

# PRELIMINARY STATUS REPORT ON MOLYCORP GOATHILL NORTH TRENCHES, QUESTA, NEW MEXICO<sup>1</sup>

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**Abstract:** Rarely do rock pile characterization methods allow for examination and sampling of the undisturbed interior of large rock piles in-situ. The regrading of the Goathill North (GHN) rock pile at the Molycorp Questa mine, New Mexico provided a unique opportunity to examine and sample the undisturbed, interior of a large rock pile through the construction of trenches cut into the rock pile as earth-moving progressed. Weekly during the regrading of the GHN rock pile, contractors excavated a trench to allow for sampling of rock pile material. Trenches typically had four benches, which were 1.5 m wide and did not exceed 1.2 m in height, to give an overall slope of 1.4 horizontal to 1.0 vertical within the trench. Each trench extended for a length sufficient to explore site conditions, maintain the regraded 2:1 slope, and ensure personnel safety.

Once excavated, trench walls and benches were surveyed using a differential global positioning system. For every trench, maps and logs of each bench were created to describe the different “mine soil” units, including the thickness, dip and extent of the units. Units were defined based on color, grain size, stratigraphic position, and other physical properties that could be determined in the field. Units were correlated between benches and to both sides of each trench, and several units were correlated downward through the series of successively excavated trenches.

The field sampling crew began sampling within each of the identified units after the unit boundaries were identified and mapped. The following *in situ* measurements were taken along either the horizontal or vertical surfaces of each exposed bench and along the base of the trench: sand cone (density), tensiometer (matric suction), gravimetric moisture content, grain size, infiltration, and nuclear gauge measurements (density, moisture content). Gravimetric water content samples were collected at the locations selected for the measurement of matric suction and infiltration tests. Samples were collected from each defined unit for geochemical, geotechnical (including shear box tests, slake durability tests), biological, and electron microprobe analyses. Channel sampling for pyrite reserve modeling was performed in short 1.5-m long horizontal slots using a rock hammer to chip material to be placed into a sample bag. Additional material from selected layers was collected for potential weathering-cell tests in the future. Typically, paste pH increases with distance from the outer, oxidized zone (west) towards the interior, unoxidized zone (east) of the GHN rock pile.

Additional Key Words: mineral weathering, acid drainage, characterization of rock piles, stability

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## **Introduction**

### **Purpose**

Geologic, mineralogical, geochemical, geotechnical, and hydrologic characterization of mine rock piles with depth is important (Dawson, 1994; Shaw et al., 2002) to characterize pre-mining background conditions (Briggs et al., 2003), to characterize and predict stability and erosion (Dawson, 1994; URS Corporation, 2000), to predict acid-rock drainage (McLemore et al., 2004b), to properly dispose of and manage mine overburden (Dawson, 1994), and to develop mine closure plans (URS Corporation, 2000; Wels et al., 2002). Most site characterizations of rock piles are based upon drilling of the rock piles (Robertson GeoConsultants, Inc. 2000a, b; URS Corporation, 2000), shallow surface test pits (URS Corporation, 2000), or composite surface sampling (Smith et al., 2000a, b; Monroe and McLemore, 1999, 2000; Briggs et al., 2003; Wildeman, 2003). Rarely do these methods of site characterization allow for examination, mapping, and sampling of the undisturbed, interior of large rock piles *in-situ*. Examination of the interior of two mine rock piles during removal was described by Fines et al. (2003) and Tran (et al., 2004) who revealed complex dipping layers within the rock piles. Most other studies of mine rock piles involve drilling, surface test pits, and modeling.

The regrading of the Goathill North (GHN) rock pile at the MolyCorp Questa mine, New Mexico provided a unique opportunity to examine, map, sample, and model the undisturbed, interior of a large mine rock pile through the construction of trenches cut into the rock pile as regrading progressed. The purpose of this report is to describe the mapping and sampling procedures and preliminary results of trenching within the undisturbed, interior of the GHN rock pile. Geologic mapping of the GHN rock pile using surface mapping, trench mapping, and correlations with drill holes is important to provide a stratigraphic and structural framework for the sampling and modeling of the rock pile. The geologic mapping techniques employed in this study differ from most studies because of the construction of wide trenches with four benches downward through the rock pile as regrading progressed. Modeling of the rock pile will be presented in future reports.

### **Description of site**

The Questa molybdenum mine is located on the western slope of the Taos Range of the Sangre de Cristo Mountains, Taos County, northern New Mexico (Fig. 1). The mine is on southward facing slopes and is bounded on the south by Red River and on the north by the mountain divides (Fig. 2). The geology and mining history of the area is complex and described by others (Carpenter, 1968; Clark, 1968; Lipman and Reed, 1989; Meyer and Leonardson, 1990; Czamanske et al., 1990; Roberts et al., 1990; Meyer, 1991; Meyer and Foland, 1991; Robertson GeoConsultants, Inc. 2000a, b). Lithologies likewise are diverse, ranging from metamorphic rocks to volcanic rocks to granites to shales, limestones, and sandstones.

The mine began production in 1919 from underground workings. Open-pit removal of overburden began in 1964; ore production began in 1965 and ended in 1981, when approximately 73.5 million metric tons of ore with an average grade of 0.185% MoS<sub>2</sub> had been processed (Schilling, 1960, 1990; Ross et al., 2002; McLemore and Mullen, 2004). In 1982, underground mining resumed. During the open-pit period of mining, approximately 317.5 million metric tons of overburden rock were stripped and deposited onto mountain slopes and into tributary valleys forming the rock piles examined in this study (URS Corporation, 2000). The elevation of these rock

piles ranges from 2301 to 3020 m. The current mine is an underground, molybdenum disulfide (“moly” or molybdenite) mine that uses block caving mining methods to extract ore.

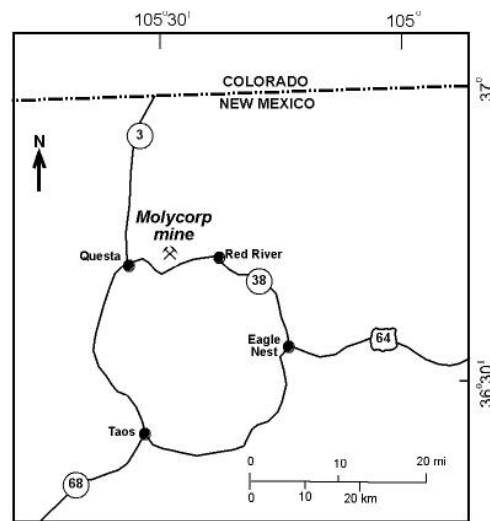


Figure 1. Location of Molycorp Questa mine, northern Taos County, New Mexico.



Figure 2. GHN before regrading, looking east. Solid line indicates approximate location of trenches in summer-fall 2004; dashed line indicates the boundary between the stable and unstable portions of the rock pile.

The GHN rock pile is one of nine rock piles created during open-pit mining and contains approximately 10.6 million metric tons of overburden material with slopes similar to the original topography. GHN is divided into two areas: a stable area and an unstable area (Fig. 2). MolyCorp is stabilizing this rock pile by pushing material off the top portion of both areas to the bottom of the pile (Norwest Corporation, 2003). This regrading is intended to decrease slope, reduce load, and create a buttress. During the progressive down-cutting of the top of GHN (regarding), trenches were constructed to examine, map, and sample the undisturbed, internal geology of the rock pile.

The Questa rock piles were constructed primarily by haul truck end dumping in high, single lifts, which involves the dumping of rock over the edge of the hill slopes (URS Corporation, 2000). End dumping generally results in the segregation of materials with the finer-grained material at the top and coarser-grained material at the base. The resulting layers are locally at or near the angle of repose and subparallel to the original slope angle. End dumping results in five zones of segregation (Fig. 3; Nichols, 1987):

1. upper traffic surface
2. top of the rock pile where fines were more concentrated than coarser material
3. intermediate zone where material is well graded and evenly distributed
4. toe of the rock pile where mostly coarse material is concentrated
5. basal rubble zone of cobbles and boulders along the contact between the rock pile and the original bedrock or colluvium.

#### Investigation approach

The purpose of the MolyCorp study is to develop a model to assess and identify conditions and processes occurring in existing rock piles, especially related to the physical, chemical and mineralogical composition of, and weathering of, rock pile materials at the MolyCorp Questa mine. **A key component of this investigation is to estimate what changes in these conditions and processes, if any, have occurred since construction of the rock piles, and thereby to extrapolate what future changes might occur in these conditions and processes.** As a result, it should be possible to obtain the information necessary and sufficient to provide a scientific basis for determining the effect of weathering on the geotechnical behavior of the rock piles as a function of time and degree of weathering. The current approach tests the geotechnical behavior of samples across a range of weathering states that are defined by petrology, mineralogy, and chemistry for samples collected from the existing rock piles and elsewhere in the Questa-Red River area.

It should be noted that chemical weathering can have at least two, qualitatively different influences on slope stability. First, dissolution of feldspars, biotite and other silicate minerals by acidic fluids generated by oxidation of sulfide minerals, can result in reduction of grain sizes and generation of clay minerals, both of which have the potential to adversely affect rock-pile stability. Secondly, secondary chemical precipitates, such as iron oxyhydroxides formed subsequent to pyrite oxidation (as well as other reaction products) can cement soil grains. In this case, the additional cohesion due to formation of such cemented aggregates has the potential to increase rock pile stability. Generation of water-soluble cements (e.g., soluble hydroxysulfates that can form during evaporation in shallow soils) has the potential to increase cohesion during the dry season, but not effectively cement the particles during runoff and snowmelt seasons. Both dissolution and cementation processes could be operational at the Questa site and have been

observed at many mining sites (Richie, 1994; Munroe and McLemore, 1999; Munroe et al., 2000; Fines et al. 2003; Tran et al., 2003).

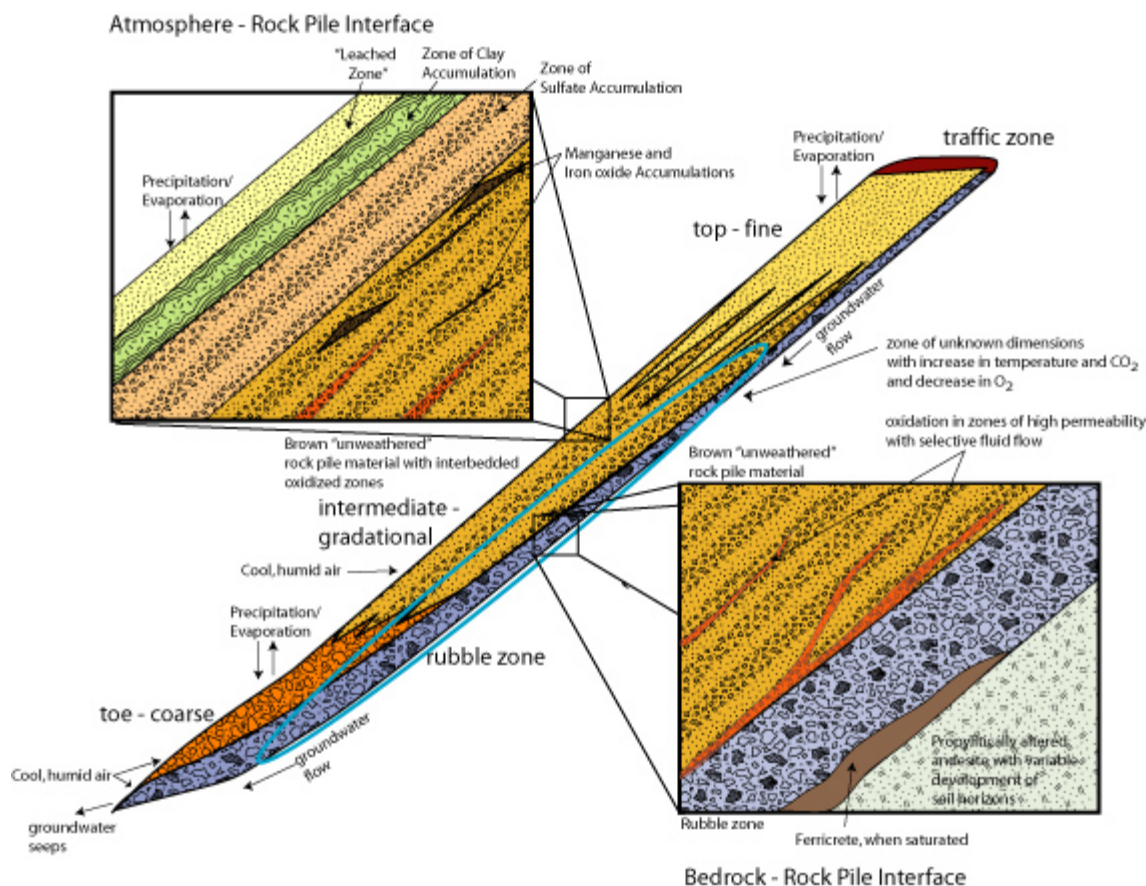


Figure 3. Conceptual model of the Questa rock piles (from field studies at GHN and from Nichols, 1987). The groundwater indicated in the figure at the toe is from perched zones not from the local ground water table. See text below for explanation of zones and processes.

Thus the first step in assessing the long-term stability of the Questa mine rock piles is to utilize new and existing data from a complete physical, mineralogical, chemical, and geotechnical characterization of samples of earth materials contained in approximately 317.5 million metric tons of rock (present in nine rock piles at the site) utilizing new and existing data. The regrading of the GHN rock pile provided a unique opportunity to examine, sample, and model the undisturbed, interior of a large mine rock pile. This report addresses the mapping, sampling, and preliminary laboratory results of trenching activities on GHN rock pile in 2004-2005. Future reports will address other aspects of the study.

## **PROCEDURES IN MAPPING AND DESCRIBING TRENCHES**

### **Mapping procedures**

Standard geologic mapping techniques were used in this study (Lahee, 1961). Surface units on the rock piles were identified visually, using Wagner and Harrington (1995) as a guide. Wagner and Harrington (1995) conducted vegetation and soil surveys of all of the rock piles at the Questa mine. They divided the mine site into subunits because of the wide range of site conditions. Each subunit was defined by surface particle size, substrate color, aspect, and overburden pile. The GHN rock pile surface consisted of nine subunits (Table 1).

Table 1. Descriptions of GHN surface subunits as defined by Wagner and Harrington (1995).  
TDS is total dissolved solids.

Molycorp Subunit or zone	Geologic Unit in this report	Vertical projection Acreage	Stability	Average slope angle (degrees)	Rooting zone pH	Rooting zone TDS ppm	Rooting zone Conductivity uS
15	A	4.31	Loose boulders eroding out	39	2.7	1640	2900
14	B	4.64	Boulders eroding out of face	39	2.1	>2000	4300
14A	H	0.55		39			
16	C	4.52	Tension cracks, appearance of past movement	39	3.2	240	410
17	D	0.94	Terraced/slumped appearance	39	2.8	940	1700
18	D	11.93	Open tension cracks, boulders raveling	27	2.7	330	530
19	E	4.89	Boulders weathering out of face	33	2.6	570	1020
18A	D	0.63	Outwash/slide debris	14			
18B	D	1.57	Outwash/slide debris	14			

Each unit on the surface and in the subsurface was examined and described, including the dip, strike, and true thickness. Longitudinal sections were made of each bench on the GHN rock pile. Each unit boundary was mapped, using the combined air photograph topographic map provided by Molycorp (Fig. 4). The project geologic mapping, work plans and procedures describe the mapping and analysis procedures that were conducted for the study and are available upon request. Surface geologic mapping was conducted in May-July 2004 by mapping the road and bench cuts along the GHN rock pile and using air photographs. Eight geologic units were differentiated, described and sampled. The units were differentiated mostly on the basis of color, grain size, composition, stratigraphic position, and other soil properties. Remote sensing results by Spectral International, Inc. (unpublished) and Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) data (Livo and Clark, 2002), and Wagner and Harrington (1995) were incorporated where appropriate.



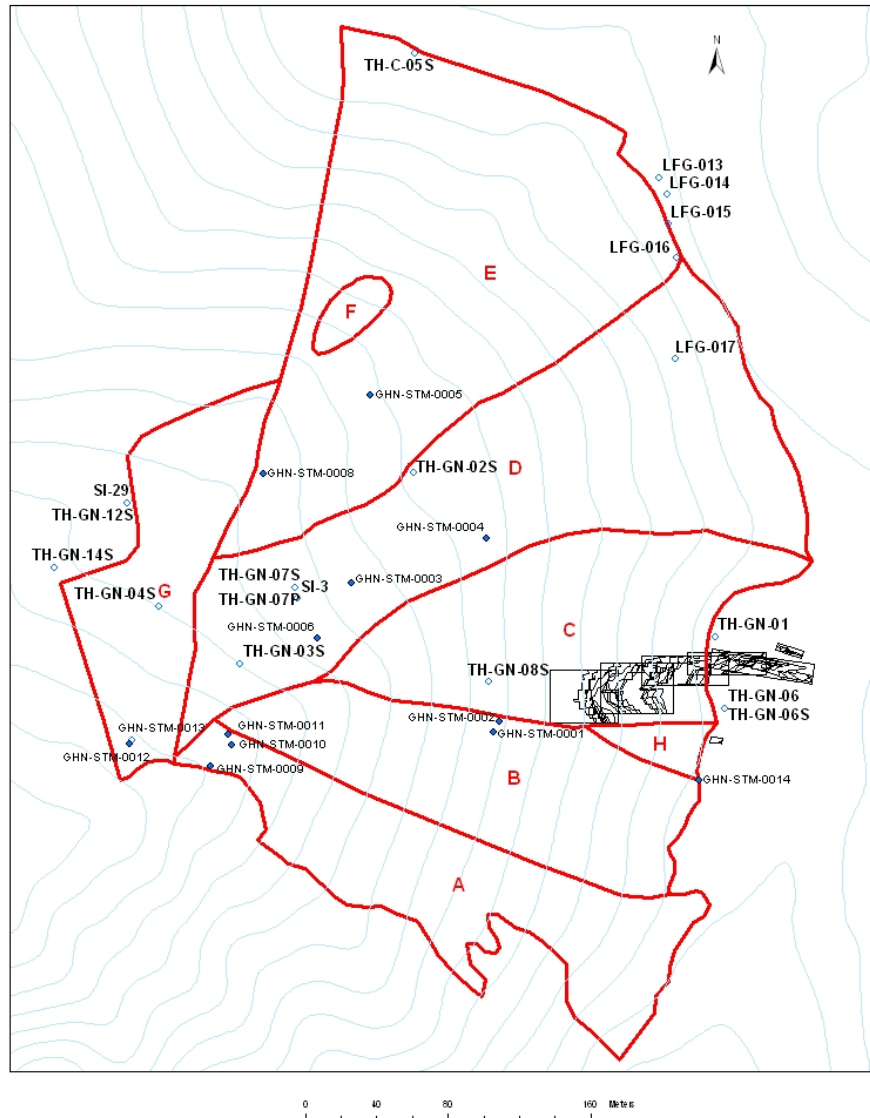


Figure 4. Geologic map of GHN rock pile before regrading showing locations of drill holes, samples, and trenches. Open circles indicate drill holes, closed circles indicate sample locations, solid lines outline geologic maps of trenches and section shown in Figure 8.

Trenches specifically were located on GHN rock pile based upon

1. surface geologic mapping
2. location of prior drill holes in the rock pile
3. geophysical surveys (van Dam et al., 2005)
4. Molycorp reconstruction plans (Norwest Corporation, 2003).

Specific location and construction data for each trench is in the Molycorp Database (McLemore et al., 2004a). Two trenches were constructed in the stable portion of GHN in June 2004 to

1. train personnel in sampling and mapping procedures
2. test mapping and sampling procedures
3. confirm the geophysical studies
4. provide a base line of the structure and stratigraphy
5. aid in locating additional trenches.

Starting in September 2004, five additional trenches were constructed during the regrading of the stable portion of GHN rock pile. In February-April 2005, 12 trenches were constructed in the unstable portion of the rock pile. Each trench was surveyed, mapped and sampled.

Trenches typically had four benches, which were approximately 1.5 m wide and did not exceed 1.2 m in height, to give an overall slope of 1.4 horizontal to 1.0 vertical within the trench (Fig. 5). Each trench was extended for a length sufficient to explore site conditions, maintain the regraded 2:1 slope, and ensure personnel safety. Several trenches in the unstable portion of GHN consisted of only one or two benches.

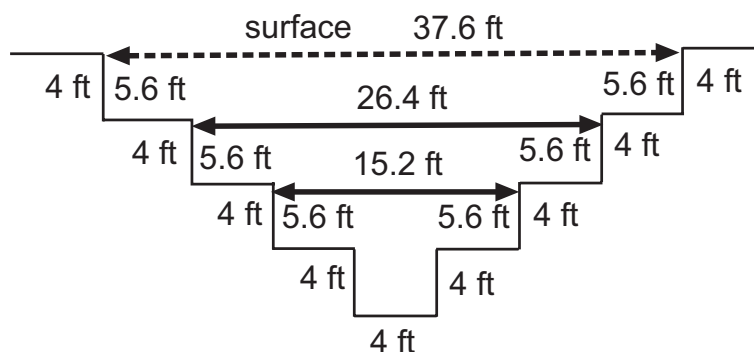


Figure 5. Sketch of a typical trench for the GHN rock pile.

Trench walls and benches were surveyed using a differential global positioning system (Fig. 6). For every trench, geologic maps (Fig. 7) of each trench and logs of each bench were created to describe the different subsurface mine soil units, including the thickness, dip, stratigraphic position, and spatial extent of the units. Subsurface units were defined based on grain size, color, stratigraphic position, and other physical properties that could be determined in the field. Units were correlated between benches and on each side of a trench, and several units were correlated downward through the series of five successively excavated trenches. Eighteen units were differentiated, described and sampled.

#### Sampling procedures

Sampling procedures, descriptions, and analytical analyses typically used for soils were employed because the material in the rock piles appears to be soil-like (i.e. mine soils) (URS Corporation, 2000; Haering et al., 2004; Stormont and Farfan, 2005). *Mine soils* are soils that



form from organic matter, mineral soil materials, sediments, and rocks redistributed by humans during or after mining process (Galbraith, 2004).

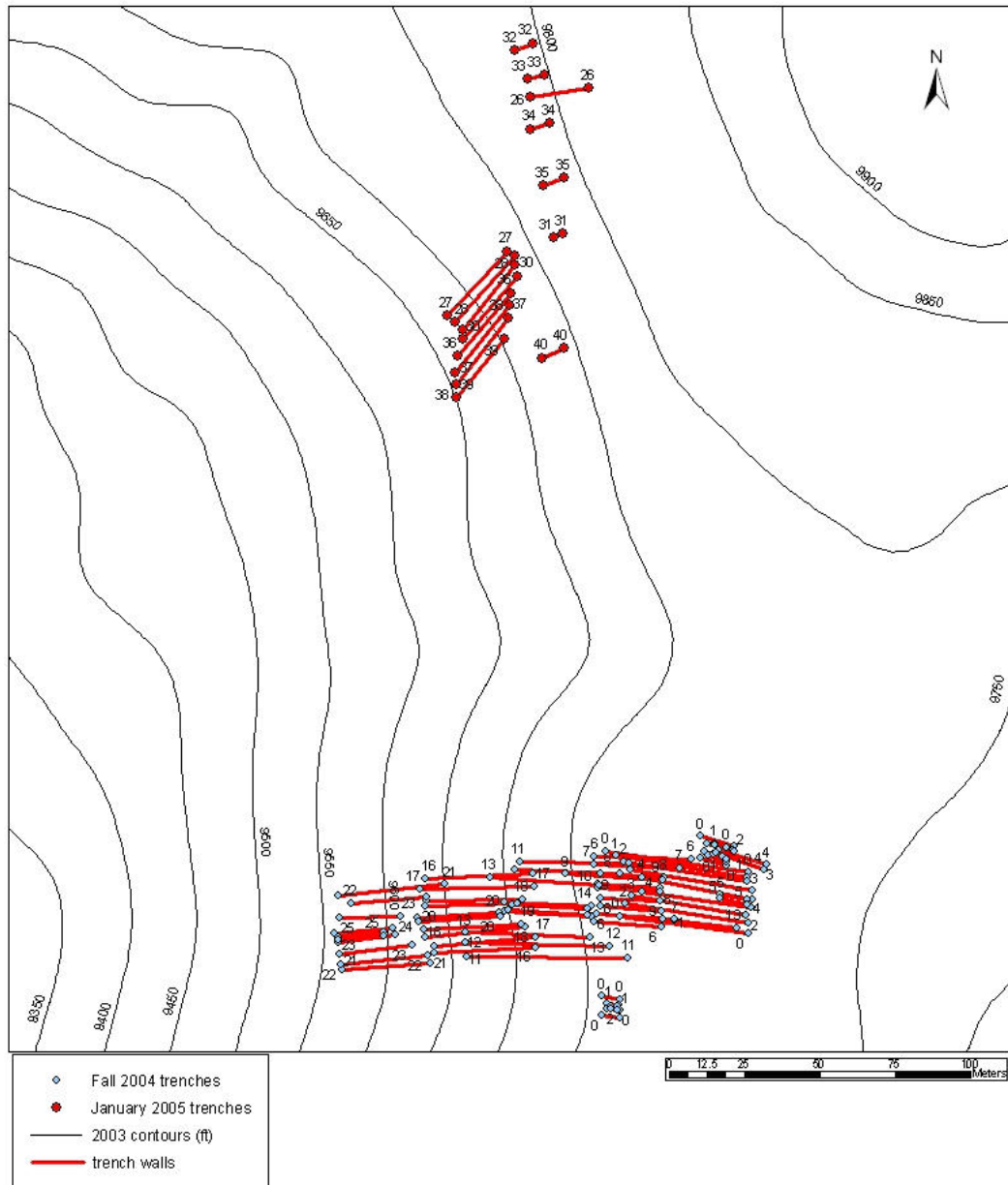


Figure 6. Map showing GHN trench locations. Red lines show trench walls. Circles show surveyed trench corner points. Black lines show elevation contours.

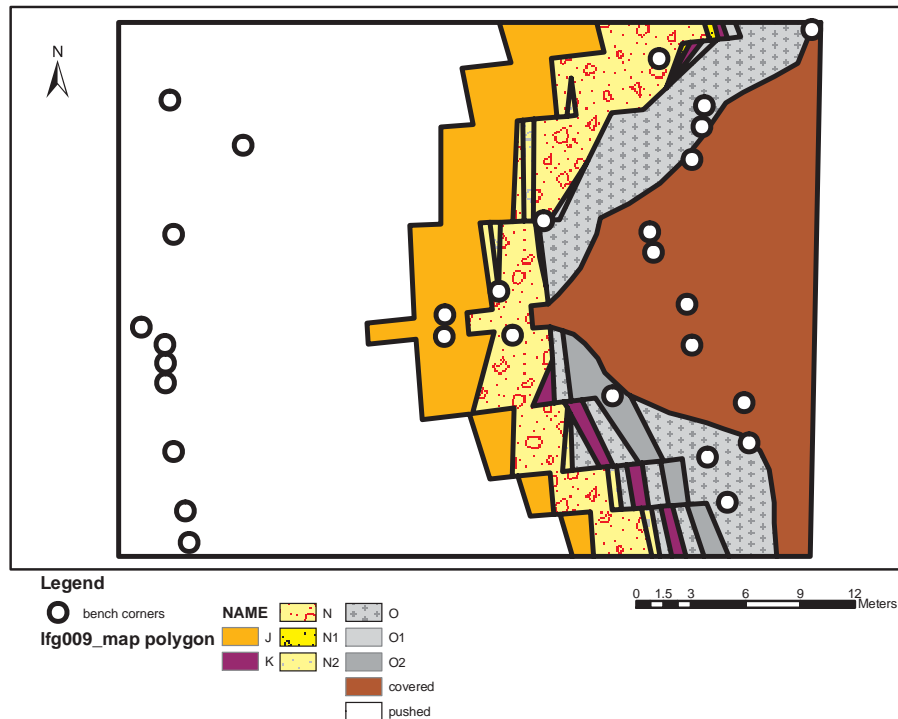


Figure 7. Geologic map of trench LFG-009, stable portion of GHN.

Fourteen samples were collected during the surface mapping with at least one sample collected from each unit. The samples were generally composites taken by digging a horizontal channel along a portion of the unit of interest. A pick and shovel were used for sampling in accordance with the project procedures that outlined sampling methods and for gravitational moisture content of approximately less than 2 cm material. A handheld GPS was used to determine the elevation and UTM coordinates of the sample locations. Ambient temperature and humidity were measured with a handheld weather station. Table 2 is a list of the samples and their locations.

During GHN regrading, the field team sampled within each of the identified subsurface unit after the unit boundaries were identified. The following *in situ* measurements were taken along either the horizontal or vertical surfaces of each exposed bench and along the base of the trench, according to ASTM standards (specific procedures are available upon request): sand cone (density), tensiometer (matric suction), moisture content, grain size, infiltration tests, and nuclear gauge measurements (density, moisture content, compaction). Gravimetric water content samples of approximately less than 2 cm diameter material also were collected at the same locations selected for the measurement of *in situ* matric suction and infiltration tests of undisturbed areas within the trenches. Team members collected samples from each defined unit for geochemical, geotechnical (including shear box tests), biological, isotopic composition, and electron microprobe analyses. Channel sampling for pyrite reserve modeling was performed in maximum 1.5-m-long horizontal slots using a rock hammer to chip material from bench walls placed into a sample bag. Additional material from selected layers was collected for potential weathering-cell tests in the future.

Table 2. Description of surface samples and their locations defined in this study (ND = Not Determined). UTM coordinates are in NAD 27 and zone 13.

Sample ID	Unit	Elevation (ft)	UTM Easting (m) UTM Northing (m)	Location Description	Air Temp (°C)	Humidity (%)	Gravimetric Moisture Content (%)	Paste pH	Paste Conductivity mS/cm
GHN-STM-0001	B	9526	453586 4062104	Top Bench of GHN. Approximately 30 ft South of the end of bench road. From a rill 1ft 2in deep by 3ft wide. Rill bearing is N105 degrees E	ND	ND	ND	2.67	0.91
GHN-STM-0002	C	9537	453589 4062110	Goat Hill North Top bench, close to boundary between Units B and C	ND	ND	ND	3.50	0.09
GHN-STM-0003	D	9516	453506 4062188	Goat Hill North Top bench.	ND	ND	ND	2.87	0.18
GHN-STM-0004	E	9489	453582 4062213	Goat Hill North Top bench.	ND	ND	ND	2.70	2.08
GHN-STM-0005	F	9460	453517 4062293	Goat Hill North Top bench	ND	ND	ND	3.77	0.12
GHN-STM-0006	D	9383	453487 4062157	Goathill North 5 ft above road on 2nd bench from top.	24	38	5.45	6.60	0.07
GHN-STM-0007	E	9415	456468 4062202	Goathill North 5 ft above road on 2nd bench from top.	21	39	6.53	4.34	2.12
GHN-STM-0008	G	9367	453457 4062249	Goathill North 5 ft above road on 2nd bench from top.	26	37	3.82	4.27	0.46
GHN-STM-0009	A	9195	453427 4062085	Toe of GHN pile, 5 ft above arroyo. Arroyo had running water.	33	23	3.01	5.11	0.06
GHN-STM-0010	B	9210	453439 4062097	Toe of GHN pile, 5 ft above arroyo. Arroyo had running water.	30	20	2.39	3.90	1.12
GHN-STM-0011	E	9220	453437 4062103	Toe of GHN pile, 2 ft above arroyo. Arroyo had running water.	42	ND	18.59	3.92	2.82
GHN-STM-0012	E	9323	453382 4062098	4ft above bench, near hole TH-GH-09	40	13	6.67	4.38	0.42
GHN-STM-0013	E	9323	453382 4062098	Same location as GHN-STM-0012.	40	13	6.77	4.34	0.86
GHN-STM-0014	H	ND	453701 4062077	Top of GHN, near test pit LFG-0004.	28	ND	6.23	4.25	2.00

## **LABORATORY TESTING**

The laboratory tests performed on the samples thus far include gravimetric moisture content and paste pH, conductivity and TDS. The tests were performed at the Mineral Engineering Soils Laboratory and the Bureau of Geology Clay Laboratory both at New Mexico Tech using laboratory procedures established as part of the overall project procedures documentation.

## **DESCRIPTION OF GOATHILL NORTH UNITS**

### **Composition of rock piles based on composition of material removed from the open pit**

The lithologies mined from the open-pit deposit are grouped into five major rock types: rhyolite tuff (Amalia Tuff), andesite breccia, andesite (including latite and quartz latite), granitic porphyry, and aplite. Estimates of the proportions of various lithologies that were mined from the open-pit deposit are in Table 3. Other lithologies present in the open-pit deposit include volcanoclastic sandstone, shale, and rhyolite dikes and are typically included with the andesite breccia or andesite in Table 3. Field and laboratory analyses indicate that the GHN rock pile consists primarily of andesite and Amalia Tuff.

Table 3. Estimates of volume of each lithology mined from the open-pit deposit determined in this study using Molycorp cross sections. These are rough estimates of the volume of each lithology in the rock piles. Explanation of the lithologies and procedures are in McLemore (2005). QSP—quartz-sericite-pyrite alteration, prop—prophyllitic alteration.

Symbol	Lithology	Volume percent	Relative estimate of strength (1 strong, 3 weak)	Comments
Tdqpt-Trt	Amalia Tuff	10	1	Mostly QSP altered, no ore
Tanbx	Andesite breccia	14	3 2	50% QSP, 50% prop, no ore
Tanfp	Andesite (including latite and quartz latite)	46	3 2	50% QSP, 50% prop, some ore
Thfp	Christmas Tree porphyry	8	2	QSP altered, no ore, pyrite rich
Tpap	Aplite	22	1	Most of ore from this unit
TOTAL		100		

### **Description of surface geologic mapping units**

Eight geologic units were differentiated, described and sampled during the surface geologic mapping (Fig. 4). These units are surface units only and no age relationships can be determined. Units A, B, C, and H are found on the southern, stable portion of the rock pile where little or no movement has occurred. Units D, E, F, G are found on the northern, unstable portion of the rock pile, which has slumped at creep rates for the last 30 to 40 years down slope with total rock pile movement vectors of up to 100 ft or more (Fig. 2; Mike Ness, written communication, 4/28/05). The rock pile lies unconformably on colluvium, which overlies bedrock of andesite and Amalia

Tuff. Creep and sliding of the unstable portion of the GHN rock pile was being caused by gradual toe erosion and sliding of the colluvium unit, which forms the rock pile foundation.

Unit A is the southern-most surface unit of the stable part of the GHN rock pile and corresponds to subunit 15 of Wagner and Harrington (1995). This unit is light brown with distinct layers. Approximately 60% is covered with cobbles or larger sized rocks of mixed volcanic rocks with vegetation growing upon the surface. The unit is layered in some of the rills near the base. A sample of this unit had a paste pH of 5.11, paste conductivity of 0.06 mS/cm, and paste TDS of 0.03 g/L (Table 2).

Unit B is massive, light brown to gray to yellow brown on the surface, contains many crusts of soluble acid salts and corresponds to subunit 14 of Wagner and Harrington (1995). Approximately 65% is covered by cobbles or larger sized rocks. This unit consists of clayey sand with gravel and cobbles and is locally cohesive. Shallow rills (0.2-1 m deep) of finer grained material are cut into the surface. Some rills are filled with large boulders of quartz-sericite-pyrite (QSP) altered Amalia (70%) and andesite (30%). This unit forms part of the stable portion of the GHN rock pile. A sample of this unit had a paste pH of 2.67-3.9, paste conductivity of 0.91-1.12 mS/cm, and paste TDS of 0.46-0.56 g/L (Table 2).

Unit C consists of massive alternating zones of grayish brown to yellowish gray fine-grained materials (sand with cobbles and gravel) and boulders of Amalia (70%) and andesite (30%). This unit corresponds to subunit 16 of Wagner and Harrington (1995). Approximately 15% is covered by cobbles and boulders. The unit is locally cohesive and well cemented by clays and soluble minerals. The unit is part of the stable portion of the GHN rock pile. A sample of this unit had a paste pH of 3.5, paste conductivity of 0.096 mS/cm, and paste TDS of 0.043 g/L (Table 2).

Unit D consists of yellow-brown gravelly sand and differs from Unit C by a marked increase in cobbles and boulders of Amalia (80%) and andesite (20%). The unit corresponds to subunits 17, 18, 18A, and 18B of Wagner and Harrington (1995). Approximately 30-40% is covered by cobbles or larger sized rocks. The unit is part of the unstable part of the GHN rock pile. A sample of this unit had a paste pH of 2.87-6.6, paste conductivity of 0.07-0.18 mS/cm, and paste TDS of 0.03-0.8 g/L (Table 2).

Unit E consists of orange brown with patches of gray sandy clay with cobbles and boulders and corresponds to subunit 19 of Wagner and Harrington (1995). Approximately 15% is covered by cobbles or boulders. Amalia is the predominant lithology in this unit and consists of approximately 70 % moderate to strong QSP altered Amalia and 30% weakly altered Amalia. The unit is part of the unstable portion of the GHN rock pile. A sample of this unit had a paste pH of 3.92-4.38, paste conductivity of 0.42-2.82 mS/cm, and paste TDS of 0.21-4.41 g/L (Table 2).

Unit F is similar to Unit A and consists of dark brown, silty sand with some gravel. The unit is part of the unstable portion of the GHN rock pile. A sample of this unit had a paste pH of 3.77, paste conductivity of 0.12 mS/cm, and paste TDS of 0.08 g/L (Table 2).

Unit G consists of orange brown to yellow brown sandy gravel with some cobbles. It is part of the unstable portion of the GHN rock pile and also includes colluvium material. A sample of

this unit had a paste pH of 4.27, paste conductivity of 0.46 mS/cm, and paste TDS of 0.203 g/L (Table 2).

Unit H is a dark gray to red-brown V-shaped unit at the top of the GHN rock pile before reconstruction and corresponds to subunit 14A of Wagner and Harrington (1995). Approximately 80% is covered by cobbles or boulders. The unit contains oxidized orange zones and consists of poorly sorted, well graded, weakly cemented, gravel sand with some fine sand to fine sand with clay. Andesite is the predominant lithology. Trench LFG-0004 exposed this unit. The lower contact with the colluvium/bedrock was not exposed in the trench. The unit is part of the stable portion of the GHN rock pile. A sample of this unit had a paste pH of 4.25, paste conductivity of 2 mS/cm, and paste TDS of 1 g/L (Table 2).

#### Description of subsurface geologic mapping units (Trenches LFG-003-009)

During trench mapping, team members identified several consistently correlative units downward through approximately 61 vertical meters of mine soil material. Unit boundaries ranged from horizontal to vertical, but most dipped between 20 and 40° westward to northwestward. Section drawings and lateral measurements of unit boundaries provided data used to compile maps of each trench. Plan maps of individual trenches show a “v-shape” indicating the westward dipping character of the beds on each bench with an apparent offset between benches due to the vertical walls separating benches (Fig. 7). Locally, thin units pinched out or graded vertically and laterally. Unit boundaries have been projected onto an east-west cross-section to show the vertical extent of units within the rock pile (Fig. 9).

A zonation of the rock pile is illustrated in Figures 3, 8 and 9 (Phillips et al., 2005). Typically, the interior, unoxidized units (east, units K-W, excluding unit N) of the piles are uniformly light to orange-brown with visible pyrite and are interbedded with occasional yellow to gray zones of oxidation associated with little or no pyrite. The inner, unoxidized zone typically contains abundant calcite, chlorite, and clay minerals and accordingly, has high paste pH values and low acid generating potential. Apparently chemical reactions within the main portion of the pile are controlled by the availability of oxygen and water. The outer units (west, Units C, I, J) are oxidized with very little pyrite. The outer, oxidized units consist of highly leached and oxidized rock comprised mainly of quartz and secondary iron sulfates, with smectite and mixed layer illite-smectite. This zone is characterized by low paste pH, low acid neutralizing potential, and high acid generating potential. Extensive interchange of water and oxygen occurs in this zone, which enhances pyrite oxidation. Internal to the leached zone (J) is a zone of clay accumulation. The clays are predominantly illite and smectite with increasing chlorite toward the center of the pile. The origin of this clay accumulation is problematic and we have not yet determined whether the clays represent originally mined and dumped high-clay material, an accumulation of material washed into the pile from the upper zone, or if the clays represent a zone of authigenic clay formation. This unit is typically green to orange with moderate to low paste pH. In between the outer, oxidized and interior, unoxidized zone is an intermediate zone (Unit N) of light to dark brown material that is well cemented by clay. It contains local zones of bright orange to punky yellow oxidized sandy clay. Clays are dominated by smectite and chlorite. Proximal to the interface are zones of dark brown to black accumulation of iron or manganese oxide material that coats grains and clasts. This accumulation of iron and manganese oxides may represent a zone of reduction.



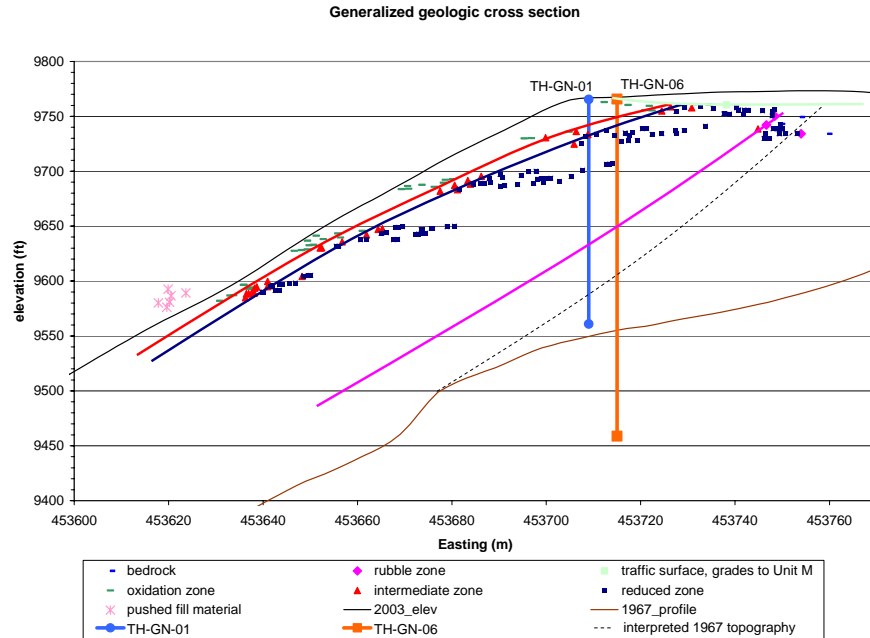


Figure 8. Generalized geologic cross-section showing pre- and post-surface mining topography, sample points from trench work, drill holes (TH-GH-01 and TH-GN-06) and boundaries between oxidized (green), intermediate (red), unoxidized (dark blue) and rubble zone (light green) as determined from field observations. Note that the dashed line represents a correction to the original 1967 topographic model for the base of the rock pile. This dashed line is based on field observations of colluvium and bedrock in Trench LFG-0003 at the top of GHN rock pile. Elsewhere in GHN rock pile, most drill holes and trenches did correlate well with the 1967 topographic model. However, in Trench LFG-0003 where the cross section goes through, the observation of the colluvium/bedrock within the trench indicates that in this area there could be a 50 m error in the 1967 topographic model that we do not see elsewhere in the rock pile. We are still addressing this problem.

Descriptions of the subsurface units identified in the trenches in the stable portion of GHN rock pile follows, generally from west to east, youngest to oldest. The descriptions combine geologic and engineering terms to assist in characterizing the units relative to slope stability. The majority of mine soil samples exhibit a clast-supported clay matrix. However, some samples contain abundant clay and are matrix supported. Pyrite, when present, ranges from cubic to rounded, but usually has somewhat rounded edges. Cementation in the rock piles varies from none to moderate, with local well-cemented layers. The samples increase in grain size with increase in depth into the rock pile, as illustrated in Fig. 3.

The traffic zone is at the very top of the rock pile and is orange brown to brown, disturbed unit of sandy gravel, which has been compacted and pushed on the top of the GHN rock pile.

Unit C represents the surface of the GHN rock pile and is described above.

Unit I in the oxidized zone consists of light-gray, poorly sorted, well graded clayey to sandy gravel, medium hard with weak cementation, and no plasticity. The matrix may be sandy clay with medium to high plasticity. The unit is less cemented and finer grained than the overlying unit C and contains mostly andesite.

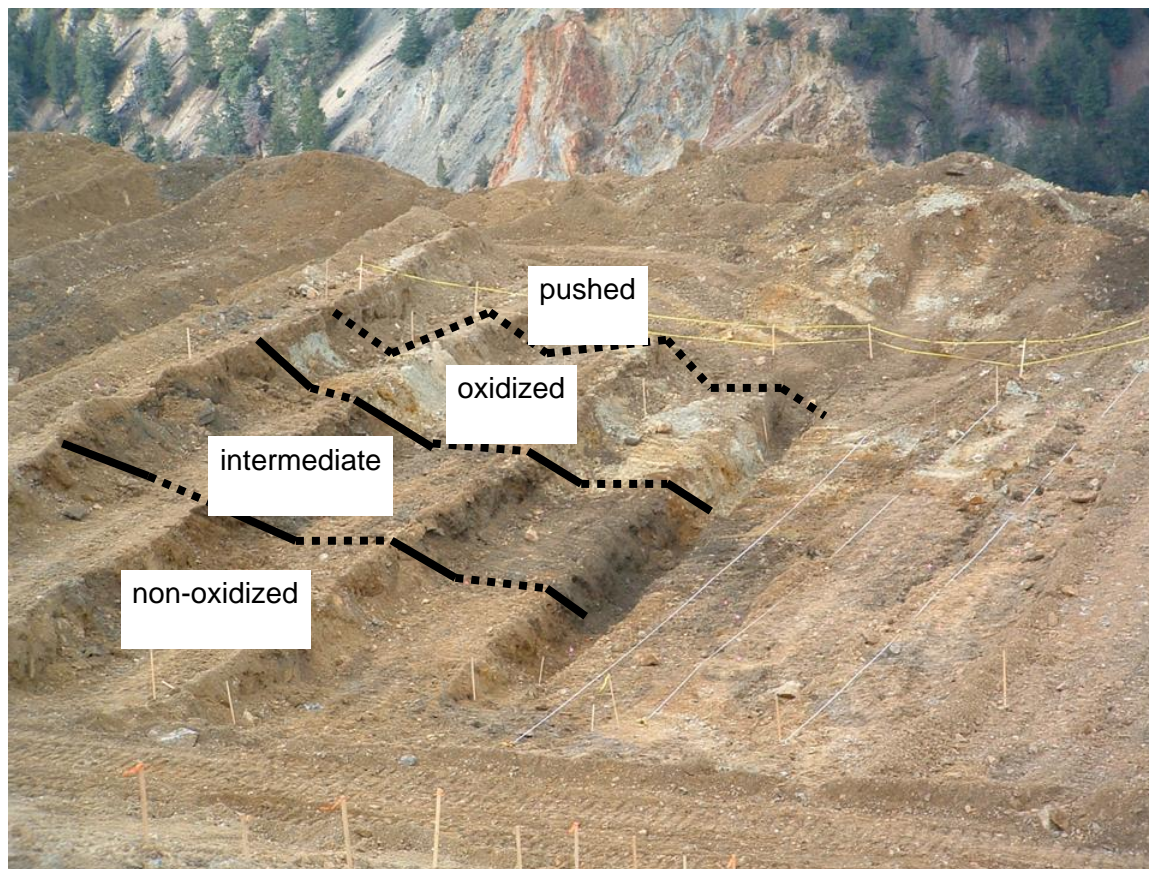


Figure 9. Southwestward view of zonation at outer margin of the GHN rock pile. White zone inside the yellow tape represents outer margin of original dumped pile (pushed material beyond the white zone). Color zones from outer zone to interior pile: Oxidized, leach zone—white to gray to yellow (Unit C, I); oxidized, sulfate accumulation—orange (Unit J); intermediate zone—dark brown (Unit N), internal, unoxidized zones—brown (Units K-W, excluding N). See conceptual model and cross-section, Figures 3, 8.

Unit J in the oxidized zone consists of dark orange-brown, poorly sorted, well graded, coarse gravel with clay matrix and weak cementation. The top of the unit locally is a bright orange oxidized layer, 2-4 inches thick and contains mostly andesite.

Unit N in the intermediate zone consists of light to dark brown moderately sorted, uniformly graded, moderately hard sandy clay with cobbles, with moderate to high plasticity and well cemented by clay. This unit contains zones of bright orange to punky yellow oxidized sandy

clay. On bench 12, the top of the unit consists of orange brown rocky layer with little matrix. The unit contains mostly andesite and Amalia Tuff.

Unit K in the unoxidized zone consists of purplish-brown gravelly sand with cobbles and is weakly cemented and very coarse. A distinctive feature is the dark purplish gray color. This unit has almost no clay. The cobble layer is locally overlain and underlain by finer gravelly sand layers and contacts are gradational. Unit K locally grades into Unit O and can not be distinguished from Unit O except by grain size and color. Unit K contains mostly andesite.

Unit L in the unoxidized zone consists of brown gray, poorly sorted, well graded gravelly sand with cobbles of mostly andesite.

Unit O in the unoxidized zone consists of brown, poorly sorted, sandy gravel matrix in coarse gravel and cobbles. Numerous coarse and fine layers at varying dips and thicknesses appear in the mass of the unit. The unit has cobbles and clay layers, is a very heterogeneous and deformed layer with numerous S-shaped clay lenses, and contains mostly andesite.

Unit M in the unoxidized zone consists of orange brown to brown, poorly sorted, well graded sandy gravel with boulders (up to 1 m diameter). Sandy gravel forms a matrix between boulders and cobbles. The fines are generally gritty. The unit contains both andesite and Amalia Tuff.

Unit P in the unoxidized zone consists of dark brown, poorly sorted, well graded, sandy gravel with medium hardness and no to weak cementation. The unit contains mostly andesite.

Unit Q in the unoxidized zone consists of steeply dipping dark brown, poorly sorted, well graded, sandy gravel with cobbles with medium hardness and no to low cementation. It contains mostly andesite.

Unit R in the unoxidized zone consists of orange gray, poorly sorted, well graded sandy gravel to gravel with cobbles with medium to weak cementation by clay. The unit contains mostly andesite.

Unit S in the unoxidized zone consists of dark gray, poorly sorted, well graded sandy silt with no cementation or plasticity. The unit contains mostly andesite.

Unit T in the unoxidized zone consists of dark gray, poorly sorted, well graded sandy gravel and contains mostly andesite.

Unit U in the unoxidized zone is a brown, poorly sorted well graded, sandy gravel with cobbles of mostly andesite.

Unit V in the unoxidized zone is a gray to brown gray poorly sorted, sandy gravel of mostly andesite.

Unit W in the unoxidized zone is olive gray clay zone seen in Trench LFG-0004 and could correlate to Unit S.

The basal, rubble zone consists of mostly orange brown, angular cobbles and large boulders (15 cm in diameter) of andesite and Amalia Tuff with little sand or clay.

In the unstable portion of GHN, significant structural differences were observed and documented compared to the stable portion of the rock pile. Units in the unstable portion show apparent deformation by folding as well as both synthetic and antithetic faulting. Faults and folds had similar orientations with measured fault planes striking 355° and 021° and a fold axis orientation of 350°. Complex deformation, winter weather, and time constraints prevented complete mapping within the unstable part of GHN.

The contact between the GHN rock pile and bedrock/colluvium has been examined at several places in the trenches at the top of the stable portion of GHN, trenches throughout the unstable portion of GHN, and at the toe of GHN. Samples were collected and are being analyzed. Preliminary observations indicate that the basal portion of the GHN rock pile consists of a cobble-supported rubble zone of gravel through boulder-sized material lying unconformably on top of either a dark gray to brown clayey soil developed on weathered andesite or a yellow to orange brown clay to sandy clay colluvium that is similar to the alteration scars. The rock pile material observed in trenches in the stable portion of GHN overlies yellow to orange brown acid weathered/oxidized soil developed on top of bedrock with jarosite, gypsum, blocky, moderate sorting, clay to pebble size material. It contains mostly andesite.

Preliminary results of paste pH, paste conductivity, and paste TDS are summarized in Tables 4 and 5. Gravimetric moisture contents range from 2 to 24% near the surface of the rock piles, but values measured in trenches within the GHN rock pile were typically between 6 and 20% (Table 6). Moisture contents as high as 25.5% are reported in previous studies (URS Corporation, 2000). The average paste pH from the GHN pile was 4.39. In previous studies, paste pH varies from 2.1 to 10, paste conductivity varies from 0.19 to 23,000 ms/cm, and paste TDS varies from 1.9 to 1700 ppm (URS Corporation, 2000). Typically, paste pH increases with distance from the outer, oxidized zone (west) towards the interior, unoxidized zone (east) of the GHN rock pile (Phillips, et al. 2005). Additional laboratory data and interpretations will be in future reports.

Table 4. Summary of paste tests results for GHN samples.

	Paste pH	Paste Conductivity ms/cm	Paste TDS g/L
Number of Samples	807	807	502
Average	4.39	2.27	1.22
Minimum	1.86	0.06	0.03
Maximum	9.79	12.35	4.41
Standard Deviation	1.59	1.45	0.78

Table 5. Summary of paste tests of samples by selected geologic unit.

Geologic Unit	average paste pH	average paste conductivity ms/cm	average paste TDS g/L
Oxidized, outer zone			
C	3.01	1.51	0.19
I	2.83	3.22	2.32
J	3.37	4.07	2.32
Intermediate zone			
N	3.34	3.34	2.00
Unoxidized, internal zone			
K	4.32	2.42	1.15
L	6.98	2.27	0.48
O	5.27	2.76	1.41
M	4.36	1.69	0.61
P	5.86	2.83	
Q	5.12	1.80	
R	6.04	1.61	0.79
S	6.17	2.24	1.52
T	3.95	1.49	
U	3.74	1.67	0.84
V	4.41	1.59	0.66
W	6.65	0.79	0.40
Basal rubble zone	3.43	1.65	0.83
Colluvium	3.29	3.24	1.63
Weathered bedrock	2.23	3.18	1.59

### **Summary**

Nineteen trenches were constructed in the GHN rock pile as it was being regraded in 2004-2005. Detailed geologic mapping and sampling indicated that geologic units could be distinguished and mapped in a rock pile. Units were defined based on grain size, color, stratigraphic position, and other physical properties that could be determined in the field. Units were correlated between benches and to both sides of each trench, and several units were correlated downward through the excavated trenches. Eighteen units were differentiated, described, and sampled. Typically, paste pH increases with distance from the outer, oxidized zone (west) towards the interior, unoxidized zone (east) of the GHN rock pile.

Table 6. Summary of moisture contents in percent of samples GHN from GHN by geologic unit.

Geologic Unit	Average	Maximum	Minimum	Number of samples
Oxidized, outer zone				
C	6.97	9.33	5.48	3
I	15.47	23.89	10.72	5
J	10.39	17.13	6.61	16
Intermediate zone				
N	13.13	17.25	9.6	17
Unoxidized, internal zone				
K	10.16	11.77	8.34	9
L	8.62			1
O	11.2	18.01	6.15	50
M	10.45	15.09	5.54	13
R	10.51	11.46	9.91	3
S	10.43	13.36	7.43	6
U	10.61	13.23	7.99	2
V	9.23	9.6	8.59	3
W	9	9.58	8.41	2
Basal rubble zone	11.23	18.49	7.05	11
Colluvium	13.55	20.78	3.89	10
Weathered bedrock	16.03	18.32	14.01	8

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