DRA 20. NATURAL ALTERATION SCARS AS AN ANALOG FOR FUTURE WEATHERING OF ROCK PILES

G. Graf, V. Lueth, A. Campbell, April 17, 2007; revised April 28, 2008, December 1, 2008 (reviewed by V.T. McLemore)

1. STATEMENT OF THE PROBLEM

What are the weathering products of natural alteration scars that have undergone protracted periods of subareal exposure? Future shear strength and pore pressure are proposed to be dependent on weathering but the extent of weathering in the piles is limited by their short exposure history.

2. PREVIOUS WORK

- Ludington et al. (2004), USGS Straight Creek Scar Study
- Meyer and Leonardson (1990), Alteration scar paper
- Campbell and Lueth (2008), Stable isotope characterization of scar and rock pile materials
- Lueth et al. (2006), Phase 1 geochronological study of alteration scars
- Nordstrom et al. (2005), USGS Surface and ground-water baseline study

3. TECHNICAL APPROACH

Detailed mineralogical, geochemical, and isotopic study of three weathered profiles in alteration scars document mineralogical and physical changes in a residual weathering environment (DRA-19). Scar materials were selected to be petrologically similar to those in the rock piles; one profile in intrusive and two in andesite (DRA-27). The profiles represent progressive weathering from residual soil down to bedrock. These profiles are broadly constrained by age determinations that allow us to calibrate mineralogic changes due to sulfide and silicate weathering upward through each profile (DRA-18) . Stable isotopes can be used to document the weathering or hydrothermal origin of sulfates and clay minerals (DRA-17).

4. CONCEPTUAL MODEL

In pyrite-bearing silicate rocks, weathering can be divided into two distinct geochemical systems: 1. pyrite-weathering reactions, 2. silicate-weathering reactions. Surface- and ground-waters contain significant amounts of dissolved Al, Si, Ca, and SO_4 suggesting significant dissolution of silicate and sulfide phases from the alteration scars.

5. STATUS OF COMPONENT INVESTIGATION

- Soil weathering profiles in rocks similar to the rock piles have been identified, sampled, analyzed and interpreted (Figure 1, DRA-19, and Graf , 2008).

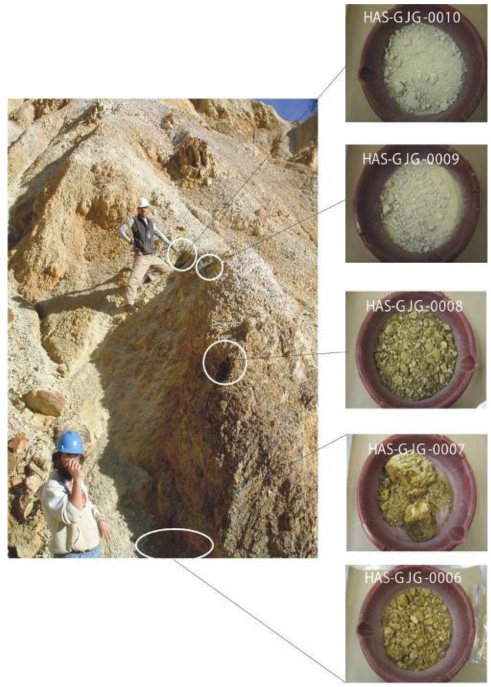

Figure 1. Hansen weathering profile.

- Grain sizes decrease upward in the selected weathered profiles, as a function of physical weathering, however superimposed on this trend are effects induced by secondary cementation and hydrothermal alteration (Fig. 1 and Fig. 18 Graf, 2008, p.58)

- Isotopic, chemical, and textural studies documented mineralogical changes in the sulfide weathering system (authigenic gypsum forming from pyrite) in the rock piles and alteration scars.
    - In general pyrite decreases upward in the profiles. Exceptions are associated with more intense hydrothermal alteration (QSP zones). Sulfate mineral iron oxide abundances vary within the profiles (Figure 2).
    - In general, sulfide:sulfate decrease upward in the profiles (Figure 2).
    - Acid-base accounting documents greater net acid producing potential at the base of each profile. Paste pH values are consistently low (2-3) throughout the profiles (Fig. 2).
    - Sulfur and oxygen isotopes indicate all analyzed sulfates are supergene in origin (Fig. 3)

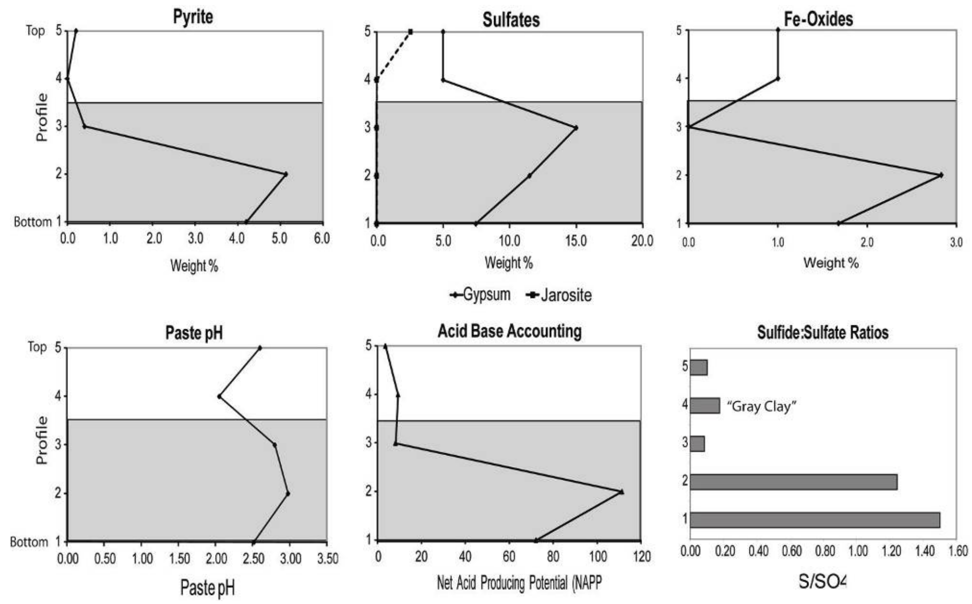

Figure 2. Geochemical and mineralogical changes associated with sulfide weathering in the Hansen alteration scar profile. Gray shades = QSP overprinting propylitic, White shades = intense QSP

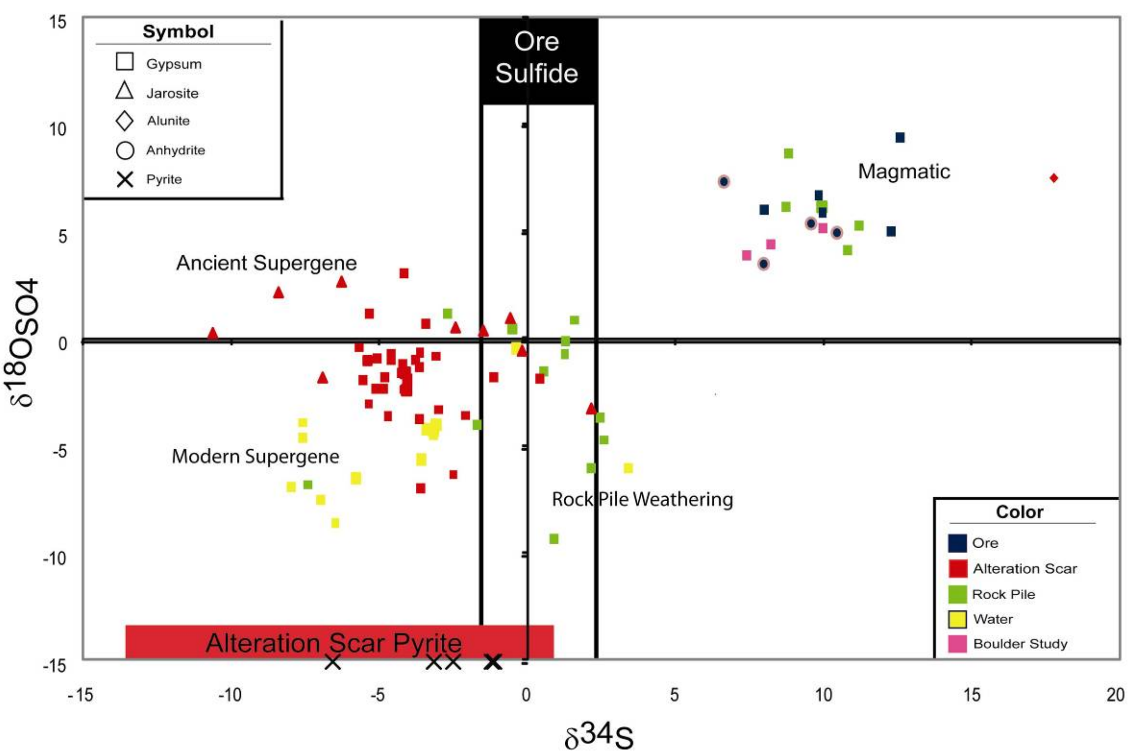

Figure 3. $\delta^{34}S$ and $\delta^{18}O_{SO4}$ diagram of sulfates and sulfides analyzed.

- Isotopic, chemical, and textural studies documented that mineralogical changes in the silicate system in the rock piles and alteration scars are predominantly due to hydrothermal alteration , not weathering.
  - Clay minerals increase and feldspar concentrations decrease upward in the profiles (Fig. 4). This relationship holds for both coarse (e.g. clasts) and fine-grained portions of single bulk samples.

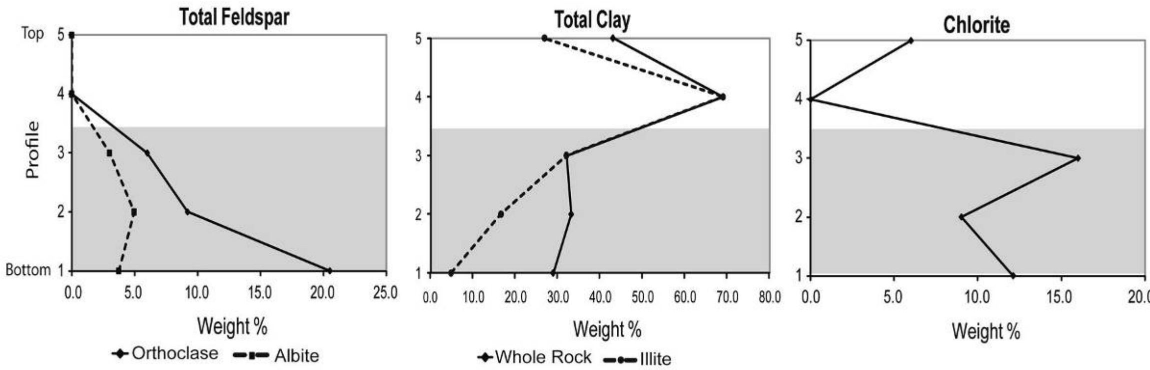

Figure 4. Silicate mineralogical changes in the Hansen alteration scar profile. Gray shades = QSP overprinting propylitic, White shades = intense QSP.

  - All clay-rich portions of the profiles are the product of hydrothermal alteration, not weathering. Stable isotope analysis indicates the clays minerals have a hydrothermal origin (Fig. 5). Silicate mineral variations within the profiles dominantly represent "alteration profiles," not weathering.

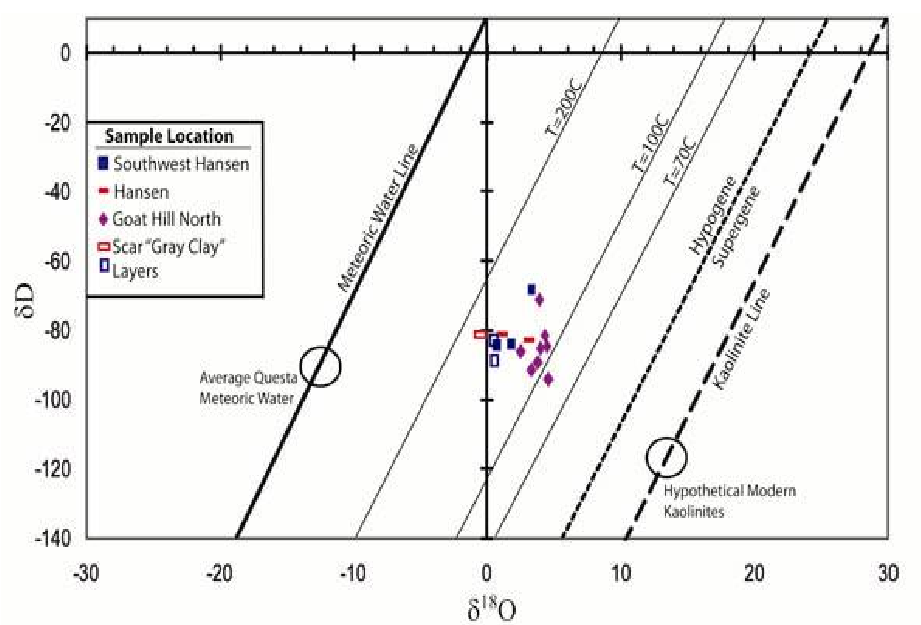

Figure 5. $\delta^{18}O$ vs. δD diagram of Questa clays. Note that all clays analyzed plot in the hydrothermal clay field.

- Chemical variations, utilizing the isocon method of Grant (1982) with respect to the least weathered rock (base of the profile) best identify alteration types (Fig. 6). Some variations may indicate dissolution of silicate minerals, especially in coarse to fine comparisons (Fig. 7).

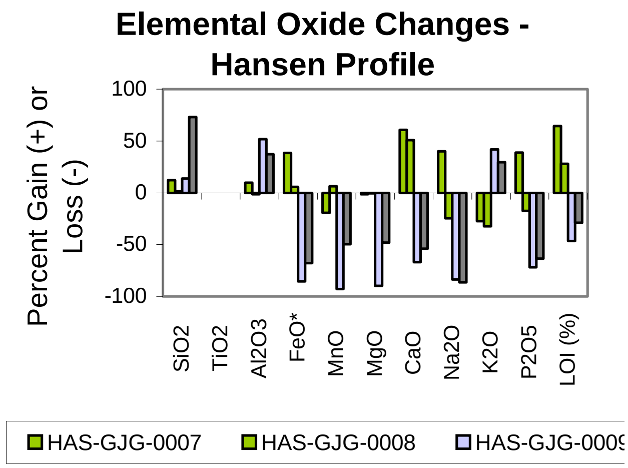

Figure 6. Chemical variation diagrams of the Hansen alteration scar profile using the isocon method. This method uses constant TiO_2 and percent gains and/or losses are relative to the least weathered sample (bottom of profile). Green bars indicate changes due to propylitic alteration; gray bars are predominantly QSP alteration effects (Graf, 2008).

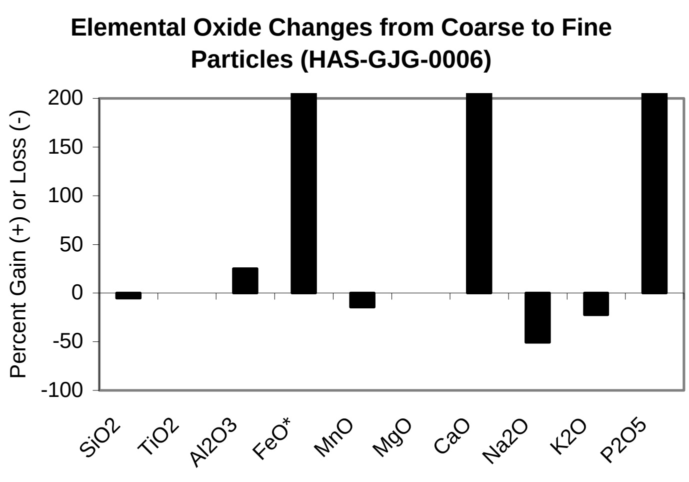

Figure 7. Chemical variation diagrams using the isocon method for coarse to fine particles in the same sample. Method uses constant TiO_2 and percent gains and/or losses relative to the least weathered sample (coarse clasts). Note the predominant changes can be related to the pyrite-calcite weathering system (e.g. Fe (pyrite), Ca (calcite). Some possible dissolution of silicate phases may be indicated by the reduction of Na and K Graf, 2008).

- Weathering products within the scars and rock piles (McLemore, et al., 2008) are mineralogically similar (DRA 27).

6. RELIABILITY ANALYSIS

- **Technical and Data Uncertainties:**

  - The weathering environment in the alteration scar profiles is different than those in the rock piles. Scars profiles are typically finer grained, armored by secondary sulfates, lack stratification, and experience more frequent wetting events throughout their profile (from precipitation) than the rock piles. These conditions may influence the rate of weathering in each environment.

  - Silicate weathering is dominated by dissolution as suggested by scar effluent chemistry. Lack of volume data does not allow for the determination of direct evidence for silicate dissolution in the alteration scars. The open system behavior of the system with respect to sulfate and iron oxides could also make volume determinations ambiguous.

  - Mineralogical analyses by two independent means (QXRD and Petrography/MODAN) were only accomplished on one profile.

- **Reliability:**

  - The weathering processes the produced the scar profiles operated over time spans on the scale of 100,000 years or more (Lueth et al., 2008; Samuels, 2008). These weathering processes produced relatively little change in silicate mineralogy although sulfide mineralogy has changed significantly (Fig. 2).

- **Uncertainties:**

  - Correlation of weathering in the scar profiles to those in the rock piles may present some uncertainties with respect to rates of weathering but the mineralogical end products would be the same (given similar rock types, climate, etc.). Whether weathering rates would be faster in the rock piles compared to scar profiles has not been evaluated.

7. CURRENT CONCLUSION OF THE COMPONENT

This study determined the types and amounts of minerals that will form or dissolve during weathering of pyrite-bearing silicate rocks over significant time periods (> 10,000 years).

- Oxidation (i.e. weathering) of sulfide produces sulfates and iron oxides both of which are potential cementing agents.
- There is evidence for the dissolution of silicates that may indicate a loss of volume.

- Distribution of gypsum in different portions of the profile (e.g. gypsum cemented zones, Fig. 2) suggests partially open-system behavior in the scar environment diminishing the robustness of sulfide:sulfate as a weathering index.
- The lack of authigenic silicate minerals and elevated concentrations of silicate-derived elements in the effluent water chemistry suggests open system behavior for silicate weathering.
- Time scales required to produce the weathering products identified in the alteration scar profiles are longer than those considered for the rock pile study (10,000 + years in scars vs. 100 to 1000 years, in rock piles).

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9. TECHNICAL APPENDICES

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