DRA-3a. DISTRIBUTION OF CLAY MINERALS AND CLAY SIZE MATERIAL IN THE QUESTA ROCK PILES AND ANALOG MATERIAL

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1. STATEMENT OF THE PROBLEM

What is the difference between clay minerals and clay sized material in the Questa rock piles and analog materials? How are the clay minerals and clay sized material distributed within the Questa rock piles and analog materials? Grain size distribution is an important physical characteristic of a soil and is different from the quantity of clay minerals within the Questa rock piles.

2. PREVIOUS WORK

The Questa rock piles contain material that is poorly sorted, ranging in size from large boulders to clay-sized particles. Clays are a confusing term that describes a specific group of minerals as well as a specific range in grain or particle size. Clay minerals are hydrous aluminium phyllosilicates, typically with variable amounts of iron, magnesium, alkali elements, and other elements. Clay minerals are fundamentally built of tetrahedral sheets and octahedral sheets. Geologists and soil scientists usually consider clay size material to occur at a particle size of <2 μm (clays being finer than silts), sedimentologists typically use <4-5 μm, and colloid chemists use <1 μm. Geotechnical engineers distinguish between silts and clays based on the plasticity properties of the soil, as measured by the Atterberg Limits of the soil. In this report, clay sized material refers to material that is less than 0.063 mm and includes clay minerals as well as other minerals that are less than 0.063 mm in size.

Mitchell and Soga (2005, p. 94) provide a discussion on the dominating influence of the clay phase on soil behavior. They conclude that "only a maximum of about one-third of the soil solids need to be clay in order to dominate the behavior by preventing direct interparticle contact of the granular particles". If the rock-pile material contains approximately 30% by weight of clay-sized material in the soil matrix of the rock piles, then there will be a significant change in the shear strength parameters of the rock-pile materials compared to the strength that would exist were the non-clay size material and rock fragments the only materials present.

Donahue et al. (2007, 2008, 2009) discuss the origins of the clay minerals from the Goathill North (GHN) rock pile (DRA-3). PetraScience Consultants Inc. (2002) identified clay minerals in 32 samples from the mine site using short wave infrared spectral analyses. URS Corporation (2003) determined the clay mineral composition expected to precipitate from the dissolution of feldspars based on rinse-water chemistry of mine rock-pile materials. Lueth (2008) presents a survey of the literature and concludes that the clays found at Questa are hydrothermal in origin.

3. TECHNICAL APPROACH

Selected samples were analyzed for total clay mineralogy using X-ray diffraction (SOP 29, Hall, 2004; Moore and Reynolds, 1987, 1997) and electron microprobe techniques (SOP 26); quantitative clay mineralogy was subsequently determined by the modified ModAn method (McLemore et al., 2009). Although, two methods of particle size distribution analyses were performed (wet and dry sieving, SOP 33, DRA-41), only the results from the dry sieving are reported here. No scalping was performed on the samples in the field other than removing very large rock fragments that could not be placed in the 5 gallon buckets. The minimum mass of a sample used for particle size analysis was related to the maximum particle size present in the bucket. Table 1 shows different size particles and the corresponding minimum mass of sample necessary to perform the test (U.S. Army Corps of Engineers, 1970).

TABLE 1. The minimum specimen weight required for particle size analysis based on the size of the largest particle in the sample (U.S. Army Corps of Engineers, 1970).

Nominal diameter of the largest particle inches (mm)	Approximate minimum mass of the sample (g)
3 (76.2)	6000
2 (50.8)	4000
1 (25.4)	2000
½ (12.7)	1000
0.18 (4.75)	200
0.079 (2)	100

4. CONCEPTUAL MODEL(S)

Grain size distribution is an important physical characteristic of a soil and is different from the quantity of clay minerals within the Questa rock piles. Hydrothermal clay minerals actually replace primary and secondary minerals within the rock fragments comprising the rock-pile material and these replacement clays are not reflected in the grain size distribution and therefore does not affect the friction angle obtained from direct shear tests. The gradation curve and the percentage of fines control the shear strength and compressibility of soil. The hydraulic conductivity of granular soils can be related to D_{10}. It also is unclear how much cementation of fines to coarse particles and "clumping" is present in the rock-pile materials and their variability within the rock piles. The differences in the fines from the particle size distribution between wet and dry sieving relates to the behavior of the rock-pile materials (DRA-41). However, the wet sieving results do not represent the behavior of the rock pile materials as there is cementation of fines to coarse particles and clumping of fines throughout the rock piles. Unless there is a major change to the geohydrological regime in the piles, e.g. large zones of saturated flow, the cementation and clumping will not be impacted. It can be argued that wet sieving results in the "true" particle size distribution of the material. However, in the rock piles the fines are cemented to the coarse particles or are present in clumps. The rock pile material therefore will behave differently from the "true" particle size distribution and dry sieving may result in a better representation of the in situ rock-pile material behavior.

5. STATUS OF COMPONENT INVESTIGATION

There is no evidence for selective release and migration after deposition in the rock piles of clay-sized or clay-mineral fines to produce continuous zones of clay minerals. There are lenses of clay material with finite lateral extensions (less than 1 m) that were observed near the surface of rock piles that were due to deposition of hydrothermal clays during mining.

Clay minerals present in both Questa rock piles and natural analogs are fully consistent in terms of their crystallography and detailed chemistry (including the oxygen-isotope chemistry of the solid phases) with formation under hydrothermal conditions (DRA-3). The empirical petrographic and geochemical results are consistent with the thermodynamic expectations derived from the solution chemistry and the geochemical modeling of the bulk hydrogeochemical evolution of the rock piles. It is a central finding of the QRPWASP study that there is no evidence of formation of new clay minerals even in the old (tens of thousands to more than one million year-old) local natural analogs.

The majority of the clay minerals are as replacements of other sand-size minerals (Fig. 1). Therefore the total amount of clay minerals is quite different from the total clay size material (Appendix 1). Particle size distribution analysis indicates that most of the Questa rock-pile and analog materials contains less than 20% clay-sized material. This clay-sized material consists of clay minerals, quartz, feldspar, and other minerals that are less than 0.063 mm in size. However, mineralogically there is as much as 60% clay minerals (mostly as illite and chlorite) in the Questa materials.

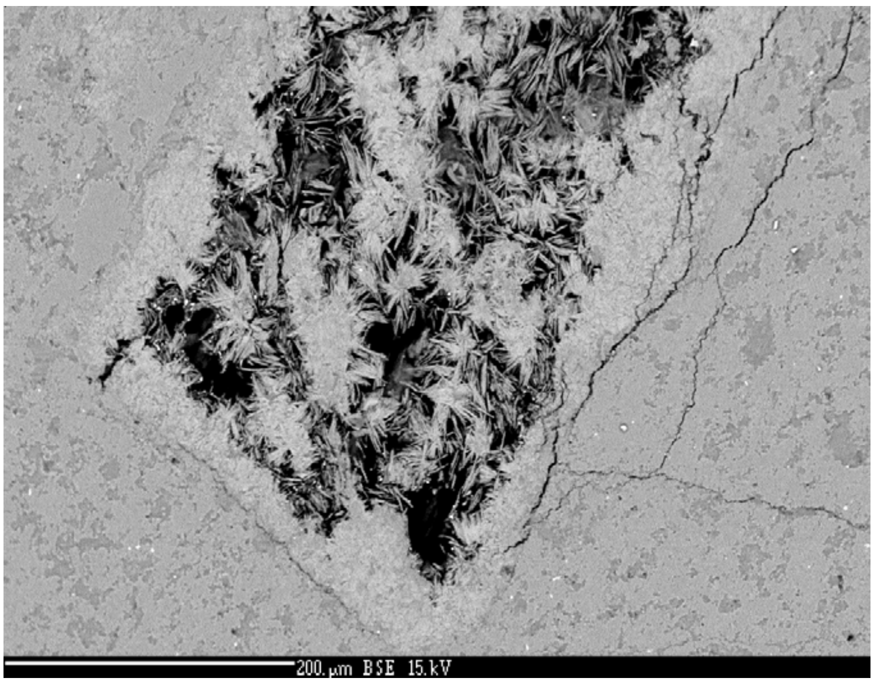

FIGURE 1. Clay minerals (mostly sericite) replacing feldspar phenocryst in QSP-altered rhyolite (Amalia Tuff; photo PIT-VCV-0004-30-01). This sample is an unweathered drill core sample of the ore body in situ before mining and has a slake durability index of 88.9%, point load index of 1.8 MPa, and total clay content of 24% (21% illite, 1% kaolinite, 1% chlorite, 1% smectite; DRA-3).

6. RELIABILITY ANALYSIS

Some of the technical and data uncertainties 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 clay mineral groups (illite, chlorite, smectite, kaolinite, mixed layered clays) are determined in this study.
- The differences in the fines from the grain size distribution between wet and dry sieving relates to the behavior of the rock-pile materials. It can be argued that wet sieving results in the "true" particle size distribution of the material. However, in the

rock piles the fines are cemented to the coarse particles or are present in clumps. The rock-pile material therefore will behave differently from the "true" particle size distribution and dry sieving may result in a better representation of the in situ rock-pile material behavior.

7. CONCLUSIONS OF THE COMPONENT

Particle size distribution analysis indicates that most of the Questa rock-pile and analog materials contains less than 20% clay-sized material. This clay-sized material consists of clay minerals, quartz, feldspar, apatite, calcite, jarosite, gypsum, and other minerals that are less than 0.063 mm in size. However, mineralogically there is as much as 60% total clay minerals (mostly as illite and chlorite) in the Questa materials. Clay minerals present in both rock piles and natural analogs are consistent in terms of their crystallography and detailed chemistry (including the oxygen-isotope chemistry of the solid phases) with formation under hydrothermal conditions (DRA-3). The clay minerals in the Questa rock-pile material are in the rock fragments as replacements of primary igneous minerals and the groundmass that were formed during hydrothermal alteration, not as free clay-mineral zones, and this clay would not be expected to affect shear strength now or in the future (Fig. 1). Despite the presence of the clay minerals partially replacing the phenocrysts and groundmass, these rock fragments are strong as determined from point load and slake durability tests (DRA-46).

8. REFERENCES CITED

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9. TECHNICAL APPENDICES

APPENDIX 1. Descriptive statistics and histograms of clay-size fraction and total clay minerals for Questa materials.

TABLE A1. Descriptive statistics for clay-size fraction (%) and total clay minerals (%). Clay-size was determined by hydrometer after dry sieving the sample. Clay minerals were determined by the modified MoDan method (McLemore et al., 2008) after standard clay mineral analysis were performed.

Type of sample	Total clay minerals Mean %	Total clay minerals Standard deviation	Total clay minerals Minimum %	Total clay minerals Maximum %	Total clay minerals No. of samples
All Questa rock pile and analog materials	24.7	10.4	0	60	688
Alteration scars	34.3	11.2	15	60	63
Colluvium	37.5	8.2	23	51	27
Questa rock piles	23.0	7.6	6	48	448
Rocks and soils	22.3	14.1	0	57.4	131

Type of sample	Clay-size fraction Mean %	Clay-size fraction Standard deviation	Clay-size fraction Minimum %	Clay-size fraction Maximum %	Clay-size fraction No. of samples
All Questa rock pile and analog materials	3.4	3.4	0	17.1	140
Alteration scars	1.7	1.1	0.3	3.6	14
Colluvium	7.0	5.5	0	15.5	15
Questa rock piles	2.3	1.4	0	6.3	82
Rocks and soils	5.6	4.8	0	17.1	27

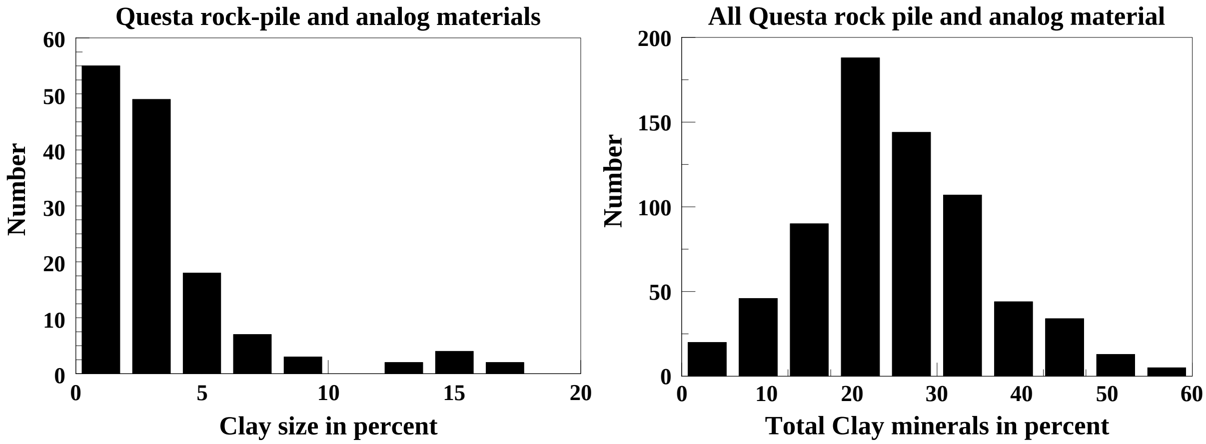

FIGURE A1. Clay size fraction (%, no=140) verses total clay mineralogy (%, no=688) for all Questa rock pile and analog materials.

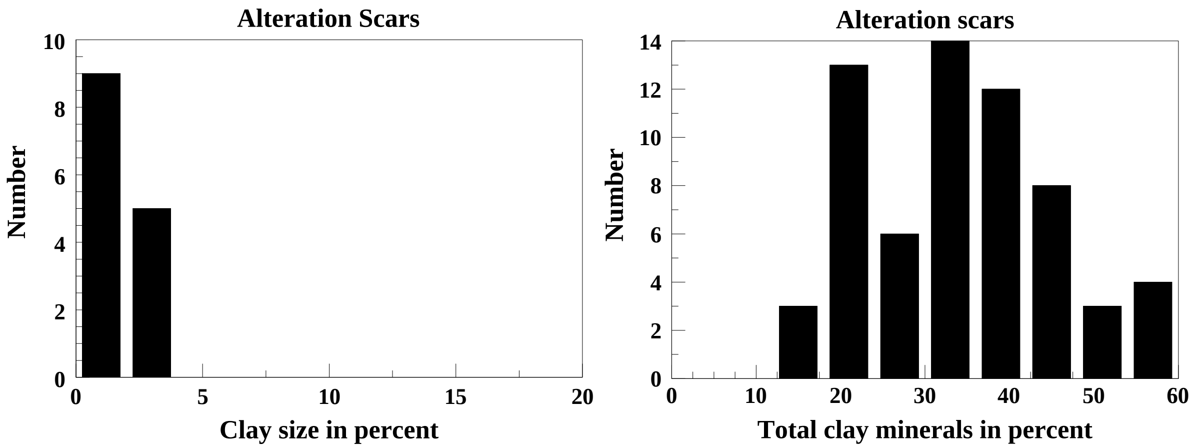

FIGURE A2. Clay size fraction (%, no=14) verses total clay mineralogy (%, no=63) for all Questa alteration scar samples.

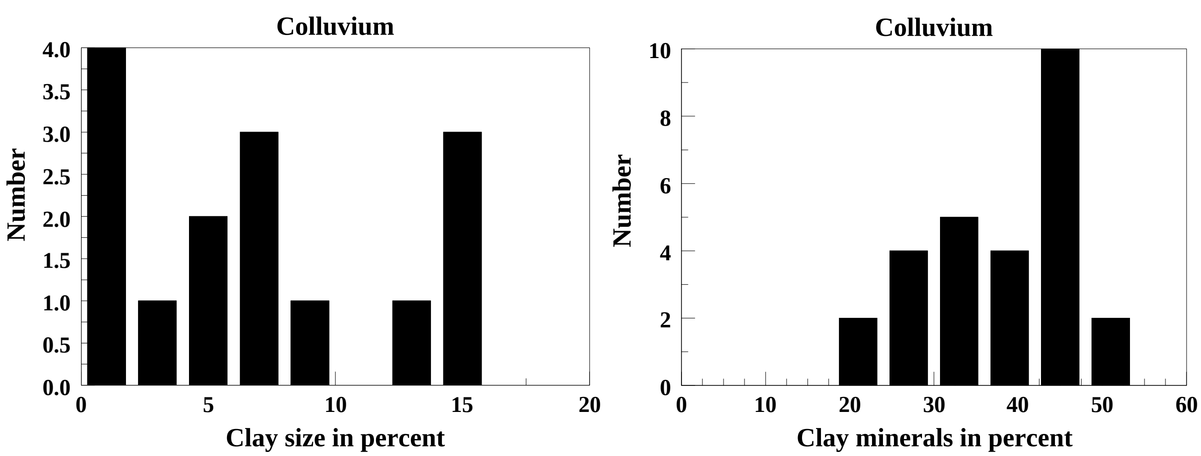

FIGURE A3. Clay size fraction (%, no=15) verses total clay mineralogy (%, no=27) for all Questa colluvium samples.

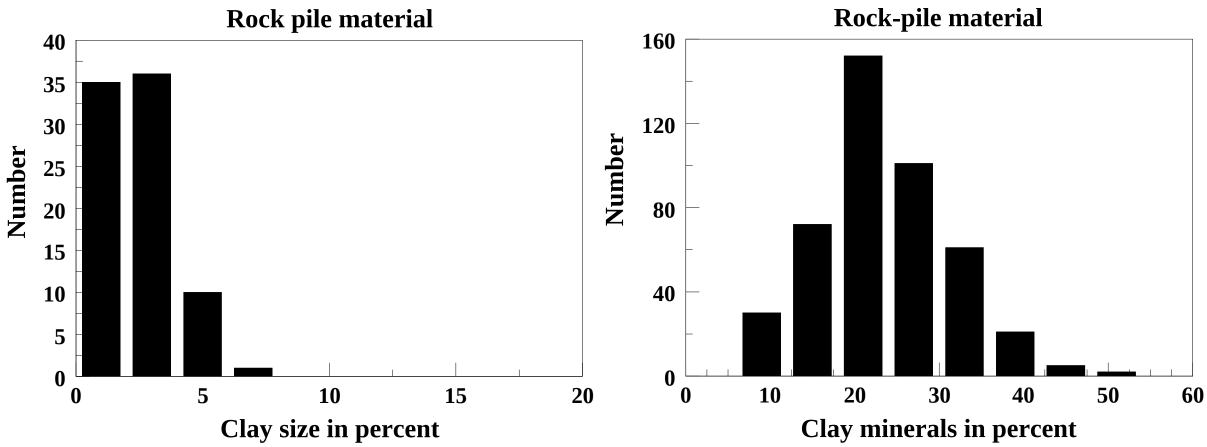

FIGURE A4. Clay size fraction (%, no=82) verses total clay mineralogy (%, no=228) for all Questa rock-pile samples.

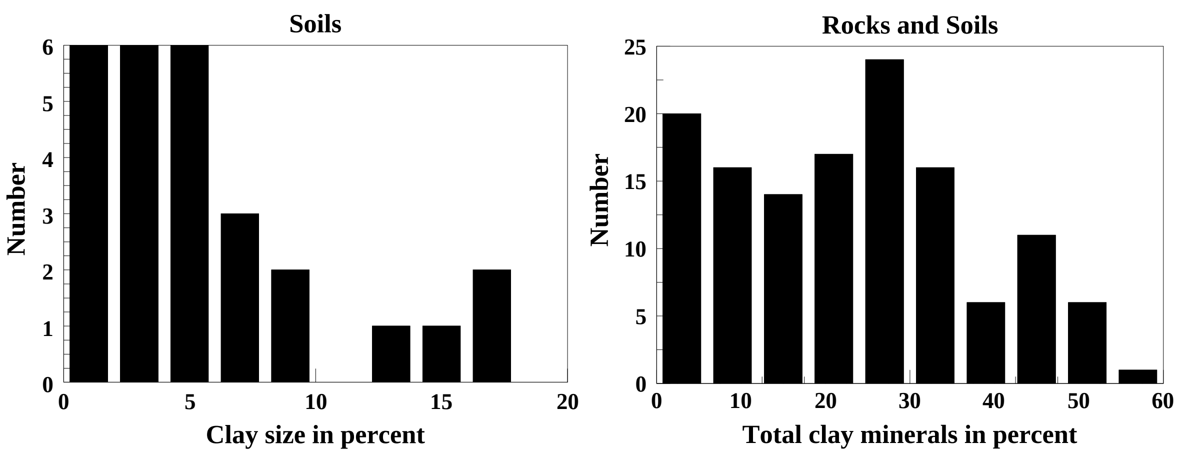

FIGURE A5. Clay size fraction (%, no=27) verses total clay mineralogy (%, no=131) for all Questa alteration scar samples.

APPENDIX 2. Statistical analysis between types of samples

Hypothesis 1. The amount of clay minerals in the Questa rock piles is different from the amount of clay minerals in the colluvium samples.

Data. Data are results obtained from NMIMT sampling and testing on Questa rock piles and colluvium 2004-2007.

Approach. Histograms (Appendix 1) indicate that the data are not approximately normally distributed, therefore the Mann-Whitney Rank Sum Test was selected, which assesses the samples in terms of median, not mean. The tests were calculated using the SigmaStat@ software.

Results. The results are summarized in Table B1.

TABLE B1. Results for the Mann-Whitney Rank Sum Test between clay mineralogy (%) in colluvium and rock-pile samples.

Group	N	Missing	Median	25%	75 %
colluvium	27	0	40.0	31.25	44.5
Rock piles	449	1	22.0	18.0	28.0

T = 11232.000 n(small)= 27 n(big)= 448 (P = <0.001)

Conclusion. The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = <0.001) between the amount of total clay minerals in the colluvium and rock-pile samples.

Hypothesis 2. The amount of clay minerals in the Questa rock piles is different from the amount of clay minerals in the alteration scar samples.

Data. Data are results obtained from NMIMT sampling and testing on Questa rock piles and colluvium 2004-2007.

Approach. Histograms (Appendix 1) indicate that the data are not approximately normally distributed, therefore the Mann-Whitney Rank Sum Test was selected, which assesses the samples in terms of median, not mean. The tests were calculated using the SigmaStat@ software.

Results. The results are summarized in Table B2.

TABLE B2. Results for the Mann-Whitney Rank Sum Test between clay mineralogy (%) in alteration scar and rock-pile samples.

Group	N	Missing	Median	25%	75 %
alteration scars	63	0	34.0	23.95	41.6
Rock piles	449	1	22.0	18.0	28.0

T = 24431.000 n(small)= 63 n(big)= 448 (P = <0.001)

Conclusion. The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = <0.001) between the amount of total clay minerals in the alteration scar and rock-pile samples.