, until the source of sulfur is consumed. Weathering or oxidation of pyrite and other sulfide minerals generally requires four components: water, sulfur (sulfide), air (oxygen) and bacteria (Fig. 1; McLemore, 2008b) and the result is sulfuric acid, locally called acid drainage (AD), acid mine drainage (AMD), or acid rock drainage (ARD). The resulting sulfuric acid does not entirely escape the rock pile, but resides as pore fluids, which can oxidize minerals in and at the surface of the rock pile. Water and oxygen appear to be the rate limiting factors in the oxidation of sulfide minerals, especially in arid and semi-arid environments (León et al., 2004). Recent experimental studies by Jerz (2002) and Jerz and Rimstidt (2004) have confirmed earlier work by Morth and Smith (1966) that shows pyrite oxidizes faster in moist air than under saturated conditions, thereby accelerating the weathering of the rock piles, at least locally. Specific factors that affect pyrite oxidation are oxygen concentration, temperature, pH, pyrite surface area, concentration of ferric iron (Fe^{+3}), the presence of bacteria or other living organisms, and water.

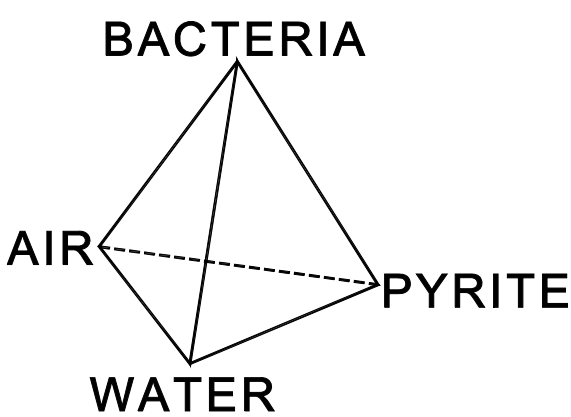

FIGURE 1. Acid drainage (AD) tetrahedron, showing the relationship between the four components that produce AD (McLemore, 2008b).

The well known Mohr-Coulomb failure criterion was used to interpret the shear tests results. This failure criterion has two constants namely cohesion (c) and friction angle (φ). Since most of the shear tests were conducted on air-dried material, two interpretations of Mohr-Coulomb failure criterion were used in obtaining the shear strength of the material for the range of normal stress of 160-750 kPa. In the first interpretation of the tests results that is being used in this DRA, the failure envelope was defined as the best straight line that passed through the four normal stress-shear strength data points, while in the second approach, this best line was forced to pass through the origin resulting in zero cohesion intercept (Gutierrez, 2006). The difference in the calculated friction angles in these two approaches in most situations is less than 3°.

5. STATUS OF COMPONENT INVESTIGATION

Goathill North (GHN) rock pile

Weathering generally decreased from the outer edge of the GHN rock pile to its interior and then increased toward the base of the rock pile where water and oxygen are available to dissolve pyrite and calcite to form gypsum, jarosite, soluble efflorescent salts and Fe oxide/hydroxide minerals. Weathering also is found in specific layers within the interior of the Questa rock piles where water and air are available (DRA-6; McLemore et al., 2008a).

Friction angle, point load strength index and slake durability index of the GHN rock pile samples decreased as the degree of weathering increased in some samples but not all (Fig. 2; McLemore et al., 2008a, figs. 125, 117, 120). However, the decreases were still small and suggest that 25-40 years of weathering have not substantially affected the shear strength properties of these rock pile materials. This supports previous investigations where friction angle decreased with increase in weathering (Arel and Tuğrul, 2001; Bryant, 2003; Tuğrul and Gürpinar, 1997; Moon and Jayawardane, 2004). These results and other studies suggest that changes in physical properties (i.e. particle size, texture and fabric) have a larger effect on friction angle than mineralogic and chemical changes (Arel and Tuğrul, 2001; Moon, and Jayawardane, 2004).

The slake durability and point load indices indicate that the rock fragments are quite strong even when weathered, although some weathered samples do show a slight decrease in slake durability and point load, but not all (Viterbo, 2007; Viterbo et al., 2007; Ayakwah et al., 2009). The rock fragments when in the rock piles are under stress (i.e. overburden) and will not break down, unless exposed to surface weathering. This was observed during regrading of GHN, where boulders within the rock pile were intact, but once released from the rock pile, some began to fall apart.

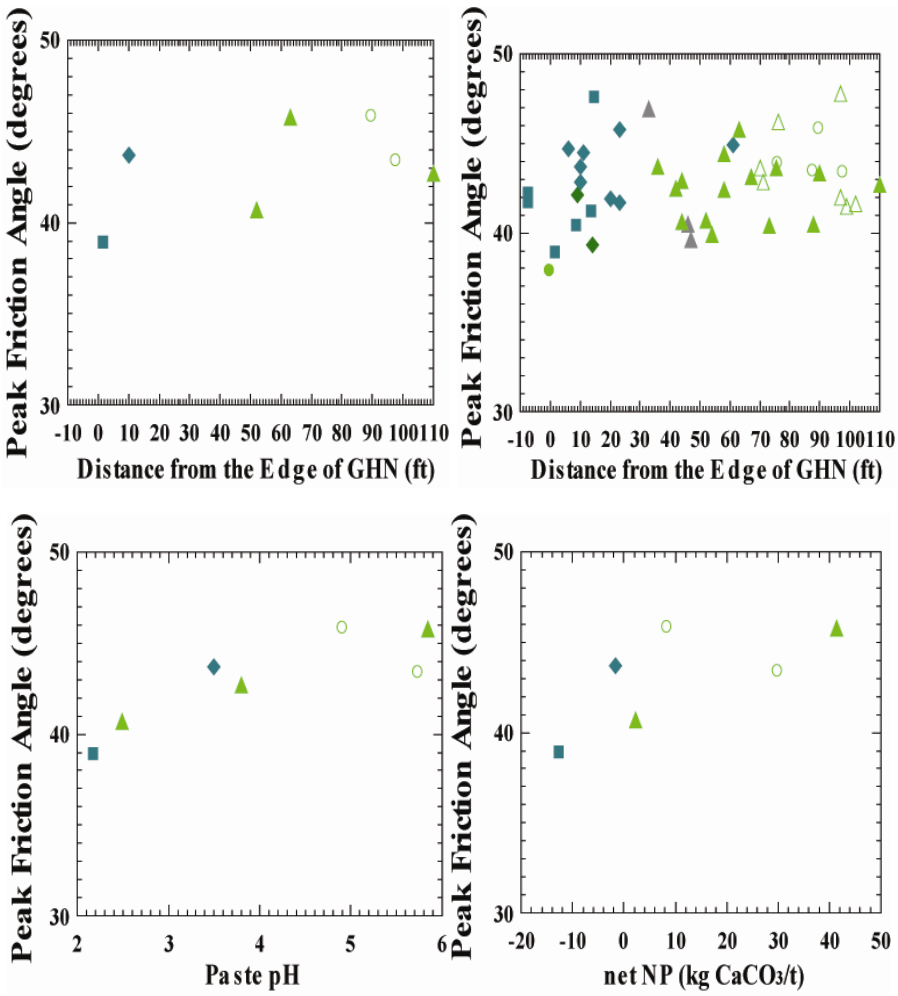

FIGURE 2. Variation of peak friction angle across bench 9 of trench LFG-0006 and all samples from GHN. The lower friction angles are from the outer part of the rock pile (more weathered), more weathered samples in the interior, and the foundation soils beneath GHN. The higher friction angles are from the interior (less weathered) part of the rock pile. A similar trend is observed in paste pH and net NP (neutralizing potential) values. Refer to McLemore et al. (2008, figure 46, table 20) for geologic section and for descriptions of the geologic units.

Other rock piles

The other rock piles are similar in composition and geotechnical parameters as GHN (DRA-2). Weathering is also similar (DRA-27).

In situ testing

Laboratory and in-situ direct shear tests were conducted on the Questa rock-pile materials to investigate the effect of weathering and time on the shear strength of these materials (Fig. 3). Higher cohesion values correspond to the debris flow samples that are older than the rock piles. To classify the rock-pile material based on the weathering intensity, several parameters indicating weathering were used. These were confirmed by petrographic analysis. Some samples that are weathered (i.e. high SWI, QMWI, SO_4 and

$SO_4/(S+ SO_4)$, SWI defined in Appendix 1 and QMWI defined in Appendix 2) have high cohesion, but not all. In fact there are some weathered samples with very low cohesion. The increased cohesion of some samples is likely due to post-deposition oxidation, and is consistent with the change in color of the oxidized sample, chemical classification as potential acid-forming, loss or obscuring of original igneous texture on the edges and within many rock fragment grains, and increase in weathered minerals within the in-situ samples (i.e. gypsum, jarosite, and Fe- oxide minerals). If the debris flow and alteration scar are analogs for the rock piles, with 95% confidence, the current mean cohesion of the rock piles will increase with time (DRA-47). This increase of cohesion with time is attributed to the gradual compaction of the rock piles and the presence of cementing agents like jarosite, gypsum, pre-existing clay minerals, Fe-oxide minerals, and soluble efflorescent salts in the rock piles.

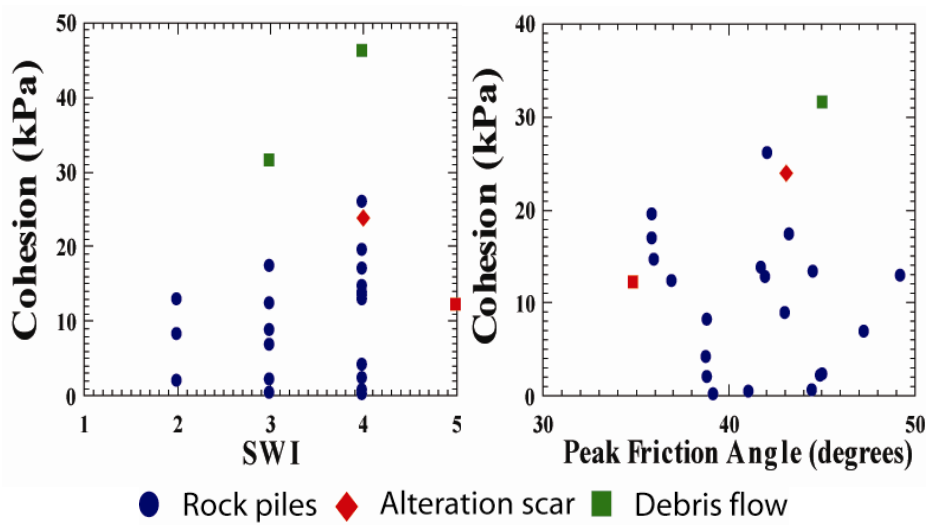

FIGURE 3. Variations between cohesion and SWI and friction angle for in-situ test sites. SWI define in Appendix 1.

Analog sites

Analog materials are from sites in the vicinity of the Questa mine that are similar in composition and weathering process as the rock piles, but are older than the rock piles. Weathering processes operating in the natural analogs are similar to those processes operating in the rock piles, although certain aspects of the physical and chemical system are different (Graf, 2008; Ludington et al., 2004). Alteration scars represent long-term weathered analogs (300,000 years to 1.8 million year; Lueth et al. 2008) to the same rocks and minerals in the rock piles and should contain products of silicate weathering. Debris flows represent intermediate-term weathering (10 to 100,000 year scale; Lueth et al., 2008), although these materials have been weathered in situ, transported, deposited, and subjected to subsequent weathering. Weathered bedrock material represents long- to intermediate-weathering (1000 to 10,000 year scale estimated). Detailed mineralogical, geochemical, and isotopic study of weathered profiles in alteration scars, debris flows, and weathered bedrock/colluvium document long-term mineralogical and physical changes in a residual weathering environment. Scar materials selected for study were petrologically similar to those in the rock piles. The profiles represent progressive

weathering from bedrock up to residual soils. These profiles are constrained by age determinations that allow us to calibrate mineralogic changes due to weathering upward through the profiles.

Samples were collected from a profile in Straight Creek alteration scar in order to examine preliminary trends in a residual soil weathering profile as weathering increases upwards in the profile. This profile consists of only four samples, and the mineralogy and chemistry of the samples are similar to those analyses found in the GHN samples (McLemore et al., 2008) and other residual soil weathering profiles in alteration scars (Graf, 2008) and in weathered bedrock at GHN (McLemore, 2008). There are some variations in peak friction angle with depth in the profile, but the changes in SWI are not significant (Fig. 4).

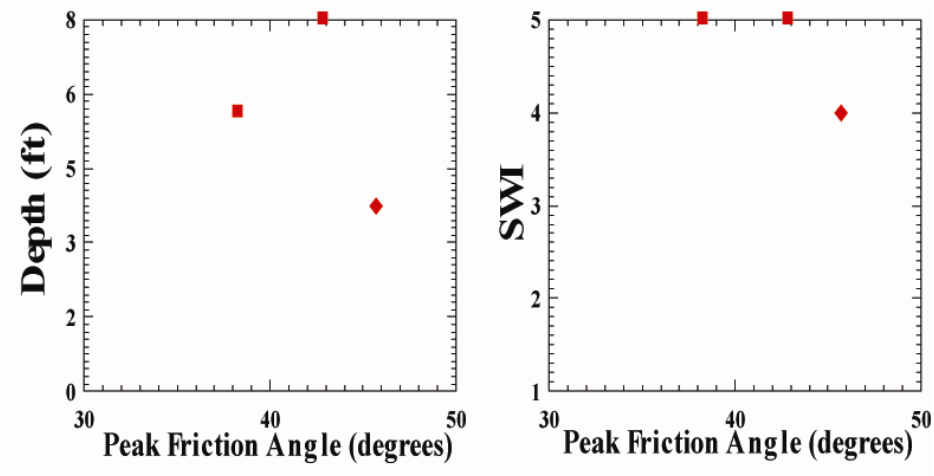

FIGURE 4. Variation in peak friction angle with depth in the Straight Creek alteration scar profile and SWI.

Graf (2008) examined three profiles in alteration scars and found that the dominant chemical weathering system is the oxidation of pyrite, dissolution of calcite, leading to the precipitation of both sulfates and Fe-oxides, similar to that found in the rock piles. Within each profile particle size decreases upward, which suggests physical weathering processes are active. Graf (2008) determined that weathering increased towards the top of the profile, but he did not examine the variation in friction angles within the profile. Subsequent direct shear testing by the Questa team however did direct shear testing of some of the profiles examined by Graf (2008) and found that the variations in friction angle within the profiles are not significant (Fig. 5).

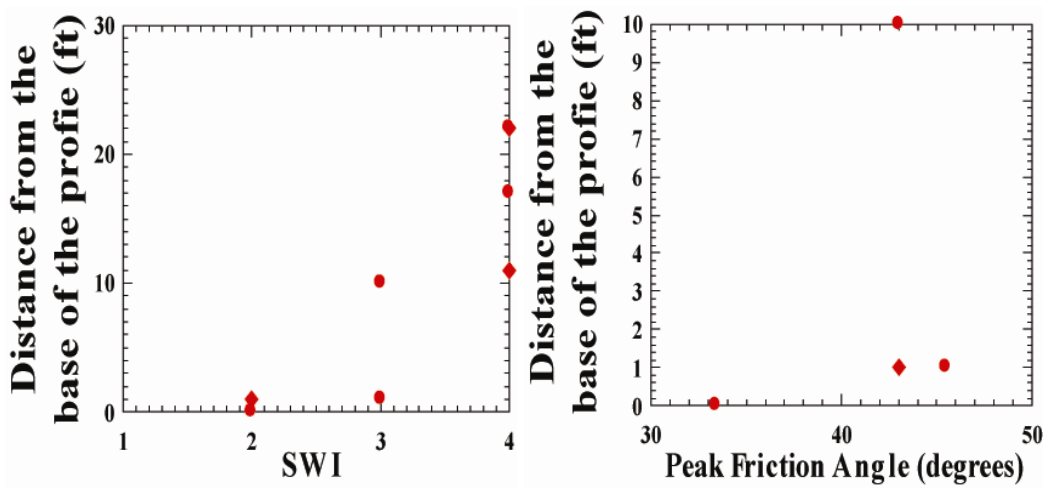

FIGURE 5. Variations in SWI and friction angle along the Hansen alteration scar profile examined by Graf (2008).

Detailed mineralogical and isotopic study of the Goat Hill debris flow documents long-term mineralogical and physical changes in another natural environment. The deposition of debris flows represents an analogy to the mining of scar material and redeposition, albeit by water as the transporting fluid phase. The results of the geochemical characterization indicate that the samples collected from the debris flow are similar to each other and to the Questa rock piles (McLemore et al., 2008), but do not show trends of decreasing weathering from the top of the profile to the bottom. The results of the geotechnical testing indicate there is no clear trend of decreasing strength with increasing depth for the samples from the debris flow profile.

However, the debris flows are moderately to well cemented. The cementation is similar to that found in the Questa rock piles and is formed by oxidation of sulfide minerals producing sulfates and iron oxides. The debris flows are well cemented, even below the surface. Portions of the Questa rock piles are poorly cemented or have no cementation, but other portions, especially the outer layers are moderate to well cemented (see McLemore et al., 2008; Boakeye, 2008; DRA-6, 8). This cementation is formed in part through the breakdown of the rock fragments during blasting and dumping to free clay minerals that then form cementing agents in the debris flow. These clay minerals are pre-debris flow hydrothermal clays and are not formed after deposition of the debris flow. Also the oxidation of pyrite forms jarosite, gypsum and iron oxides.

Similar studies in weathered bedrock material also document changes in environments characterized by in-situ weathering and minor transport producing weathered materials that are more similar to the rock piles with respect to grain size distribution (but not shape) but only in a single lithology. Weathering increases from the base of the Questa weathering profile (LFG-016) to the top of the profile (McLemore, 2008b). The age of the weathering profile is uncertain, but is older than the rock piles. The predominant chemical weathering system is the oxidation of pyrite (forming H_2SO_4) and dissolution of calcite, which leads to the precipitation of gypsum, jarosite, and Fe-oxides. Decrease in particle size is evident with increase in weathering and could be due to: 1) initial particle size reduction by hydrothermal alteration, 2) freeze-thaw action, and

3) precipitation of gypsum and jarosite. Decrease in particle size allows for increased chemical oxidation because of the increased surface area due to the smaller particle sizes. Cementation is variable in the profile and is attributed to the precipitation of gypsum, jarosite, and iron oxide minerals. Even though the samples in the weathering profile have been hydrothermally altered, weathered, show a decrease in particle size and an increase in clay minerals, the samples have high durability and strength. Both the friction angle and slake durability index are similar to the Questa rock-pile material and do not change significantly in the profile (Fig. 6).

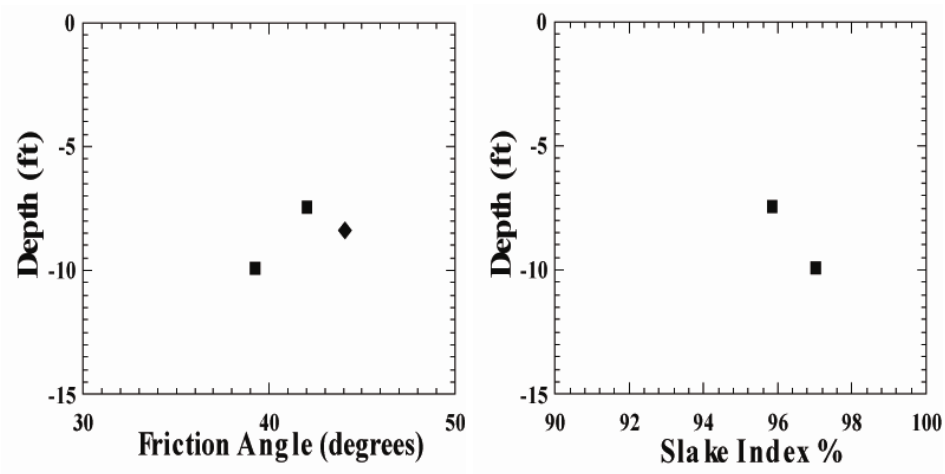

FIGURE 6. Variations in friction angle and slake durability with depth of the weathering profile. Friction angle is determined in the laboratory using high normal stress (160 to 750 kPa) and a 2-inch shear box (Gutierrez, 2006). The samples were air-dried material, passed No. 6 sieve and were compacted to a dry density mostly in the range of 1600-14,900 kg/m^3.

6. RELIABILITY ANALYSIS

Samples collected for the project are complete, comparable, and representative of the defined population at the defined scale. Precision and accuracy are measured differently for each field and laboratory analysis (parameter), and is explained in the project reports, SOPs and summarized in DRA 0 and McLemore and Frey (2008). Most laboratory analyses depend upon certified reference standards and duplicate and triplicate analyses as defined in the project SOPs. The sampling and analysis plans for each segment of the field program and the control of accuracy and precision as defined in the SOPs, provides a large high-quality set of observations and measurements that are adequate to support the interpretations and conclusions of the various technical studies documented in the individual component DRAs and ultimately supports the programmatic DRA.

Some of the technical and data uncertainties in this DRA include:

- The mineralogical and petrographic techniques used for this study are not able to detect small differences in the types of clay minerals or minor changes in their mineral chemistry.
- Only the upper third of the stable portion GHN rock pile was trenched, mapped, and sampled, although three drill holes also were drilled into the rock pile; these data were extrapolated for the entire rock pile. Samples from the surface of the toe of GHN were used to define the toe region.
- The GHN rock-pile materials are a mixture of different lithologies and hydrothermal alteration mineral assemblages before being emplaced in the rock piles, therefore changes of mineralogy and chemistry between the outer, oxidized zone and the interior, unoxidized zones of the rock pile are a result of differences due to pre-mining composition as well as chemical weathering. These differences can be difficult to distinguish, except by detailed field observations and petrographic analysis and the changes due to hydrothermal alteration are more pronounced than those due to weathering.

7. CONCLUSION OF THE COMPONENT

Physical weathering is more prominent when the rock-pile material is first laid down at time 0. The rock fragments when in the rock piles are under stress (i.e. overburden) and will not break down, unless exposed to surface weathering. Chemical weathering involving the dissolution of pyrite, calcite, and to a lesser extent chlorite, illite, and other silicate minerals are more important chemical reactions that results in 1) dissolution in water seeping from the rock piles and 2) the precipitation of gypsum, jarosite, soluble efflorescent salts, and Fe oxide/hydroxide minerals.

Friction angle, point load strength index and slake durability index of the GHN rock pile samples decreased as the degree of weathering increased in some samples but not all. However, the decreases were still small and suggest that 25-40 years of weathering have not substantially affected the shear strength properties of these rock-pile materials. Some, but not all samples located on the outer edge of the rock pile disintegrated more and presented lower durability. Comparison of point load and slake durability indices of fragments in the rock pile to values of un-weathered drill cores of rocks with similar lithologies to those in the pile shows that rock fragments in the Questa rock pile have not experienced considerable weathering after emplacement. Therefore, lower values of friction angle, point load strength index and slake durability index of

samples from the outer edge of the pile are likely due to post-deposition oxidation, which is consistent with the change in color, loss or obscuring of original igneous texture on the edges and within many rock fragment grains, and increase in weathered minerals (i.e. gypsum, jarosite). Conversely, the point load and slake durability indices values of GHN samples on the interior of the pile are similar to the values of un-weathered drill core samples. Consequently, the samples from the interior of the GHN rock pile are not noticeably more weathered since its emplacement.

Even though some weathering indices were developed that show some aspect of the weathering at Questa (DRA-16, 27), a weathering index that could be related to the geotechnical parameters and be used to predict the future effect of weathering on geotechnical parameters with time could not be developed, because:

- The weathering indices cannot adequately differentiate between the hydrothermal alteration present in the original rock and subsequent alteration due to weathering.
- Geotechnical parameters of Questa mine materials are not controlled by lithology or mineralogy (DRA-42, 47, 50).
- The existence of surface coatings provides little evidence of the extent of weathering of the interior of the rock fragments and the rock fragments comprise most of the rock-pile sample.
- The chemical weathering indices, adapted from literature citations (McLemore et al., 2008d) mostly are based largely on hydrolysis of silicates, which is minor at Questa.
- The "Simple Weathering Index" (SWI), which was used as a field-screening tool, is based largely on the visual characteristics of the soil matrix, particularly color, presence or absence of igneous textures, cementation, and presence or absence of pyrite, calcite, jarosite, and gypsum. Color is exaggerated because it is related to coatings of the rock fragments.
- The site-specific Questa Mineralogic Weathering Index (QMWI, DRA-16) not only includes the faster weathering system of pyrite, calcite and gypsum, but also has the potential to reflect systematic changes in the bulk rock-fragment materials and because of the very small mass changes that have occurred in 25-40 years the ability to distinguish weathering mineralogically in the manner of QMWI did not have sufficient power to establish reliable trends.
- In the low pH system as in the Questa rock piles, the dominance of congruent weathering reactions and the similarity of dissolution rates for many alumino-silicates results in only subtle changes since most minerals would simply dissolve from the exterior inward without leaving a pseudomorphous successor.
- The QRPWASP mineralogical and geochemical data show that the extent of silicate weathering in the rock piles is slight and that there is not enough variation in solid phase chemistry to lie outside the range of mineral chemistries present in the starting materials due to their protolithologic variation and, especially, the additional redistribution of mass associated with the extensive hydrothermal alteration.

In, general, Questa rock fragments presented high durability and strength even after undergoing hydrothermal alteration, blasting, deposition, and exposure to weathering. Collectively, these results suggest that future weathering will not substantially decrease the friction angle of the rock piles with time. These results and

other studies suggest that changes in physical properties (i.e. particle size, texture and fabric) have a larger effect on the friction angle than do mineralogic and chemical changes. It is expected that friction angle will not change significantly over time. Indications are that the cohesion will increase over time as the material settles and weathers. This is due to particle interlocking, cementation and matric suction. Collectively, these results suggest that future weathering will not substantially decrease the friction angle of the rock piles with time.

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9. TECHNICAL APPENDICES

McLemore, V.T., Donahue, K., Dunbar, N. and Heizler, L., 2008c, Characterization of physical and chemical_weathering in the rock piles and evaluation of weathering indices for the Questa rock piles: unpublished report to Chevron, Task 1.3, B1.1.

APPENDIX 1. SIMPLE WEATHERING INDEX (SWI)

Simple weathering index for rock-pile material (including rock fragments and matrix) at the Questa mine (McLemore et al., 2008a).

SWI	Name	Description
1	Fresh	Original gray and dark brown to dark gray colors of igneous rocks; little to no unaltered pyrite (if present); calcite, chlorite, and epidote common in some hydrothermally altered samples. Primary igneous textures preserved.
2	Least weathered	Unaltered to slightly altered pyrite; gray and dark brown; very angular to angular rock fragments; presence of chlorite, epidote and calcite, although these minerals not required. Primary igneous textures still partially preserved.
3	Moderately weathered	Pyrite altered (tarnished and oxidized), light brown to dark orange to gray, more clay- and silt-size material; presence of altered chlorite, epidote and calcite, but these minerals not required. Primary igneous textures rarely preserved.
4	Weathered	Pyrite very altered (tarnished, oxidized, and pitted); Fe hydroxides and oxides present; light brown to yellow to orange; no calcite, chlorite, or epidote except possibly within center of rock fragments (but the absence of these minerals does not indicate this index), more clay-size material. Primary igneous textures obscured.
5	Highly weathered	No pyrite remaining; Fe hydroxides and oxides, shades of yellow and red typical; more clay minerals; no calcite, chlorite, or epidote (but the absence of these minerals does not indicate this index); angular to subround rock fragments

The SWI accounts for changes in color, texture, and mineralogy due to weathering, but it is based on field descriptions. Some problems with this weathering index are:

- It is subjective and based upon visual field visual characteristics of the soil matrix, particularly color, presence or absence of igneous textures, cementation, and presence or absence of pyrite, calcite, jarosite, and gypsum.
- This index does not always enable distinction between pre-mining supergene hydrothermal alteration and post-mining weathering.
- The index is developed from natural residual soil weathering profiles, which typically weathered differently from the acidic conditions within the Questa rock piles and,

therefore, this index may not adequately reflect the weathering conditions within the rock piles.

- This index refers mostly to the soil matrix; most rock fragments within the sample are not weathered except perhaps at the surface of the fragment and along cracks.
- The index is based primarily upon color and color could be indicative of other processes besides weathering intensity.
- This index was developed for the Questa rock piles and may not necessarily apply to other rock piles.
- Weathering in the Questa rock piles is an open not a closed system (i.e. water analysis indicates the loss of cations and anions due to oxidation).

APPENDIX 2. QUESTA MINERALOGICAL WEATHERING INDEX (QMWI)

The QMWI is a quantified index that ranges from 0-7 (0 is least weathered and 7 is most weathered) and accounts for changes in the pyrite-calcite-gypsum system that is the most predominant weathering system at Questa. The Questa Mineralogical Weathering Index is a measure of the short-term mineralogical changes with the rock pile material (McLemore et al., 2008c; DRA-16). The following flow chart describes the various classes of QMWI.