DRA-0. SAMPLE COLLECTION AND PREPARATION FOR LABORATORY ANALYSES

V.T. McLemore, December 31, 2008, revised March 24, 2009 (Mark Logsdon, George Robinson, Ariel Dickins, Nelia Dunbar, Art Rose reviewed)

1. STATEMENT OF PROBLEM

What is a sample? What types of samples were collected and why? Are the samples representative? How were the samples prepared for laboratory analyses? The samples and field data (including field observations and measurements) are the basic component of the data collection and interpretation, which ultimately leads to the project conclusions. Therefore, it is important to understand the spatial and geological context and to describe the types of samples collected, sample preparation, and sample analyses.

2. PREVIOUS WORK

A *sample* is a representative portion, subset, or fraction of a body of material representing a defined population (Koch and Link, 1971; Wellmer, 1989; Rollinson, 1993; Davis, 1998; Schreuder et al., 2004; Neuendorf et al., 2005; Downing, 2008). A sample is that portion of the population that is actually studied and used to characterize the population. Collecting a representative sample of rock-pile material can be difficult because of the compositional, spatial, and size heterogeneity of the material. It also is necessary to define the particle-size fraction of the sample required and analyzed, because of the immense size heterogeneity in many rock piles (Smith et al., 2000). The sampling process is defined in the project sampling plan and Standard Operating Procedures (SOPs, listed in Appendix 1), and is summarized below:

- Define the sample population
- Define the parameters to be measured
- Define the number of samples to be collected and where
- Define the sample collection method
- Define the quantity of sample collected
- Collect the sample according to the SOP
- Record field observations and sample description
- Review the sampling process.

The determination of total error of a measurement depends upon several parameters, including the sample error and analytical error (Rollinson, 1993; Schreuder et al., 2004). The sample error is the error that results from studying the collected sample instead of the entire population and depends upon completeness, comparability, and representativeness, as defined below:

- *Completeness*—the comparison between the amount of valid, or usable, data originally planned to collect, versus how much was collected
- *Comparability*—the extent to which data can be compared between sample locations or periods of time within a project, or between projects
- *Representativeness*—the extent to which samples actually depict the true condition or population being evaluated.

Sample error is the error caused by observing a sample instead of the whole population and typically is dependent upon the sample-to-sample variation and is controlled by collecting a sample of suitable size relative to the heterogeneity of the sampled material, as well as a sufficient number of samples to characterize the population (Wellmer, 1989).

Basically, all analytical measurements are incorrect at some level and are measured against an agreed upon standard of analysis. It is just a question of how large the errors are compared to an agreed upon standard of accuracy and if those errors are acceptable; these are typically define in the original sampling plan. Analytical error is the error that results from laboratory analysis, is typically reported by the laboratory, and is defined by precision and accuracy, as defined below:

- *Precision*—the degree of agreement among repeated measurements of the same characteristic and monitored by multiple analyses of many sample duplicates and internal standards. It can be determined by calculating the standard deviation, or relative percent difference, among samples taken from the same place at the same time (i.e. duplicates and triplicates, Fig. 1).
- *Accuracy*—measures how close the results are to a *true* or accepted value and can be determined by analyzing certified reference standards as unknown samples and comparing with known certified values (Fig. 1).

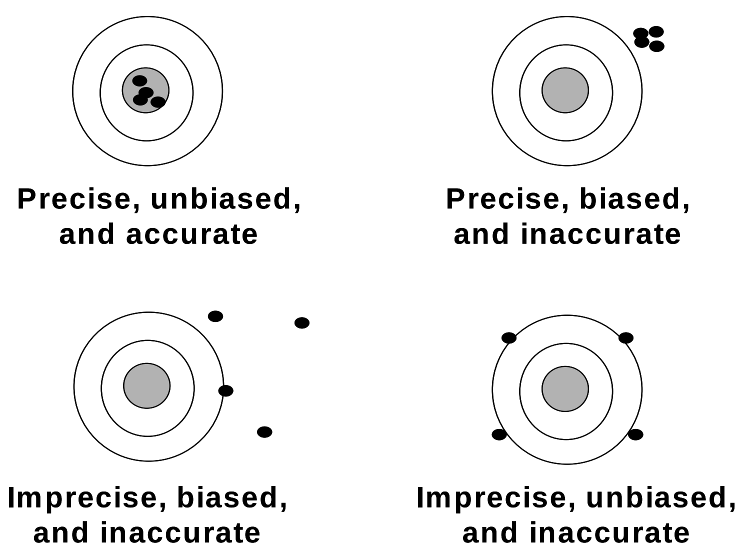


FIGURE 1. Diagram illustrating the difference between precision, bias, and accuracy.

3. TECHNICAL APPROACH

General technical approach

Chevron Mining, Inc. (formerly Molycorp, Inc.) operates a molybdenum mine at Questa, New Mexico. Open-pit mining between 1964 and 1982 resulted in approximately 350 million tons of rock being placed in nine rock piles near the mine. Rock piles, the preferred term by many in the metal mining industry today, refer to the man-made structures consisting of piles of non-ore material that had to be removed in order to extract the ore. This material, referred to as mine waste, overburden, subore, or proto-ore in older literature, does not include the tailings material, which consists of non-ore material remaining after milling. It can include mineralized rock that was too low grade to be processed. The Questa rock piles are up to 1600 feet high and hundreds of feet wide, and one of them, Goathill North (GHN), experienced some movement due to a pre-existing weak foundation (URS Corporation, 2003; Norwest Corporation, 2004). The final goal of the QRPWASP (Questa Rock Pile Weathering and Stability Project) investigation is to develop a procedure that will assess the potential for gravitational instability of existing mine rock piles over time (100 and 1000 yrs) based on the physical, chemical, mineralogical, biological, and geotechnical characteristics and the weathering of the material in the rock piles.

The QRPWASP was divided into specific tasks accomplished during several stages of study, and is only summarized here. The first stage of the project was to develop operational plans and SOPs (listed in Appendix 1) to reduce the error and ensure proper procedures were employed. A project database was developed to store collected data (McLemore et al., 2004a). Data forms were developed to ensure that all spatial (including detailed location data), geological, and other data, including field observations, were collected and preserved (Appendix 2). Appendix 3 lists the abbreviations used to describe the various mine and geographic features in the Questa-Red River area. The parameters measured are summarized in Appendices 4-5.

Field sampling is required to 1) characterize the overburden, rock piles, underlying rocks, and other country rocks (i.e. the predominant sample populations of interest, other sample populations are described in Table 2-1, Appendix 2 and 4), 2) select samples that go into the humidity cells, 3) select sites for in-situ shear testing, 4) characterize the weathering of the rock-pile material and 5) determine the effect of weathering on slope stability. Different types of samples (Table 2-1, Appendix 2), sample collection methods (Table 2-2, Appendix 2) and amount of each sample (Appendix 6) to obtain these objectives are described below and summarized in the appendices.

The exploratory stage of characterization followed, primarily to determine which samples were selected for humidity cell tests and to characterize the mined rock. A summary of the geologic setting of the area is by McLemore (2008a). The characterization results were used later to select sites for the in-situ shear tests and other selected studies (Appendix 4). During this stage, samples were collected for characterization of the material that went into the rock piles, rocks that underlie the rock piles, alteration scars, and debris flows. Samples of all of the major lithologic units were collected from outcrop localities, open pit, drill core and cuttings, rock piles, test pits/trenches, and pit high walls and included different degrees of hydrothermal alteration and weathering as defined by different mineral assemblages and alteration zonation (McLemore et al., 2008b). Additional samples were collected from throughout the rock piles as needed to characterize the rock piles since their formation. The alteration scar areas were studied during this stage and more details are described elsewhere (DRA-20; Graf, 2008). Samples for geotechnical tests were selected and collected, not for typical stability analysis, but for determining the relationship between geotechnical parameters and changes in hydrothermal alteration and weathering intensity. Mineral textures were described in order to define the paragenesis (i.e. the sequence in which minerals formed) of hydrothermal alteration and subsequent weathering (Delvigne, 1998; Jambor, 2003).

Additional field stages followed. The next stage of study involved characterization of Goathill North (GHN) rock pile through trenches constructed during reclamation (Gutierrez, 2006; Shannon, 2006; Tachie-Menson, 2006; Viterbo, 2007; McLemore et al., 2004b, 2005, 2006a, b, 2008a; Gutierrez et al., 2008). Other rock piles were studied (McLemore et al., 2008c, f) The last stage of field data collection was to develop and perform in-situ direct shear tests to determine cohesion and friction angle directly in the field (Fakhimi et al., 2008; Boakye, 2008; McLemore and Dickens, 2008). Other more specific samples and studies were conducted throughout the study to address specific questions and concerns and are described in the component DRAs and summarized in Appendix 4. Samples and other observational and measured data were collected and analyzed in the field during these phases. Other project tasks used these same samples and data obtained from the field study and are described in the component DRAs and project reports. This component DRA only describes the sample collection and preparation for laboratory analyses of samples collected during the project.

Sample collection

Samples were collected to provide and document data for the following project objectives:

- Define weathering processes, both at the surface and within the mine rock piles that could affect the mechanical properties of the piles (DRA-27, 51).
- Measure the rate at which such weathering processes occur over time in the Questa rock piles (DRA-35).
- Determine the effect of these processes on key geological, hydrological and geotechnical properties (e.g., composition, grain size, grain shapes and textures, cementation, moisture content) and the bulk mechanical behavior (e.g., shear strength) of rocks within the piles (DRA-2, 6, 13, 27, 51).
- Evaluate the effect of weathering on the long-term gravitational stability of the piles (DRA-51).

The field characterization investigation was designed to collect samples and other data to:

- Characterize the overburden bedrock lithologies, including drill core from open pit deposit and surface outcrops to identify and characterize hydrothermal alteration assemblages, weathering and cementation (DRA-1).
- Characterize the underlying country rocks (DRA-1, 21).
- Characterize the drill core through rock piles (DRA-2, 6, 7).
- Characterize the rock piles in trenches and test pits (DRA-2, 6).
- Characterize samples for selection for humidity cells experiments (DRA-34).
- Characterize the selected samples before and after humidity cells testing (DRA-34).
- Characterize the alteration scars and debris flows (DRA-20, 22).
- Characterize samples collected for selected specific analysis (stable isotope, age determinations, etc., summarized in Appendix 4; DRA-8, 11, 12, 17, 18, 24, 25, 26, 27a, 42).

A standardized protocol was followed for tasks employed in the QRPWASP (operating plans and Standard Operating Procedures or SOPs, listed in Appendix 1) and especially for each sample collected (SOP 2, 5). Different sampling strategies were employed based upon the purpose of each sampling task. Typically, at each site, a select, grab, or bulk sample of rock or other material was collected for petrographic study and geochemical analyses. A hand sample was collected from some sites for thin section analysis. Each sample was stored in a separate bag or bucket, assigned a unique number (Tables 2, 3, Field ID), logged on a field description form (Appendix 2), and entered into the project database. Other procedures are summarized in Appendix 5. Selected sample sites were marked in the field and a digital photograph (SOP 4) was taken at most localities. Photographs provide a visual record of the sample site (Table 3). The photograph form identified site specifics, provided basic location and other data about the photograph (SOP 4).

Location information obtained by global positioning system (GPS, SOP 3), type of sample, and field petrographic descriptions were collected. Location maps of the samples are in Appendix 7. Two GIS ARCMAP projects were completed that shows the locations of samples along each bench in GHN (GIS_trenches) and shows the locations of all samples collected for the Questa project (GIS_Samples). These ARCMAP projects are part of the project data repository.

Geologic observations were recorded on the field description form and each site was located on a map, if possible (SOP 5). Hand sample descriptions provided a record of what was collected, which aided in petrographic descriptions and provided information on the sample selection for the laboratory analysis. The hand sample description was the preliminary data required to determine what samples required additional detailed analyses. For example, high pyrite samples were treated differently in terms of XRF analyses than low pyrite samples. Cobble-supported samples with little or no fine material, were not subjected to Atterbergs limits and shear testing, unless several buckets were obtained, in order to obtain enough fine-grained material for these tests. Several different types of samples were collected:

- Rock-pile material that includes both the soil matrix and rock fragments of mixtures of different lithologies and alteration assemblages (DRA-2, 4, 6, 42, 47).
    - Samples collected from the surface and from test pits throughout the rock piles.
    - Samples of the rock-pile material collected from trenches in GHN (5 ft channel or composite of selected layers).
- Soil profiles of colluvium/weathered bedrock, alteration scars, and debris flows (DRA-20, 21, 22).
- Outcrop samples of unweathered (or least weathered) igneous rocks representative of the mined rock (overburden) (includes all predominant lithologies and alteration assemblages at various hydrothermal alteration and weathering intensities; DRA-1).
    - andesite
    - quartz latite
    - rhyolite tuff (Amalia Tuff)
    - aplite, granitic porphyry
    - miscellaneous dike, flow, and tuffaceous rocks
    - alteration scars
- Samples of the vein material within altered host rocks (typically veins are <2 cm; DRA-1).

    - quartz-molybdenite-pyrite (orthoclase flooding, biotite)
    - quartz-sericite-pyrite of rhyolite porphyry dikes
    - quartz-fluorite-sericite-pyrite-base metal sulfides (halo above mineral deposits)
    - calcite-gypsum/anhydrite
- Sections of drill-core samples of the mined rock (overburden) and ore deposit before mining (DRA-1, 46).
- Splits of drill cuttings from holes drilled into the rock piles and underlying colluvium/bedrock (DRA-2, 6, 7, 46).
- Samples selected for specific analysis (dating, stable isotopes, etc., Appendix 4, 5; DRA-8, 11, 12, 17, 18, 24, 25, 26, 27a, 42).

Samples were collected from

- The surface of GHN rock pile
- Horizontally along the benches within the trenches which transect GHN rock pile, including near the base of the rock pile (Appendix 7, Figure 7-2)
- Vertically down three drill holes through GHN rock pile.

Although the entire rock pile was not completely sampled, the distribution of samples from the surface, trenches and drill holes is probably representative of the entire rock pile.

GHN rock-pile samples, drill cuttings from holes drilled into the rock piles, and samples collected from test pits throughout the rock piles represent varying degrees of hydrothermally-altered samples, some of which have been exposed to surface weathering since the construction of the rock pile (approximately 25-40 years). The collected samples from the rock piles consisted of a heterogeneous mixture of rock fragments ranging in size from boulders (0.5 m) to <1 mm in diameter within a fine-grained soil matrix (DRA-2, 4, 6). Most rock fragments were hydrothermally altered before mining occurred; some show signs of oxidization and weathering since emplacement in the rock pile (McLemore et al., 2008a, b, d, 2009). Outcrop samples of unweathered (or least weathered) igneous rocks are critical to obtain the characterization of the material before it went into the rock piles. Drill-core samples represent hydrothermally-altered rocks of the pit deposit before mining that have not been exposed to post-mining surface weathering processes. Alteration scar, debris flow, and colluvium/weathered bedrock samples represent hydrothermally-altered samples that have been weathered under similar surface weathering processes as the rock piles, but for significantly longer periods of time than the rock piles. These analog sites are analogous to the Questa rock piles, because they are similar in lithology, hydrothermal alteration assemblages, mineralogy, chemistry, and clay types to the rock-pile samples, but represent long-term weathering.

Sample and Photograph Nomenclature Scheme

Each sample was assigned a unique field identification (Field ID) number (Table 1). The Field ID number for Questa samples comprises three components, separated by dashes, as described in Table 2 and SOP 2, for example SSW-HRS-0001.

TABLE 1. Scheme for identifying samples collected in the field, designated the Field ID. Description of mine-feature abbreviations is in Appendix 3.

Component 1	Component 2	Component 3
Three letter abbreviation for the mine feature, for example SSW for Sugar Shack West.	Three letter initials of the sample collector, for example HRS for Heather R. Shannon.	Sequential four number designation, for example 0001

Each sample is then assigned in the laboratory a separate sample identification number (Sample ID) designating the different sample preparation methods (Appendix 2, Table 2-3). The first part is identical to the Field ID number and is followed by a sequential two numbers, for example SSW-HRS-0001-01. The two digit lab sample can be correlated to sample preparation methods by Table 2-3 (Appendix 2).

TABLE 2. Scheme for identifying subsamples or splits of the collected field sample for specific laboratory analysis designated the Sample ID. Description of mine-feature abbreviations is in Appendix 3.

Component 1	Component 2	Component 3	Component 4
Three letter abbreviation for the mine feature, for example SSW for Sugar Shack West.	Three letter initials of the sample collector, for example HRS for Heather R. Shannon.	Sequential four number designation, for example 0001	Sequential two number designation, for example 01

Photographs were taken of most sample sites (SOP 4; information recorded on photograph form, Appendix 2). The numbering system for the photograph consists of the Field ID or Test Pit ID number followed by a letter representing the type of image (F-field, T-thin section, P-probe, H-test pit, D-drill core/cuttings, G-general, O- historic) 001 sequentially (Table 3). For example SSW-HRS-0001-F001 is the photograph no. 1 that HRS took at sample site no. 1. Photographs were taken at the highest resolution as jpeg or tif and are part of the project data repository.

TABLE 3. Scheme for identifying field photographs, designated the Photo no. Description of mine-feature abbreviations is in Appendix 3.

Component 1	Component 2	Component 3	Component 4	Component 5
Three letter abbreviation for the mine feature, for example SSW for Sugar Shack West.	Three letter initials of the sample collector, for example HRS for Heather R. Shannon.	Sequential four number designation, for example 0001.	Sequential two number designation, for example 01.	Letter of image type (F, T, P, H, D, G, O, M), followed by a sequential three number designation, 001.

Sample preparation

Some samples collected in the field were selected and prepared for specific laboratory analyses. A generalized flow chart of sample analyses is in Figure 2 and described in detail in the project SOPs (listed in Appendix 1). Many samples were split from the original sample collected in the field to form a subsample for the specific laboratory analysis. A split is defined here to represent the same size fraction and sample, whereas a subsample is defined as a portion, generally of different size fraction, then the collected sample. A summary of the sample preparation for laboratory analyses is in Appendix 5.

4. CONCEPTUAL MODEL

Ideally, the sample is a subset of a specific population at some defined scale being studied (such as a single geologic layer within a rock pile) and the sample is assumed to be homogeneous at that scale, with the same values (or range of values) for each parameter throughout the population, which do not significantly vary spatially within the population or vary with time (for example the sample of the geologic layer represents the true composition of that layer; McLemore et al., 2008a). A sample is collected using standard sample collection methods (i.e. SOPs) that provide the best sample collected that is representative of the population being studied for the specific parameter, comparable to other samples collected within the population whenever they were collected, and are complete in that they represent the range of actual values of each parameter describing the population. For example, there are two populations of permeability within the rock pile; one population is representative of fine-grained, matrix-supported layers and a second population is representative of coarse-grained, clast-supported layers.

5. STATUS OF COMPONENT INVESTIGATION

Descriptions of the collected samples and field data are in project SOPs, reports and component DRAs. Sample preparation procedures are in the SOPs and summarized in Appendix 5. Remaining samples are archived at the New Mexico Bureau of Geology and Mineral Resources at New Mexico Institute of Mining and Technology in Socorro, New Mexico.

6. RELIABILITY ANALYSIS

Samples collected 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 are explained in the project reports, SOPs, component DRAs, and described in more detail in McLemore and Frey (2008). Most laboratory analyses depend upon certified reference standards and duplicate and triplicate analyses as defined in the project SOPs. Field and laboratory audits by independent auditors were performed to ensure that procedures were followed.

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. Published papers, component DRAs and many project reports were reviewed by independent professionals.

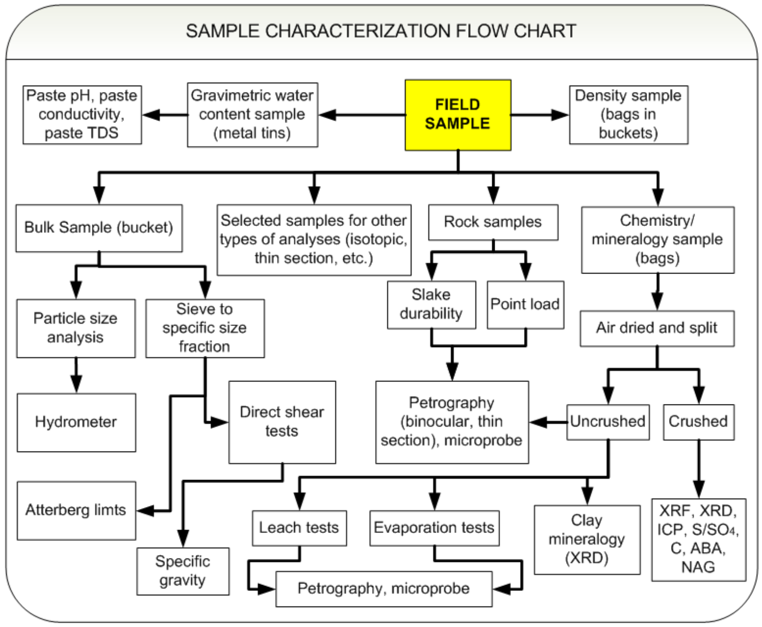


FIGURE 2. Flow chart showing analyses of selected samples. Not all analyses are performed on every sample. Bucket (5 gallons), metal tin, and bags (quart to gallon) refers to size of sample collected. XRF–X-ray fluorescence analyses, XRD–X-ray diffraction analysis, ICP–Induced-coupled plasma spectrographic analysis, NAG–net acid producing tests, ABA–acid base accounting tests. Specific details describing the sample preparation are in the project SOPs and summarized in Appendix 5.

7. CONCLUSION OF THE COMPONENT

A sample is a representative portion, subset, or fraction of a domain or body of material representing a defined population. Samples of all of the major lithologic units were collected from outcrop localities, open pit, drill core and cuttings, rock piles, test pits/trenches, and high walls and included different degrees of hydrothermal alteration and weathering mineral assemblages and alteration zonation (i.e. the predominant sample populations of interest, other sample populations are described in Appendix 4, 5). Additional samples of different layers of the rock pile were collected to determine the spatial and temporal changes within the rock pile or layer (DRA-6, 7). Spatial and geologic descriptive data for each sample are in the project database and Appendix 1 and described specifically in the project reports. The parameters to be measured are summarized in Appendix 5 and SOPs were written for each project task (listed in Appendix 1). A sufficient number and amounts of samples were collected to obtain the project objectives (Appendix 6). Typically a bulk sample was collected; other sampling methods are described in Appendix 5. Samples were prepared according to standard methods for each specific laboratory analysis and are described in the project SOPs and Appendices 1, 4 and 5. Other field observations and measurements were collected during the field investigations and recorded in the project database and summarized in Appendix 1, theses and other project reports. The rock-pile materials are a mixture of different lithologies and hydrothermal alteration mineral assemblages before being emplaced in the rock piles (DRA-1), therefore changes of mineralogy and chemistry between the various zones of the rock piles are a result of differences due to pre-mining composition, mining history, material segregation during emplacement, and post-mining chemical weathering.

8. REFERENCES

Ayakwah, G., Dickens, A., and McLemore, V.T., 2008, Characterization of a debris flow profile, Questa, New Mexico: revised unpublished report to Molycorp Task B1.4.

Boakye, K., 2008, Large In Situ Direct Shear Tests on Rock Piles at The Questa Mine, Taos County, New Mexico: M.S. thesis, New Mexico Institute of Mining and Technology, Socorro,http://geoinfo.nmt.edu/staff/mclemore/Molycorppapers.htm, accessed on October 16, 2008.

Campbell, A. and Hendrickx, J., 2008, Final report on the stable isotopic composition of precipitation and soil samples at the Questa mine: revised unpublished report to Molycorp Tasks 1.12.3 and 1.12.4, 21 p.

Campbell, A.R. and Lueth, V.W., 2008, Isotopic and textural discrimination between hypogene, ancient supergene, and modern sulfates at the Questa mine, New Mexico: Applied Geochemistry, v. 23, no. 2, p. 308- 319.

Davis, B., 1998, What is a sample? What does it represent? Australian Institute of Geoscientists Bulletin, v. 22, p. 39-34.

Delvigne, J.E., 1998, Atlas of micromorphology of mineral alteration and weathering: Canadian Mineralogist, Special Publication 3, 494 p.

Downing, B., 2008, ARD sampling and sample preparation: http://technology.infomine.com/enviromine/ard/sampling/intro.html, accessed August 7, 2008.

Fakhimi A., Boakye K., Sperling D., and McLemore V., 2008, Development of a modified in situ direct shear test technique to determine shear strength of mine rock piles: Geotechnical Testing Journal, v. 31, no. 3, 6 p., paper on line http://www.astm.org/JOURNALS/GEOTECH/TOC/3132008.htm, accessed on October 16, 2008.

Giese, L., McLemore, V.T., Osantowski, E., and Wilson, G.W., 2008, Characterization of Questa Rock Pile Crusts: unpublished report to Chevron, Task B1.1.

Graf, G.J., 2008, Mineralogical and geochemical changes associated with sulfide and silicate weathering, natural alteration scars, Taos County, New Mexico: M.S. thesis, New Mexico Institute of Mining and Technology, Socorro, 193 p., http://geoinfo.nmt.edu/staff/mclemore/Molycorppapers.htm, accessed April 28, 2008.

Gutierrez, L.A.F., 2006, The influence of mineralogy, chemistry and physical engineering properties on shear strength parameters of the Goathill North rock pile material, Questa Molybdenum mine, New Mexico: M.S. thesis, New Mexico Institute of Mining and Technology, Socorro, 201 p., http://geoinfo.nmt.edu/staff/mclemore/Molycorppapers.htm, accessed December 06, 2007.

Gutierrez, L.A.F., Viterbo, V.C., McLemore, V.T., and Aimone-Martin, C.T., 2008, Geotechnical and Geomechanical Characterisation of the Goathill North Rock Pile at the Questa Molybdenum Mine, New Mexico, USA; *in* Fourie, A., ed., First International Seminar on the Management of Rock Dumps, Stockpiles and Heap

Leach Pads: The Australian Centre for Geomechanics, University of Western Australia, p. 19-32.

Jambor, J.L., 2003, Chapter 6. Mine-waste mineralogy and mineralogical perspectives of acid-base accounting; in Jambor, J.L., Blowes, D.W., and Ritchie, A.I.M., Environmental Aspects of Mine Wastes: Mineralogical Association of Canada, Short Course Notes, v. 31, p. 117-145.

Koch, G.S., Jr. and Link, R.F., 1971, Statistical analysis of geological data: Dover Publications, Inc., New York, ISBN 0-486-64040-X, 438 p.

McLemore, V.T., 2008a, Geologic Setting and Mining History of the Questa mine, Taos County, New Mexico: Unpublished report to Molycorp, Inc, Task 1.2.2, B1.1, 20 p. (revised from appendix 1.1, May 2005 report).

McLemore, V.T., 2008b, Characterization of a weathering profile through bedrock beneath Goathill North Rock Pile, New Mexico: unpublished report to Chevron Mining, Inc., Task B1.4, 30 p.

McLemore, V.T., Anim, K., Fakhimi, A., Dickens, A.K., and Nunoo, S., 2008f, Characterization of Questa rock piles, New Mexico: Unpublished report to Chevron Mining, Inc and the QRPWASP, Task B1.1.

McLemore, V.T., Ayakwah, G., Boakye, K., Campbell, A., Dickens, A.K., Donahue, K., Dunbar, N., Gutierrez, L., Heizler, L., Lynn, R., Lueth, V., Osantowski, E., Phillips, E., Shannon, H., Smith, M., Tachie-Menson, S., van Dam, R., Viterbo, V.C., Walsh, P., and Wilson, G.W., 2008a, Characterization of Goathill North Rock Pile: revised unpublished report to Molycorp, Tasks: 1.3.3, 1.3.4, 1.4.2, 1.4.3, 1.11.1.3, 1.11.1.4, 1.11.2.3, B1.1.1, B1.3.2.

McLemore, V.T. and Dickens, A.K., 2008, Petrographic Analysis, Mineralogy, and Chemistry of Samples Analyzed by In-Situ Direct Shear Methods, Questa, New Mexico: report to Chevron, Task B1.

McLemore, V.T., Donahue, K.M., Walsh, P., Tachie-Menson, S., Phillips, E.H., Gutierrez, L. A. F., and Shannon, H. R., 2005, Trench Sampling of the Molycorp Goathill North rock piles, Questa Rock Pile Stability Study, New Mexico: National Meeting of the American Society of Mining and Reclamation, Breckenridge, Colo, June, CD-ROM, 26 p., http://geoinfo.nmt.edu/staff/mclemore/Molycorppapers.htm, accessed on October 16, 2008.

McLemore, V.T., Donahue. K.M., Phillips, E.H., Dunbar, N., Walsh, P., Gutierrez, L.A.F., Tachie-Menson, S., Shannon, H.R., Lueth, V.W., Campbell, A.R., Wilson, G.W., and Walker, B.M., 2006a, Characterization of Goathill North mine rock pile, Questa molybdenum mine, Questa, New Mexico; in 7th ICARD, March 26-30, 2006, St. Louis MO.: Published by American Society of Mining and Reclamation., Lexington, KY. CD-ROM, p. 1219-1249.

McLemore, V.T., Donahue, K., Phillips, E., Dunbar, N., Smith, M., Tachie-Menson, S., Viterbo, V., Lueth, V. W., Campbell, A.R., and Walker, B.M., 2006b, Petrographic, mineralogical and chemical characterization of Goathill North Mine Rock Pile, Questa Molybdenum Mine, Questa, New Mexico: 2006 Billings Land Reclamation Symposium, June, 2006, Billings, Mt. Published by Published by American Society of Mining and Reclamation, 3134 Montavesta Rd., Lexington, KY, CD-ROM, http://geoinfo.nmt.edu/staff/mclemore/Molycorppapers.htm, accessed on October 16, 2008.

McLemore, V.T., Donahue, K., Dunbar, N. and Heizler, L., 2008d, 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.

McLemore, V., Donahue, K., Dunbar, N., and Heizler, L., 2009, Characterization of Weathering of Mine Rock Piles: Example from the Questa Mine, New Mexico, USA: paper to be presented at the 8th ICARD, June 2009.

McLemore, V.T. and Frey, B., 2008, Quality control and quality assurance report: unpublished report to Chevron, Task B1.

McLemore, V.T., Heizler, L., Dunbar, N., Phillips, E., Donahue, K., Sweeney, D., Dickens, A.K., and Ennin, F., 2008e, Petrographic Analysis of Humidity Cell Samples: unpublished report to Chevron, Task B1.5.2.

McLemore, V.T., Hoffman, G.K., Wilks, M., Raugust, J.S., and Jones, G.R., 2004a, Use of Databases in Characterization at mine Sites: 2004 National Meeting of the American Society of Mining and Reclamation, Morgantown, WV, April 2004, p. 1239-1247, CD-ROM,http://geoinfo.nmt.edu/staff/mclemore/Molycorppapers.htm accessed on October 16, 2008.

McLemore, V.T., Sweeney, D., and Donahue, K., 2008b, Lithologic atlas: revised unpublished report to Molycorp (revised from appendix 2.3, May 2005 report).

McLemore, V.T., Tachie-Menson, S., Sweeney, D., Donahue, K., Dickens, A.K., and Campbell, A., 2008c, Characterization of hot zones in the Questa rock piles: unpublished report to Chevron, Task B1.3.2.

McLemore, V.T., Walsh, P., Donahue, K.M., Gutierrez, L. A. F., Tachie-Menson, S., Shannon, H.R., and Wilson, G.W., 2004b, Preliminary status report on Molycorp Goathill North trenches, Questa, New Mexico: 2005 National Meeting of the American Society of Mining and Reclamation, June 2005, p. 679-701, CD-ROM, http://geoinfo.nmt.edu/staff/mclemore/Molycorppapers.htm, accessed on October 16, 2008.

Neuendorf, K.K.E., Mehl, J.P., Jr., and Jackson, J.A., 2005, Glossary of Geology: American Geological Institute, 5th ed., Alexandria, Virginia, 779 p.

Norwest Corporation, 2004, Goathill North Slide Investigation, Evaluation and Mitigation Report: unpublished report to Molycorp Inc., 99 p., 3 vol.

Rollinson, H.R., 1993, Using geochemical data: evaluation, presentation, interpretation: Longman Scientific and Technical, John Wiley and Sons, New York, 352 p.

Schreuder, H.T., Ernst, R., and Ramirez-Maldonado, H., 2004, Statistical techniques for sampling and monitoring natural resources: U.S. Department of Agriculture, Rocky Mountain Research Station, Fort Collins, CO, General Technical Report-GTR-126, 111 p.

Shannon, H.R., 2006, Fluid Transport through a Variably Saturated Rock Pile hill slope system: M.S. thesis, New Mexico Tech, New Mexico, http://geoinfo.nmt.edu/staff/mclemore/Molycorppapers.htm, accessed November 19, 2006.

Smith, K.S., Ramsey, C.A., and Hageman, P.L., 2000, Sampling strategy for the rapid screening of mine-waste dumps on abandoned mine lands: U.S. Geological Survey, Open-file Report 00-016, 9 p.

Sweeney, V.T., Dunbar, N., Heizler, L., Logsdon, M., and McLemore, V.T., 2008, Characterization of weathered boulders, Questa mine, Taos County, New Mexico: unpublished report to Chevron.

Tachie-Menson, S., 2006, Characterization of the acid-producing potential and investigation of its effect on weathering of the Goathill North Rock Pile at the Questa Molybdenum Mine, New Mexico: M.S. thesis, New Mexico Institute of Mining and Technology, Socorro, NM, 209 p., http://geoinfo.nmt.edu/staff/mclemore/Molycorppapers.htm, accessed November 19, 2006.

URS Corporation, 2003, Mine rock pile erosion and stability evaluations, Questa mine: Unpublished Report to Molycorp, Inc. 4 volumes.

Viterbo, V.C., 2007, Effects of pre-miming hydrothermal alteration processes and post-mining weathering on rock engineering properties of Goathill North rock pile at Questa mine, Taos County, New Mexico: M.S. thesis, New Mexico Institute of Mining and Technology, Socorro, 274 p., http://geoinfo.nmt.edu/staff/mclemore/Molycorppapers.htm, accessed December 06, 2007.

Wellmer, F.W., 1989, Statistical evaluations in exploration for mineral deposits: Springer-Verlag, New York, ISBN 3-540-61242-4, 379 p.

9. TECHNICAL APPENDICES

APPENDIX 1. List of Standard Operating Procedures (SOPs).

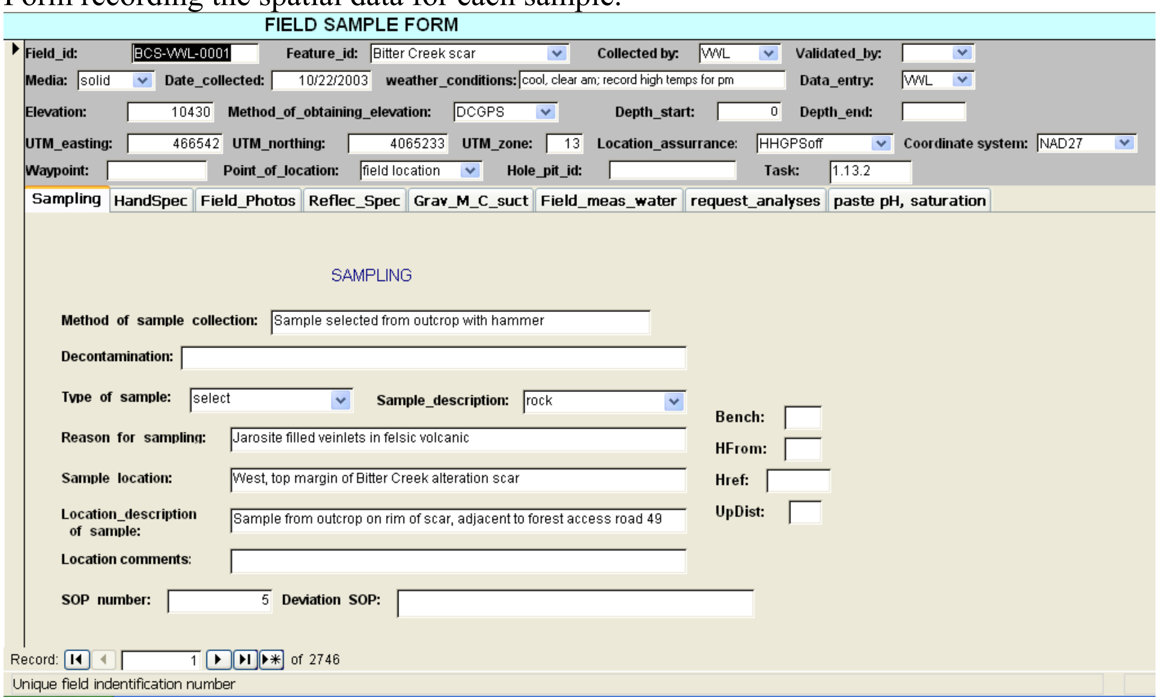
Number	Name	Description
MP	Project Management Plan	Overall project management plan
WP	Work plan	Work plan for the project
HASP	Health and Safety Plan	Health and safety plan for filed and laboratory work
QAPP	Quality Assurance Project Plan	Quality assurance and quality control plan
FSP	Field Sampling Plan	Field sampling plan
DP1	Drilling plan, phase 1	Drilling plan
DP2	Drilling plan, phase 2	Drilling plan
GMP	Geologic mapping plan	Geologic mapping plan
SOP 1	Data management	entering, reporting, verification, and validation of data to the database
SOP 2	Sample management	procedures of handling samples from field to laboratory to archive
SOP 3	Surveying (GPS)	field procedures using GPS and other surveying methods
SOP 4	Photography	procedures taking photographs in the field and laboratory
SOP 5	Sampling outcrops, rock piles, and drill core	field procedures for taking surface solid samples
SOP 6	Drill logging and sampling of subsurface	field procedures for drilling, logging, and sampling of subsurface samples (solids)
SOP 7	Sample equipment Decontamination	field procedures for decontamination of sampling equipment
SOP 8	Sample preparation	laboratory procedures for sample preparation (solids)
SOP 9	Test pit excavation, logging, and sampling (solid)	field procedures for test pit excavation, logging, and sampling (solid)
SOP 10	Met station maintenance	field procedures for maintaining meteorological station
SOP 11	Paste pH and paste conductivity	laboratory procedures for paste pH and paste conductivity
SOP 12	Field measurements of water	field procedures for measuring water flow, pH, conductivity, alkalinity, temperature when collecting water samples
SOP 13	Water elevation measurements	field procedures for measuring water elevations in drill holes
SOP 14	Field filtration of water samples	procedures for filtering water samples in the field
SOP 15	Surface water and seep sampling	field procedures for collecting samples of surface and seep water samples
SOP 16	Groundwater sampling	field procedures for collecting ground-water samples
SOP 17	Borehole logging	field procedures for borehole logging
SOP 18	Pump testing	field procedures for collecting information during pump testing
SOP 19	Geophysical logging	field procedures for borehole geophysical logging
SOP 20	Well development	field procedures for development of wells
SOP 21	Monitoring well installation	field procedures for installing monitoring wells and instrumentation
SOP 22	Analytical data validation	procedures for data validation
SOP 23	Geophysics with electromagnetic induction	procedures for geophysical surveys
SOP 24	Petrographic analysis	laboratory procedures for describing petrographic samples
SOP 25	Stable isotope analysis	laboratory procedures for stable isotope analyses
SOP 26	Electron microprobe analyses	laboratory procedures use for analyses using the electron microprobe
SOP 27	X-ray diffraction (XRD) analyses	laboratory procedures for mineralogical analyses by x-ray diffraction (XRD)
SOP 28	X-ray fluorescence (XRF) analyses	laboratory procedures for chemical analyses by x-ray fluorescence (XRF)
SOP 29	Clay mineralogy analyses	laboratory procedures for sample preparation and XRD analyses of clay minerals
SOP 30	ICP-OES analyses	laboratory procedures for chemical analyses using ICP-OES

Number	Name	Description
SOP 31	ICP-MS analyses	laboratory procedures for chemical analyses using ICP-MS
SOP 32	Bulk density	laboratory procedures for determining bulk density
SOP 33	Particle size analysis	laboratory procedures for determining particle size analyses
SOP 34	Sampling for the Remaining Pyrite Model	approach, collection of samples and laboratory procedures required for sampling for remaining pyrite model
SOP 35	Volumetric moisture content	collection of samples and laboratory procedures for determining volumetric moisture content
SOP 36	Sample preservation, storage, custody, shipping	procedures for sample preservation, storage, and shipment
SOP 38	DI leach	laboratory procedures for leaching solid samples by deionized water to provide for soluble material
SOP 39	Samples for Pore water measurements	laboratory procedures for collecting samples for pore water measurements
SOP 40	Gravimetric moisture content	collection of samples and laboratory procedures for gravimetric moisture content
SOP 41	Reflectance spectroscopy	field procedures for mineralogical analyses using reflectance spectrography
SOP 42	Porosity	laboratory procedures for determining porosity
SOP 43	Tensiometer and thermal conductivity thermal conductivity sensor installation	field procedures for installing tensiometers and thermal conductivity sensors procedures for argon/argon dating
SOP 44	Argon/argon geochronology	laboratory procedures for argon/argon dating
SOP 45	Moisture retention relation by hanging column	procedures for determining moisture relations
SOP 47	Rain and snow collection for isotope	field procedures for collecting rain and snow
SOP 48	Dye tracer studies	Tracer studies using dyes
SOP 49	Chip tray preparation	How to prepare chip trays of drill cuttings for examination
SOP 50	Direct Shear tests	How to do simple shear box tests
SOP 51	Collecting Thermal images	How to collect thermal images using thermal camera
SOP 52	Static Net Acid Generation (NAG) Test	Nag test for laboratory
SOP 53	Tension Infiltrometer	procedures for tension infiltrometer measurements
SOP 54	Atterberg Limits	procedures for Atterberg Limits
SOP 55	General Microbial Sampling - Solids	General Microbial Sampling - Solids
SOP 56	Classical microbial analysis - solids	Classical Microbial Analysis - Solids
SOP 57	Microbial laboratory safety	Microbial Laboratory Safety
SOP 58	Microbial metabolic profiles - biology	Microbial Metabolic Profiles - Biology
SOP 59	Microbial nucleic acid analysis	Microbial Nucleic Acid Analysis
SOP 60	Slurry pH-redox-condictivity-temperature	Slurry Ph – Redox – Conductivity - Temperature
SOP 61	Neutron density gauge	Describes measurements taken with the nuclear density gauge (density, water content)
SOP 62	Acid-base accounting (ABA)	Procedures for acid base accounting in laboratory
SOP 63	Kelway soil acidity and moisture measurements	Kelway Soil Acidity and Moisture Tester for field measurements
SOP 64	Portable tensiometer	procedures for using field portable tensiometers as opposed to in place monitoring
SOP 65	Sandcone	procedures for sand cone
SOP 66	Gas analyzer	procedures for gas analyzer
SOP 67	Solid sample collection and compound analysis	procedures for solid sample collection and compound analysis
SOP 68	Water analyses	water analyses in lab
SOP 69	Other chemical analyses on solids	other chemical analyses on solids (ammonia, nitrate, fluorine, etc)
SOP 70	Sand replacement	calculates volumetric moisture content and bulk density
SOP 71	Guelph permeameter	procedures for guelph permeameter measurements

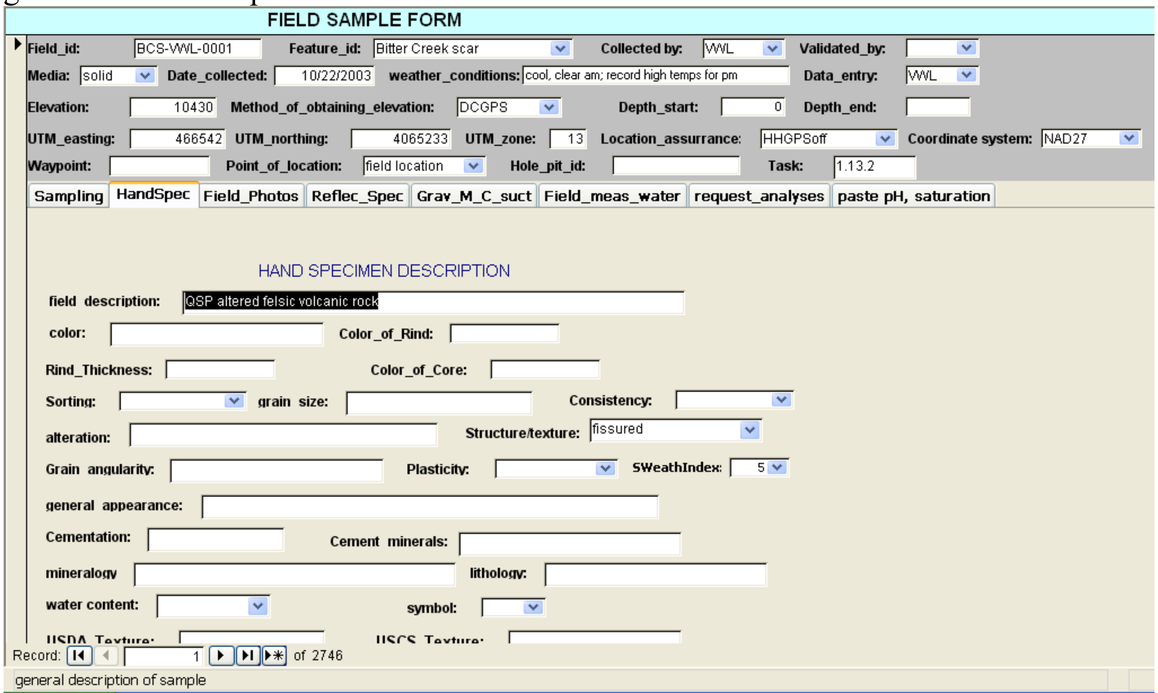
Number	Name	Description
SOP 72	SWCC	Soil water characteristic curve (UBC)
SOP 73	Falling head Permeability	Permeability by falling head method
SOP 75	Specific gravity	procedures for determining specific gravity
SOP 76	Slake durability	procedures for slake durability tests
SOP 77	Point load	procedures for point load tests
SOP 78	Humidity cell testing	procedures for weathering cells tests
SOP 79	Sample preparation for humidity cell testing	procedures for weathering cells sample selection and preparation
SOP 90	XRD sample preparation for pyrite reserve model	XRD sample preparation for pyrite reserve model
SOP 91	Color	procedures for obtaining the color of a soil sample

APPENDIX 2. Field sample forms in the database used to record field location and descriptive data obtained in the field during sample collection. Field ID described in Table 2-1.

Form recording the spatial data for each sample.



Form recording the geological descriptions of the samples. A mixture of geological and geotechnical descriptions are used.



Form recording information on photographs taken in the field.

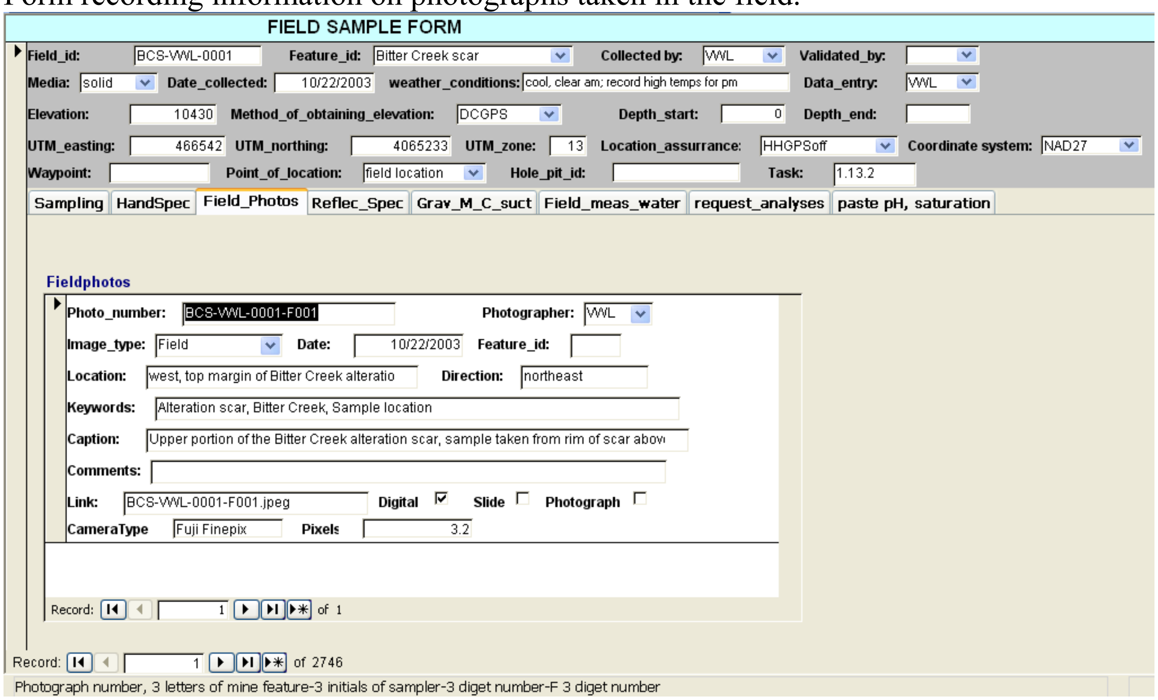


TABLE 2-1. Description of Sample description field in the sample form.

Sample description	Description
well	water from well or drill hole
subsurface unsaturated/vadose zone	selected subsurface sample
waste water	waste water
mine drainage	water sample from mine drainage
rock	unaltered or slightly altered rock
mineralized rock	rock is altered or mineralized
ore	mined or extractable ore material
rock pile	rock material
soil	soil sample
sediment	stream or lake sediment
select	select sample for specific analysis
microbe	sample collected for microbe analyses
core	drill core
cuttings	drill cuttings

TABLE 2-2. Description of type of sample field in the sample form.

Type of sample	Description
drill cuttings	cuttings from reverse circulation
Becker cuttings	drill cuttings from Becker drill rig
sonic core	core obtained from sonic drilling
split spoon	sample collected from split spoon, indicate size in comments
drill core	diamond drill core
bucket	sample collected from backhoe bucket
grab	randomly collected sample by hand
hand auger	sample collected by hand using an auger
channel sample	continuous sample over a specified length and width
composite	sample collected from different locations and combined to form one sample
composite rock pile	sample collected from different locations and combined to form one sample in a rock pile
select	sample selected for specific analysis
screened	solid sample screened to specified size fraction, specify size in comments
pump sample	
field blank	field blank, typically used for only water
field replicate	Field replicate sample
quality control sample	As required by SOP, generally 1 duplicate per 25 samples collected
biological	samples selected for biological purposes
Gas analyses	TBD

TABLE 2-3. Description of 2-digit sample preparation numbers (the last 2 digits in the Sample Identification Number). See SOPs for more details.

Sample Preparation Number	Definition
00	field sample as collected, moisture content, water
01	thin section
02	XRF, XRD
03	ICP
04	DI leach (uncrushed)

Sample Preparation Number	Definition
05	Moisture content, paste pH, paste conductivity
06	Clay mineralogy
07	Stable isotopes
08	Ar/Ar dating
09	Reflectance spectroscopy (uncrushed)
10	Powdered Archive
11	Aqueous pH, conductivity
12	geotech sample (shear box)
13	microprobe
14	ABA/NAG
15	pyrite reserve
16	paste pH, paste conductivity
17	biology
18	volumetric sample
19	sand cone
20	pea size, crushed for archive
21	sand replacement
22	bulk density
23	volumetric sample
24	bulk density
25	pore water
30	different samples taken in the field for microprobe, typically soil sample
31	different samples taken in the field for microprobe
32	different samples taken in the field for microprobe
33	humidity cell sample, after tests
34	humidity cell sample, after tests
35	humidity cell sample, after tests
36	humidity cell sample, after tests
37	humidity cell sample, after tests
38	humidity cell sample, after tests
39	humidity cell sample, after tests
40	humidity cell sample, after tests
41	duplicate isotope sample
42	duplicate isotope sample
43	duplicate isotope sample
44	duplicate isotope sample
45	duplicate isotope sample
46	duplicate isotope sample
47	duplicate isotope sample
48	duplicate isotope sample
49	duplicate isotope sample
50	duplicate isotope sample
51	particle size analyses (6in ASTM sieve opening)
52	particle size analyses (4in ASTM sieve opening)
53	particle size analyses (3in ASTM sieve opening)
54	particle size analyses (2in ASTM sieve opening)
55	particle size analyses (1.5in ASTM sieve opening)
56	particle size analyses (1in ASTM sieve opening)
57	particle size analyses (0.75in ASTM sieve opening)
58	particle size analyses (0.5in ASTM sieve opening)
59	particle size analyses (0.375in ASTM sieve opening)

Sample Preparation Number	Definition
60	particle size analyses (3mesh ASTM sieve opening)
61	particle size analyses (4mesh ASTM sieve opening)
62	particle size analyses (6mesh ASTM sieve opening)
63	particle size analyses (8mesh ASTM sieve opening)
64	particle size analyses (14mesh ASTM sieve opening)
65	particle size analyses (16mesh ASTM sieve opening)
66	particle size analyses (20mesh ASTM sieve opening)
67	particle size analyses (30mesh ASTM sieve opening)
68	particle size analyses (40mesh ASTM sieve opening)
69	particle size analyses (50mesh ASTM sieve opening)
70	particle size analyses (70mesh ASTM sieve opening)
71	particle size analyses (100mesh ASTM sieve opening)
72	particle size analyses (140mesh ASTM sieve opening)
73	particle size analyses (200mesh ASTM sieve opening)
74	particle size analyses (Pan)
75	GeoTech Atterberg Limits
76	GeoTech shear box
77	GeoTech drying
78	GeoTech extra
79	GeoTech extra
80	GeoTech extra
81	GeoTech extra
82	GeoTech extra
83	Ar/Ar dating
84	Ar/Ar dating
85	Ar/Ar dating
86	slake testing
87	slake testing
88	duplicate for boulder samples
90	coarse fraction, solid sample in the weathering cell
91	fine size material separated from humidity cell sample at NMIMT
92	fine size material washed/separated from humidity cell sample at Utah
93	water sample of DI wash from Utah
94	water sample of DI leach of fines at NMIMT
95	leachate sample from weathering cells collected at a specific date
96	biological sample
97	duplicate for boulder samples
98	duplicate analyses
99	duplicate analyses

APPENDIX 3. Description of mine-feature abbreviations used in sample nomenclature scheme (Tables 2-4).

Symbol	Site name	Type of feature
BIR	Birdfoot scar	alteration scar
BCS	Bitter Creek scar	alteration scar
CAP	Capulin	mine waste rock pile
CAS	Capulin scar	alteration scar
ERS	Eagle Rock scar	alteration scar
EJB	East June Bug scar	alteration scar

Symbol	Site name	Type of feature
ELE	Elephant Rock campground	campground
FSR	Forest Service Ranger Station scar	alteration scar
GOH	Goathill	natural hill
GDF	Goathill debris flow	debris flow
GSR	Goathill Gulch scar	alteration scar
GHN	Goathill North	mine waste rock pile
GHS	Goathill South	mine waste rock pile
GOO	Goose Creek	alteration scar
ROC	Hand sample or nonmine samples	lithology
HAS	Hansen scar	alteration scar
HTS	Hottentot scar	alteration scar
JBS	June Bug scar	alteration scar
LEG	legacy data sample	legacy data
LHA	Little Hanson scar	alteration scar
LBS	Lower Bitter Creek scar	alteration scar
MCS	Mallette scar	alteration scar
MID	Middle	mine waste rock pile
MIL	mill	mill
MIN	mine	mine area, including underground workings
QPS	Pit scar	alteration scar
PIT	Questa open pit	open pit with pit lake
QAS	Questa scar	alteration scar
RED	Red River	river valley
SJB	South June Bug scar	alteration scar
SSC	South Straight scar	alteration scar
SHE	Southeast Hottentot scar	alteration scar
ESS	Southeast Straight Creek scar	alteration scar
SET	Southeast Truck Shop scar	alteration scar
SWH	Southwest Hansen scar	alteration scar
SPR	Spring Gulch	mine waste rock pile
SCS	Straight Creek Scar	scar
SSS	Sugar Shack South	mine waste rock pile
SSW	Sugar Shack West	mine waste rock pile
SGH	Sulphur Gulch North/Blind Gulch	mine waste rock pile
SGN	Sulphur Gulch North/Blind Gulch scar	rock pile
SGS	Sulphur Gulch South	mine waste rock pile
TAL	tailings	tailings
WER	West Eagle Rock scar	alteration scar
WGH	West Goathill scar	alteration scar

APPENDIX 4. Additional specialized studies in the QRPWASP where samples and other field data were collected.

Study	Purpose	Type of samples	SOP	DRA	Other reference
Characterization of alteration scars	Describe a potential weathering analog	Bulk samples along weathered residual soil profiles	5	20	Graf (2008), McLemore et al. (in preparation)
Characterization of debris flows	Describe a potential weathering analog	Bulk samples along weathered residual soil profiles	5	22	Ayakwah et al. (2008)
Characterization of weathered bedrock	Describe a potential weathering analog	Bulk samples along weathered residual soil profiles	5	21	McLemore (2008b)
Characterization of the hot zones	Describe the material in the hot zones within the front rock piles	Rock-pile drill cuttings	5, 6	7	McLemore et al. (2008c)
Characterization of the crust	Describe the weathered crust that forms on the surface of the rock piles and the effect on	Selected samples of the crust, samples of precipitation runoff	5	8	Giese et al. (2008)
Characterization of humidity cells	Describe the samples before and after humidity cell tests	Selected samples based on total S concentration	5	34	McLemore et al. (2008e)
Characterization of weathered boulders	Describe weathered boulders at the surface	Large boulders	5	25	Sweeney et al. (2008)
Isotope geochemistry of pore water	Compare isotopic signatures of pore water to other waters	Matrix-rich solid samples, collected precipitation and other water samples	39, 47	12	Campbell and Hedrickx (2008)
Sulfur and oxygen isotopes	Determine stable isotopes	Selected samples	25	17	Campbell and Lueth (2008)
Geochronology	Determine age	Selected samples	44	18	
Tritium Analysis	Use of tritium analyses to determine a hydraulic barrier	Selected samples		11	
DI leach and column studies	Approximate pore water compositions	Selected samples	38	26, 23	
Microbiology	Determine microbial populations	Selected samples of solid material for microbial analyses	55-60	24	

APPENDIX 5. Summary of sample preparation for specific laboratory analyses. XRF–X-ray fluorescence analyses, XRD–X-ray diffraction analysis, ICP–Induced-coupled plasma spectrographic analysis, NAG–net acid producing tests, ABA–acid base accounting tests. Solid materials remaining after the tests were archived. Pulverized and crushing are the steps in SOP 5 that reduce the particle size to <35 μm required for chemical analysis.

Laboratory analysis	Type of sample	Sample Preparation	Method of obtaining accuracy and precision	SOP
Petrographic analyses	Collected in the field, used split from chemistry sample	Uncrushed, typically smaller than gravel size material used, thin sections made of selected rock fragments	Selected samples were analyzed by outside laboratory	24
Microprobe analyses	Collected in the field or split from chemistry sample	Uncrushed, generally 2 splits; rock fragments and soil matrix	Use reference standards	26
Whole-rock chemical analysis (XRF, S/SO4)	Collected in the field in separate bag, analysis performed on powdered sample	Crushed and pulverized	Use reference standards and duplicates and triplicates	8
Whole-rock chemical analysis (ICP)	Collected in the field in separate bag, analysis performed on powdered sample	Crushed, pulverized, and dissolved in a liquid for analysis	Use reference standards and duplicates and triplicates	8, 30, 31
X-ray diffraction (XRD) analyses (including remaining pyrite analysis)	Used split from chemistry sample	Crushed	Compared to detailed analysis by electron microprobe	27, 34
Clay mineralogy analyses	Used split from chemistry sample	Uncrushed, typically smaller than gravel size material used, thin sections made of selected rock fragments, clay separation obtained by settling in a beaker of DI water	Use duplicate analysis, compared to other results performed by consultant companies, compared to detailed analysis by electron microprobe	29
Particle-size analysis	Bulk sample collected in the field	Sample sieved for each size fraction weighed	Use duplicate analysis, compared to other results performed by consultant companies	33
Paste pH and paste conductivity	Collected in the field, used split from chemistry sample or gravimetric sample	Uncrushed, typically smaller than gravel size material used	Use duplicates, compared with field measurements using Kelway instrument (SOP 63), compare to mineralogical analysis	11
ABA/NAG tests	Used split from chemistry sample	Crushed, typically smaller than gravel size material used	Use duplicate analysis, compared to other results performed by consultant companies	52, 62
DI leach	Collected in the	Uncrushed, typically	Use reference standards	38

Laboratory analysis	Type of sample	Sample Preparation	Method of obtaining accuracy and precision	SOP
	field	smaller than gravel size material used	and duplicate analyses	
Gravimetric moisture content	Collected in the field in a sealed metal canister	Uncrushed, typically smaller than gravel size material used	Use duplicates	40
Atterberg Limits	Bulk sample collected in the field	Sample sieved to <0.425 mm	Use duplicate analysis, compared to other results performed by consultant companies	54
Bulk density and specific gravity	Collected in sealed buckets in the field	None, typically smaller than gravel size material used	Use duplicate analysis, compared to other results performed by consultant companies	32, 65, 70, 75
Direct Shear Test	Bulk sample collected in the field	Sieved to pass through the no. 6 sieve (<3.35 mm) for 2 inch shear test	Use duplicate analysis, compared to other results performed by consultant companies	50
Slake durability and point load index tests	Rock fragments 40 and 60 g for slake durability tests and approximately 4-10 cm in dimension for point load tests	None	Duplicate tests	76, 77
Stable isotope analysis	Selected mineral grains	See SOP	duplicate analysis and use of international standards	25

APPENDIX 6. Amounts of collected sample material required for the project.

Laboratory analysis	Amount of material to be collected
Archive sample	250 g
Clay mineralogy	1 lb
Leaching studies	50 g
Whole rock chemical analysis	200 g
Particle size	5 gallon bucket
Shear tests and Atterberg Limits	5 gallon bucket
Thin section	Rock fragments (>cm diameter)
Pore water chemistry	Mason jar
Stable isotopes and age determination	Few g
Paste tests and gravimetric moisture content	Small tin (~200 g)
Biological samples	Small collection tube
Pyrite reserve analysis	1 kg
Bulk density	5 gallon bucket

APPENDIX 7. Location of samples examined in the Questa project.

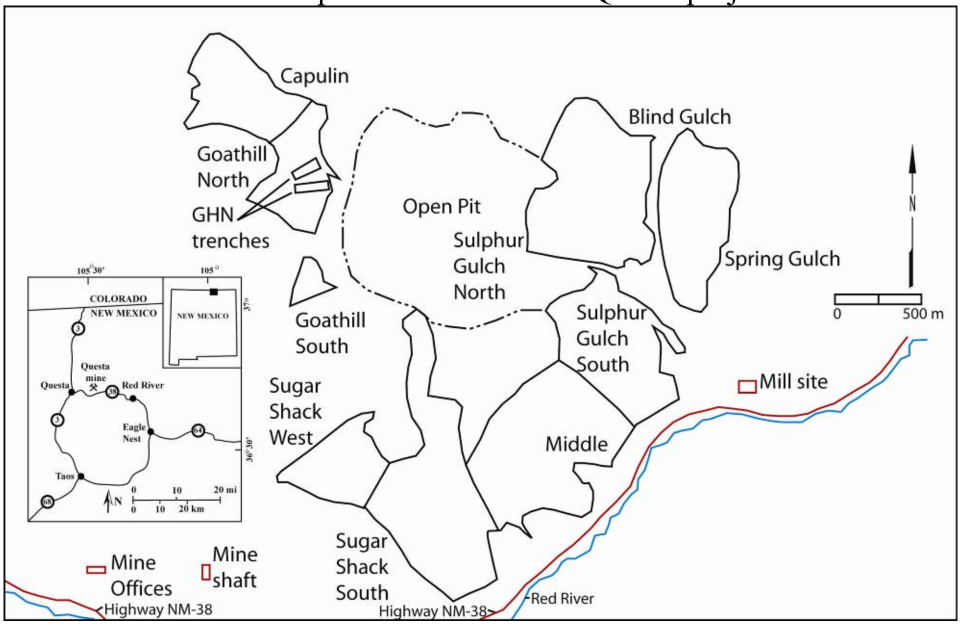


FIGURE 7-1. Questa rock piles and other mine features, including location of trenches constructed in GHN (DRA-2; McLemore et al., 2008f).

LOCATION OF GHN SAMPLES (more detailed locations in McLemore et al., 2008a, appendices 4-6) (DRA-3, 4, 5, 6, 12, 13, 16, 24, 26, 27, 27a, 42, 46, 50, 51; Gutierrez, 2006; Gutierrez et al., 2008)

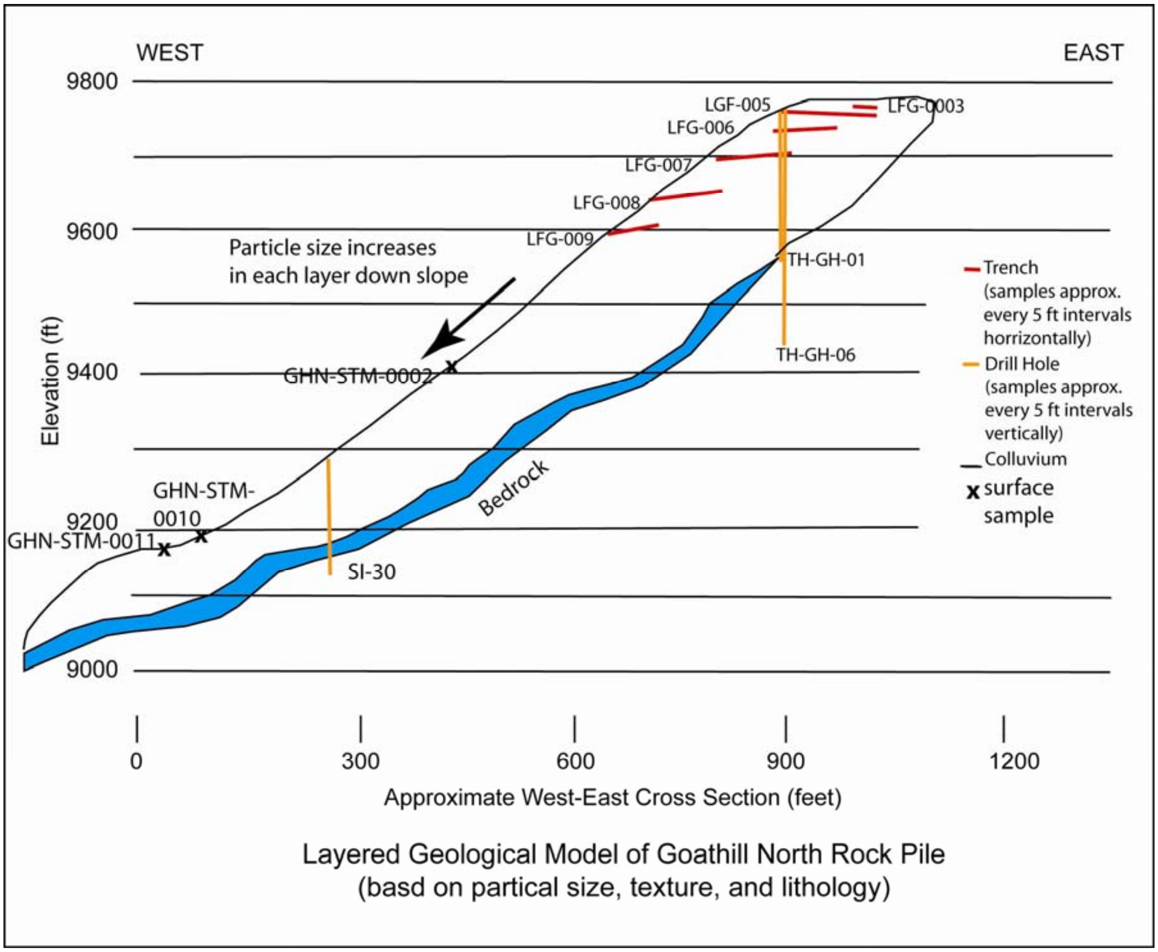


FIGURE 7-2. Approximate locations of samples in Goathill North rock pile. Samples were collected at approximately 5 ft intervals horizontally along the benches within each trench and at approximately 5 ft intervals vertically down each drill hole. See McLemore et al. (2008a, appendices 3, 4, 5, 6) for detailed maps showing locations of samples.

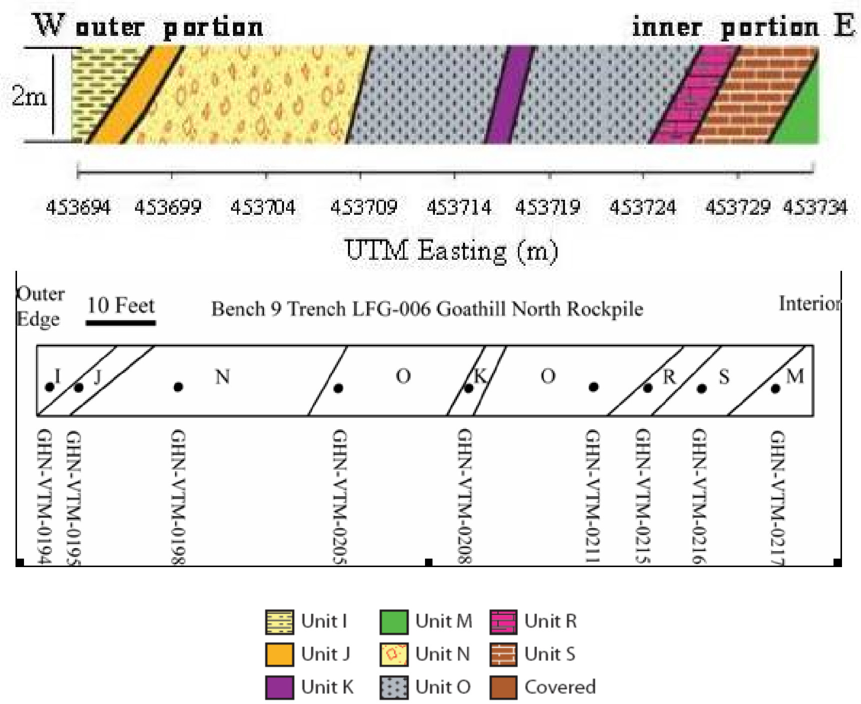


FIGURE 7-3. Geologic cross section of bench 9, trench LFG-006. Note that not all 18 geologic units are present in this bench. Note the vertical exaggeration; actual dips of strata were 20°-40°.

TABLE 7-1. Location of samples (surface, drill holes and trenches) in GHN rock pile as shown in Figure 7-2.

Drill hole or trench	Samples
TH-GN-01	GHN-ACT-0001 through GHN-ACT-0032
GHN-SI-30	GHN-PXW-0001 through GHN-PXW-0016
LFG-003	GHN-HRS-0001, 2, GHN-LFG-0018 through GHN-LFG-0024, 41
LFG-004	GHN-LFG-0037
LFG-005	GHN-LFG-0085 through GHN-LFG-0090, GHN-VTM-0035-GHN-VTM-0040 through GHN-VTM-0120
LFG-006	GHN-KMD-0013 though GHN-KMD-0027, GHN-VTM-0168 through GHN-VTM-0217
LFG-007	GHN-KMD-0048 through GHN-KMD-0065, GHN-VTM-0231 through GHN-VTM-0303
LFG-008	GHN-KMD-0072 through GHN-KMD-0100, GHN-VTM-0353 through GHN-VTM-0361
LFG-009	GHN-JRM-0001 through GHN-JRM-0027, GHN-VTM-0404 through GHN-VTM-0455

Drill hole or trench	Samples
Traffic zone (top of GHN)	GHN-LFG-0018, 20, GHN-VTM-0053
Rubble zone	GHN-VTM-0598, 0607, 0624, GHN-EHP-0003, GHN-ACT-0023 through GHN-ACT-0032, GHN-LFG-0041, 57, 60, 89
colluvium	GHN-ACT-0033, 34, GHN-EHP-0004, 5, GHN-HRS-0095, 96, GHN-LFG-0001 through GHN-LFG-0006, 91, GHN-SAW-0200, 201, GHN-VTM-0500 through GHN-VTM-0502, 506, 507, 508, 509, 510, 553, 605, 606, 611 through 614
Surface samples	GHN-STM-0001 through GHN-STM-0005
Unstable GHN	GHN-EHP-0001, 2, GHN-HRS-0088 through GHN-HRS-0094, GHN-JRM-0037 through GHN-JRM-0047, GHN-SAW-0002 through GHN-SAW-0005m GHN-VTM-0003

LOCATION OF IN-SITU TEST SITES AND SAMPLES (DRA-47, 47a; Boakye, 2008; Fakhimi et al., 2008; McLemore and Dickens, 2008)

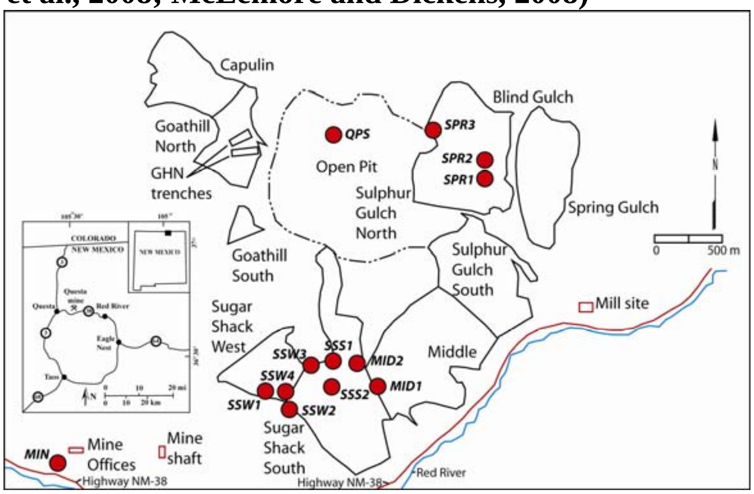


FIGURE 7-4. Location of in-situ samples (red circles). Test site identification numbers are listed in Table 7-2.

TABLE 7-2. The number of in-situ direct shear tests performed at each location.

Location	Number of in-situ direct shear tests performed	Number in Figure 1 (Test site identification number)
Middle Rock Pile	5	MID1 (MID-AAF-1-1, 2-1, 2-2, 3-1) MID2 (MID-VTM-0002-1)
Spring Gulch Rock Pile	10	SPR1 (SPR-AAF-0001-1, 1-2) SPR2 (SPR-VTM-0005-1, 8-1) SPR3 (SPR-VTM-0012-1, 12-2, 12-3, 19-1, 19-2)
Sugar Shack South Rock Pile	7	SSS1 (SSS-AAF-0001-1, 5-1, 5-2, 9-1, 9-2) SSS2 (SSS-VTM-0600-1, 601-1)
Sugar Shack West Rock Pile	17	SSW1 (SSW-AAF-0001-1, 2-1, 2-2, 2-3, 4-1) SSW2 (SSW-AAF-0005-1, 7-1) SSW3 (SSW-VTM-0016-1, 16-2, 23-1, SSW-VTM-0600-1, 600-2, 600-3) SSW4 (SSW-VTM-0026-1, 26-2, 30-1, 30-2)
Questa Pit Alteration Scar	8	QPS (QPS-AAF-0001-1, 1-2, 1-3, 8-1, 9-1, 20-1,

Location	Number of in-situ direct shear tests performed	Number in Figure 1 (Test site identification number)
		22-1, QPS-VTM-0001-1)
Debris Flows	5	MIN (MIN-AAF-0001-1, 4-1, 10-1, 12-1, 15-1)

LOCATION OF UBC SAMPLES AND STRAIGHT CREEK PROFILE (DRA-43)

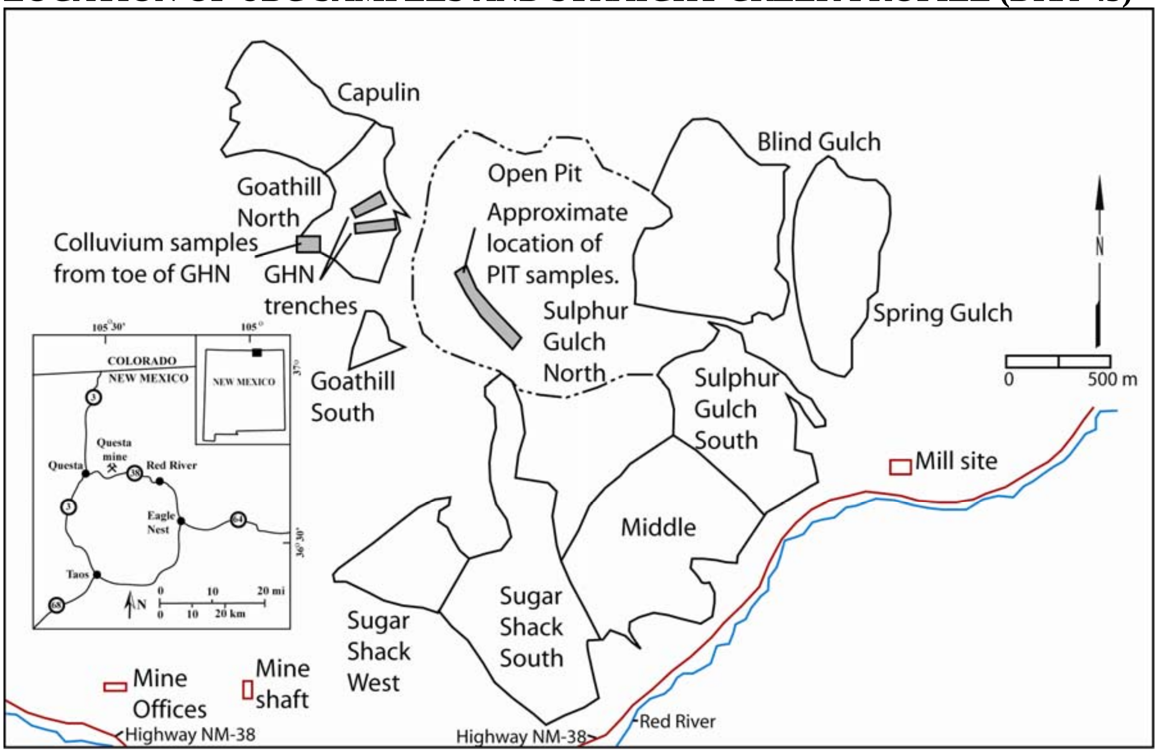


FIGURE 7-5. Questa rock piles and other mine features, including locations of UBC samples (trenches constructed in Goathill North (GHN) rock pile, colluvium samples from toe of GHN, and PIT samples from the open pit).

LOCATION OF HUMIDITY CELL SAMPLES (DRA-34, 35; McLemore et al., 2008e)

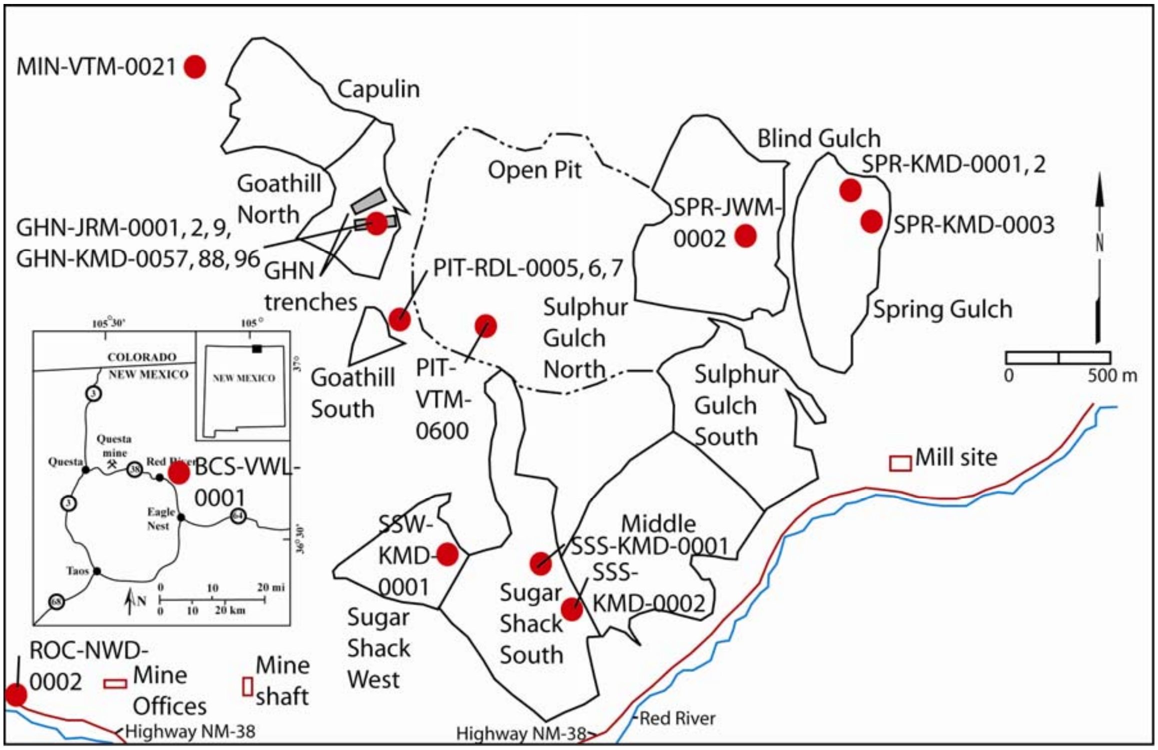


FIGURE 7-6. Location of humidity cell samples.

TABLE 7-3. Location of samples used in the humidity cell tests. Three sets of samples of the humidity cell tests were by University of Utah (UU) samples (15 samples), Robertson Geoconsultants, Inc. (8 samples, RGC), and splits of the Golder humidity cell samples (2 samples). Detailed descriptions and chemical and mineralogical data of humidity cell samples are in Appendices 1 and 2. The two Golder samples SPR-OTH-0001 were composite samples from test plots from Spring Gulch rock pile and the exact locations are unknown.

Sample	unit	UTM easting (m)	UTM northing (m)	Elevation (ft)	Depth (ft)	Actual hole identification number	Correlates with sample identification number
UU samples							
BCS-VWL-0004	scar	466549	4065237	10340	0		
GHN-JRM-0001	Unit J	453642.2	4062137	9602			
GHN-JRM-0002	Unit N	453642.4	4062137	9601			
GHN-JRM-0009	Unit J	453634.2	406123	9585.8			
GHN-KMD-0057	Unit O	453695.8	4062140	9694			
GHN-KMD-0088	Unit O	453657.4	4062127	9635.4			
GHN-KMD-0096	Unit J	453658.4	4062119	9640.3			
MIN-VTM-0021	andesite	453817	4062418	9968	0		
PIT-RDL-0005	rhyolite	453822	4061505	9912	0		

Sample	unit	UTM easting (m)	UTM northing (m)	Elevation (ft)	Depth (ft)	Actual hole identification number	Correlates with sample identification number
PIT-RDL-0006	rhyolite	453822	4061588	9916	0		
PIT-RDL-0007	rhyolite	453822	4061588	9916	0		
PIT-VTM-0600	andesite	454215	4061522	9476	0		
ROC-NWD-0002	rhyolite	451697	4060400	8023.5	0		
SPR-JWM-0002	andesite	455254	4062384	9319	0		
RGC humidity cells							
SPR-KMD-0001		455795	4062171	9043.4	5-10	MMW-40A	WRD 1 (5-10 ft), cell 1
SPR-KMD-0002		455795	4062171	8998.4	50-55	MMW-40A	WRD 1 (50-55ft), cell 2
SPR-KMD-0003		455838	4062293	9017.7	45-50	WRD-20	WRD 2 (55-60ft), cell 3
SSS-KMD-0001		454181	4060503	9263	0-5	WRD-5	WRD 5 (5-10ft), cell 5
SSS-KMD-0002		45424.8	4060204	8692.3	25-30	WRD-3	WRD 3 (20-25ft), cell 4
SSW-KMD-0001		453872.1	4060686	9372.5	34-39	SI-1	WRD 6 (30-35 ft), cell 6
Golder humidity cells							
SPR-OTH-0001		unknown	unknown	unknown	surface		
SPR-OTH-0002		unknown	unknown	unknown	surface		

LOCATION OF ALTERATION SCAR SAMPLES (DRA-20; Graf, 2008)

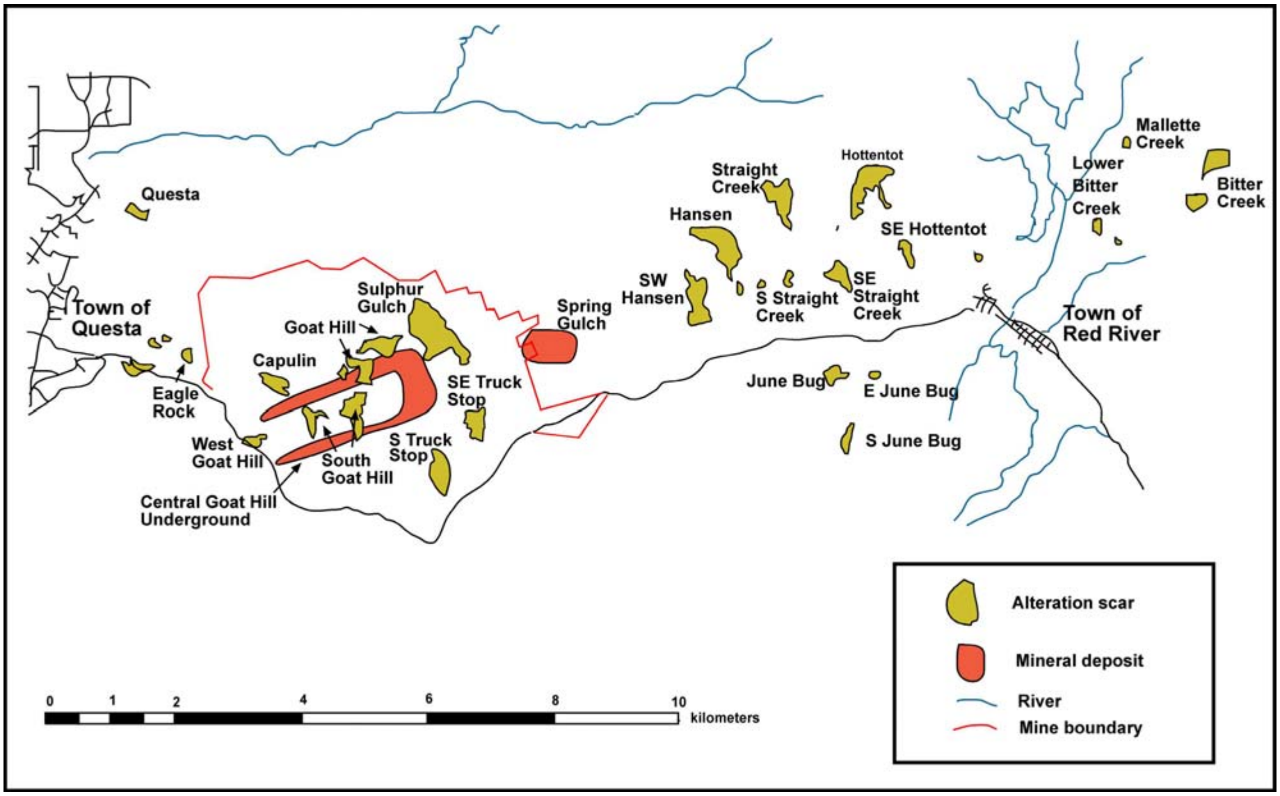


FIGURE 7-7. Map showing the alteration scars and mineral deposits of the Red River area. Alteration scar names from Meyer and Leonardson (1990).

LOCATION OF CRUST SAMPLES (DRA-8; Giese et al., 2008)

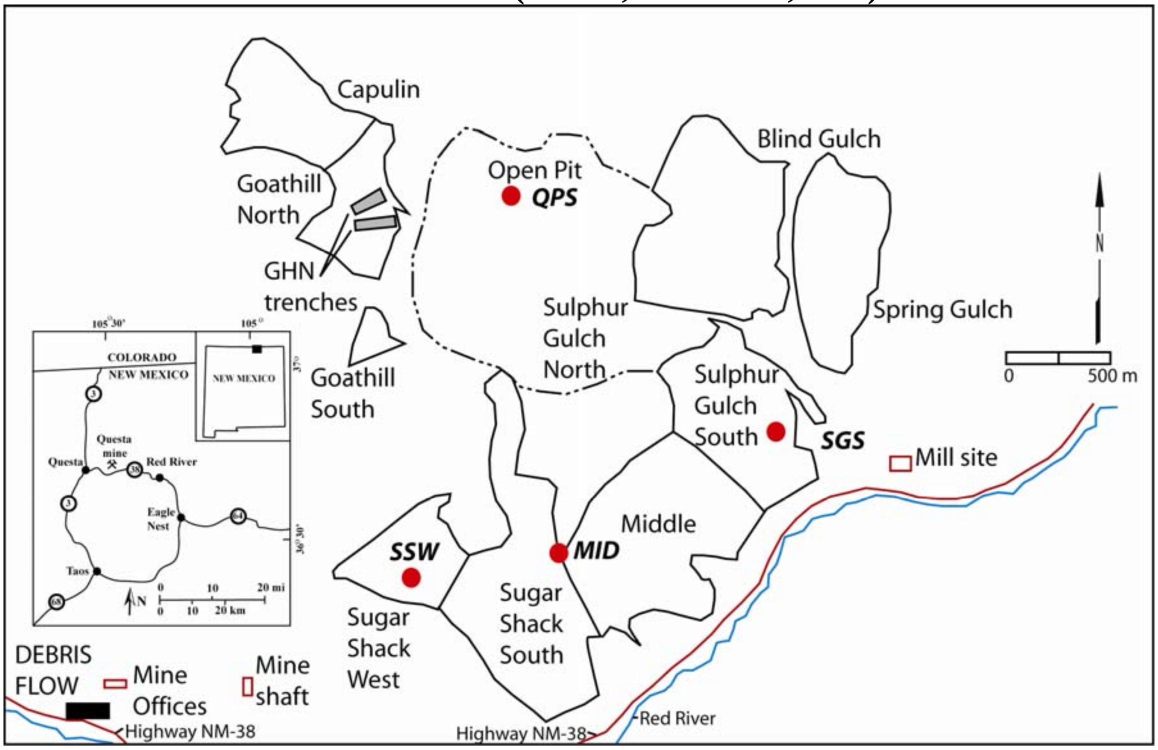


FIGURE 7-8. Questa rock piles and other mine features, including approximate locations of crust samples (Table 7-4).

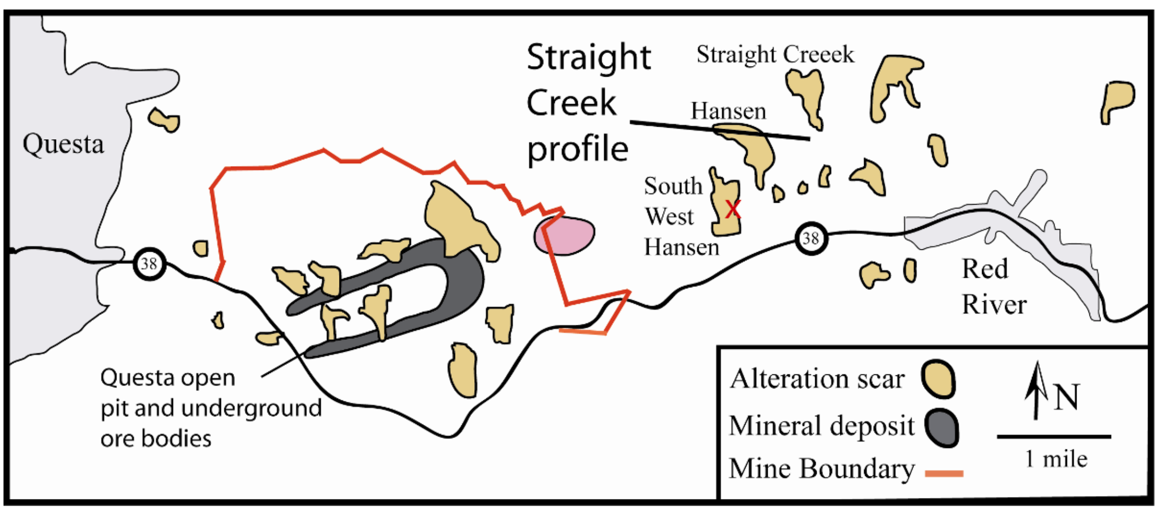


FIGURE 7-9. Location of alteration scars in the Red River valley, including the approximate location of the crust sample from Southwest Hansen (SWH sample).

TABLE 7-4. Location and sample type of crust samples. *Samples collected by D.C. Jacobs, approximate location taken near SSW-VTM-0010.

Sample Number	Sample type	UTM easting (m)	UTM northing (m)	Elevation (ft)
SSW-VTM-0006	Crust	453668	4060609	9054
SSW-VTM-0008	Sub-Crust	453668	4060609	9054
SSW-VTM-0010	Crust	453691	4060578	9015

Sample Number	Sample type	UTM easting (m)	UTM northing (m)	Elevation (ft)
SSW-VTM-0012	Sub-Crust	453691	4060578	9015
SSW-VTM-0013	Crust	453802	4060691	9319
SSW-VTM-0015	Sub-crust	453802	4060691	9319
SGS-VTM-0024	Crust	454271	4061364	9454
SGS-VTM-0026	Sub-Crust	454271	4061364	9454
QPS-VTM-4001	Crust Before (none taken after)	454155	4062554	9621
MID-VTM-4000	Runoff Jug	454277	4060551	9314
MID-VTM-4001	Crust before	454265	4060535	9293
MID-GJG-4001	Crust above MID-VTM-4000 After	454277	4060551	9314
SWH-VTM-4000	Runoff Jug	458734	4062430	8717
SWH-VTM-4001	Crust Before	458734	4062430	8717
SWH-GJG-4000	crust above SWH-VTM-4000 After	458734	4062430	8717
SSW-VTM-4001	Crust Before	453693	4060537	8977
SSW-VTM-4000	Runoff Jug	453699	4060533	9017
SSW-GJG-4000	Crust above SSW-VTM-4000 After	453699	4060533	9017
HAS-GJG-4000	creek drainage	458802	4061912	8425
SWH-GJG-4001	creek drainage	458696	4062385	8648
QPS-GJG-4000	puddle	454349	4062555	9524
MID-GJG-4000	puddle	455280	4061460	8846
MID-GJG-4002	puddle	454559	4060902	9320
MIN-GJG-4000	puddle	455741	4061450	8638
CAT-GJG-4000	Catchment pond	455455	4061676	8633
SSW-DCJ-0003*	Crust	453691	4060578	9015
SSW-DCJ-0004*	Crust	453691	4060578	9015
SSW-DCJ-0005*	Crust	453691	4060578	9015
SSW-DCJ-0006*	Crust	453691	4060578	9015

LOCATION OF HOT ZONE SAMPLES (DRA-7, 9, 10; McLemore et al., 2008c)

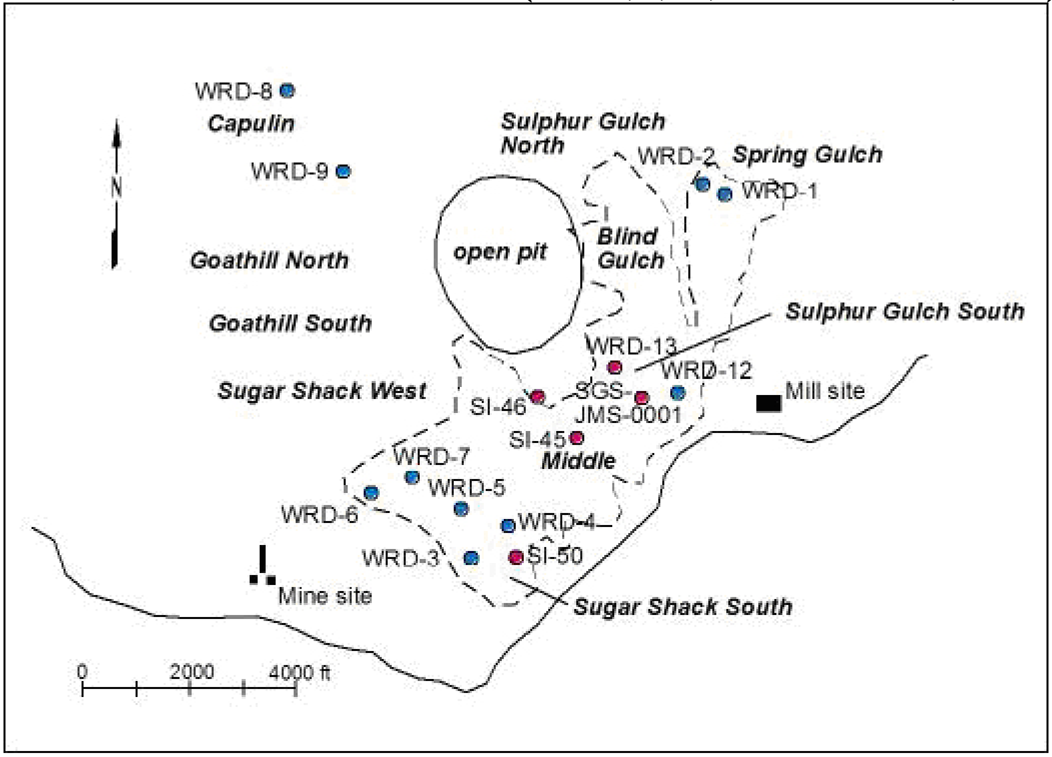


FIGURE 7-10. Location of venting drill holes (Table 7-5) and surface vent area (SGS-JMS-0001). Blue circles indicate drill holes drilled in 1999 that contain monitoring instruments for temperature, O_2 and CO_2. Red circles indicate drill holes and a surface vent area that do not contain temperature and gas instrumentation and are sites monitored by the NMIMT team.

TABLE 7-5. Drill holes through the hot zones (Robertson GeoConsultants, 1999; URS Corporation, 2003).

Drill Hole Number	Location	Total Depth (ft)	Date drilled	Type of thermal data	Depth rock pile (ft)	Depth colluvium (ft)	Depth weathered bedrock (ft)	Depth bedrock (ft)
WRD-1	SPR 4062356 N 455778 E 9076.8 ft	100	7/31/1999	Instrumented for temperature, O_2, and CO_2	100			
WRD-2	SPR 4062410 N 455619 E 9279.4 ft	75	7/31/1999	Instrumented for temperature, O_2, and CO_2	75			
WRD-3	SSS 4060204 N 454248 E 8717.3 ft	100	7/30/1999	Instrumented for temperature, O_2, and CO_2, gas analysis	120			
WRD-4	SSS 4060413 N 454506 E 8908.79 ft	75	7/29/1999	Instrumented for temperature, O_2, and CO_2,	75			

Drill Hole Number	Location	Total Depth (ft)	Date drilled	Type of thermal data	Depth rock pile (ft)	Depth colluvium (ft)	Depth weathered bedrock (ft)	Depth bedrock (ft)
				gas analysis				
WRD-5	SSS 4060510 N 454179 E 9267.3 ft	80	8/1/1999	Instrumented for temperature, O_2, and CO_2	80			
WRD-6	SSW 4060572 N 453698 E 8976.1 ft	60	8/4/1999	Instrumented for temperature, O_2, and CO_2	60			
WRD-7	SSW 4060680 N 453908 E 9433.8 ft	80	8/2/1999	Instrumented for temperature, O_2, and CO_2	80			
WRD-8	Capulin 4062975 N 453173.8 E 9816.6 ft	85	8/3/1999	Instrumented for temperature, O_2, and CO_2	85			
WRD-9	Capulin 4062581 N 453505 E 9790.6 ft	125	8/3/1999	Instrumented for temperature, O_2, and CO_2	120			
WRD-13	SGS 4061349 N 455109.6 E 9067.87 ft			gas analysis	199			
SI-1	SSW 4060693 N 453869 E 9429.7 ft	208	9/21/2002		197			197 - 208
SI-2	SSS 4060198 N 454228 E 8719 ft	140	9/23/2002		130.7			130.7 - 140
SI-4	Middle 4060594 N 454853.2 E 8663.0 ft	284	10/5/2002		272.25			272.25 - 284
SI-6	SGS 4060893 N 455116.9 E 8645.3 ft	298	10/3/2002		284			284 - 298
SI-36	SSW 4060682 N 453801.8 E 9301.3 ft	233			182	182 - 184	184 - 211	211-233
SI-37	SSW 4060645 N 453883.3 E 9429.1 ft							
SI-39	SSW 4060633 N 453668 E							

Drill Hole Number	Location	Total Depth (ft)	Date drilled	Type of thermal data	Depth rock pile (ft)	Depth colluvium (ft)	Depth weathered bedrock (ft)	Depth bedrock (ft)
	8955.3 ft							
SI-44	SGS 4061055 N 454913 E 9046.4 ft	255	7/25/2004	gas analysis	241	241-244 or 246	244 or 246 - 250	>250
SI-45	Middle 4060686 N 454750.2 E 8899.4 ft	145	8/7/2004	gas analysis	145			
SI-46	SSS 4060456 N 454340.3 E 9136.91 ft	437	8/12/2004	gas analysis	388			388 - 437
SI-47	SSS 4060690 N 454331 E 9420.7 ft	265.5	7/11/2004		134		134 - 165	165 - 265
SI-48	Middle 4061069 N 454410.5 E 9320.2 ft	273	7/16/2004		185	185-201	201-215	215 273
SI-49	SSS 4059932 N 454521.1 E 7991.9 ft	149	8/19/2004		159			
SI-50	SSS 4060246 N 454388.6 E 8710.1 ft	119	8/19/2004	gas analysis	304	304-400		400-453
SI-51	SGS 4060767 N 455319.7 E 8173.4 ft	187	8/19/2004		153			
SI-52	SGS 4061065 N 455349.5 E 8566.4 ft	237	11/15/2004		184	184-197		197-246
SI-53	4060452 N 455160 E 8054.4 ft							
SI-62								
MMW 37A	SSS 4060246 N 454400.1 E 8707.58 ft	360	10/12/2000		345	345-360		

LOCATION OF MEGASAMPLES SENT TO GOLDER FOR GEOTECHNICAL TESTING (DRA-49)

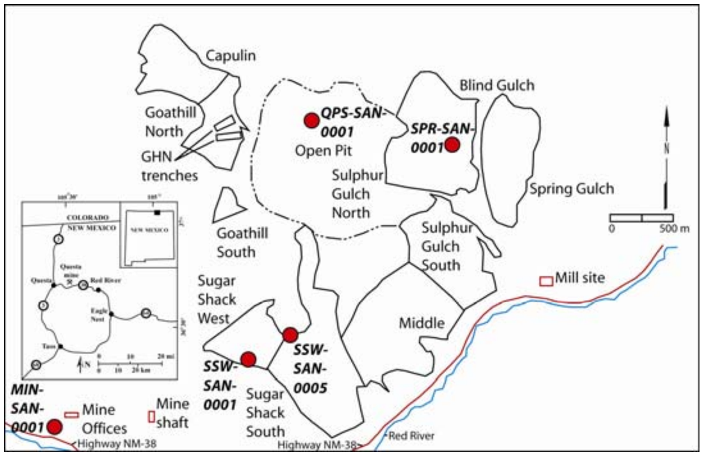


FIGURE 7-11. Location of megasamples, Questa mine, New Mexico.

LOCATION OF SAMPLES FOR CHEMICAL ANALYSES OF PARTICLE SIZE FRACTIONS (DRA-7a)

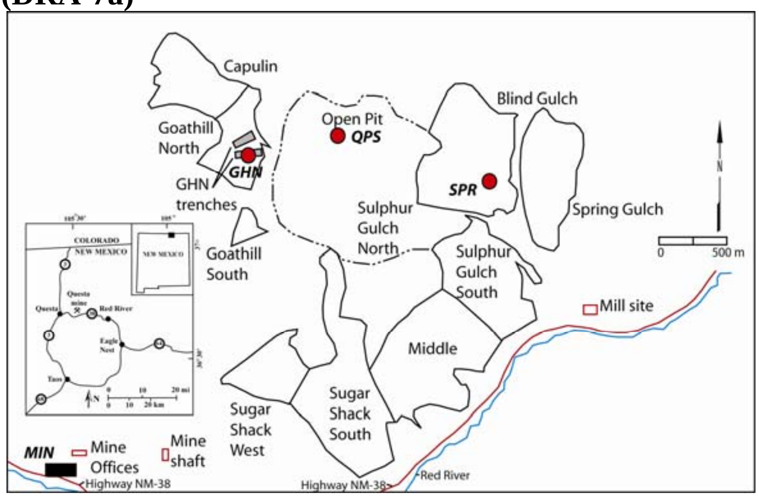


FIGURE 7-12. Questa rock piles and other mine features, including approximate locations of samples used for particle size analysis.

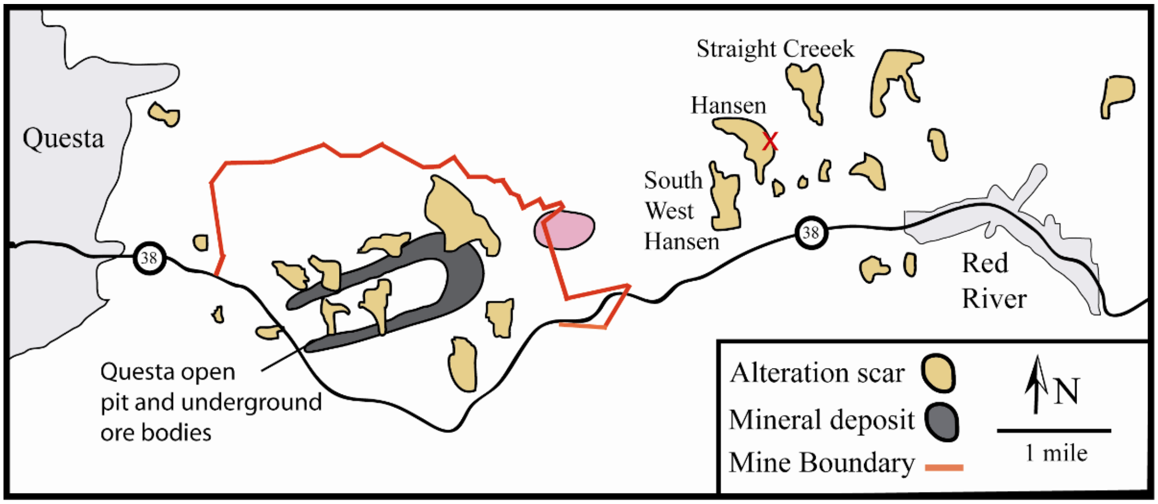


FIGURE 7-13. Location of alteration scars in the Red River valley, including the approximate location of the samples for particle size analysis from Hansen alteration scar (HAS samples; Graf, 2008).

TABLE 7-6. Samples used for the particle size fraction study. The geologic unit for samples from GHN is in parenthesis and described in more detail in McLemore et al. (2008a). Locations of samples are in Figures 7-12 and 7-13.

Location	Samples	Number of Size Fraction	Size Fractions (inches)
Goathill North (GHN) rock pile	GHN-JRM-0001 (J) GHN-JRM-0002 (N) GHN-KMD-0088 (O)	5	0.75, 0.5, 0.187, 0.0787, <0.0787
Goat Hill Debris Flow	MIN-AAF-0001 MIN-AAF-0004 MIN-SAN-0002	5	1, 0.75, 0.5, 0.187, 0.0787
Questa Pit Alteration Scar	QPS-AAF-0001 QPS-AAF-0003 QPS-AAF-0005 QPS-AAF-0009 QPS-SAN-0002	5	1, 0.75, 0.5, 0.187, 0.0787
Spring Gulch (SPR) rock pile	SPR-SAN-0002	4	0.75, 0.5, 0.187, 0.0787

LOCATION OF WEATHERED BEDROCK PROFILE (DRA-21; McLemore, 2008)

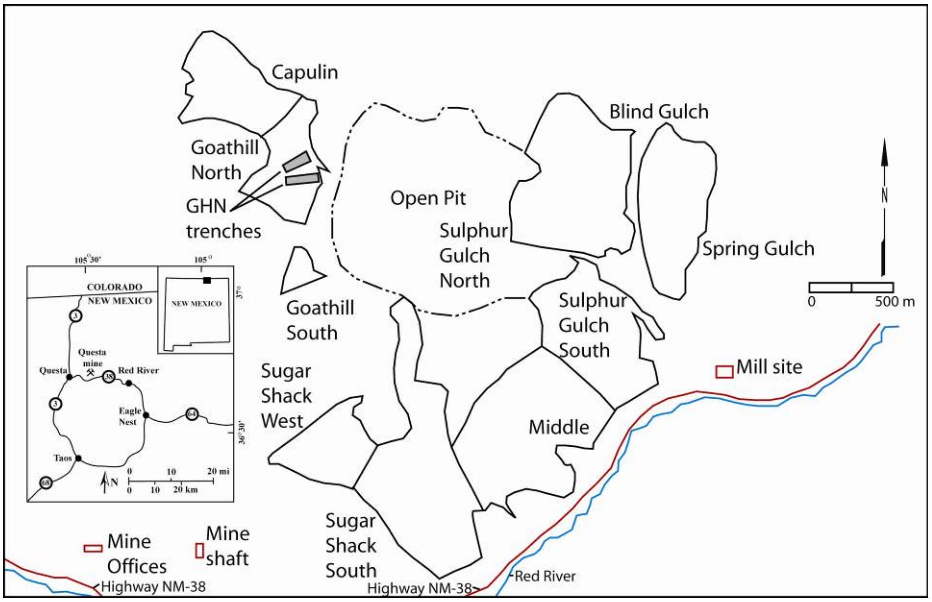


FIGURE 7-14. Location of weathered bedrock profile in Trench LFG-019, bench 42.

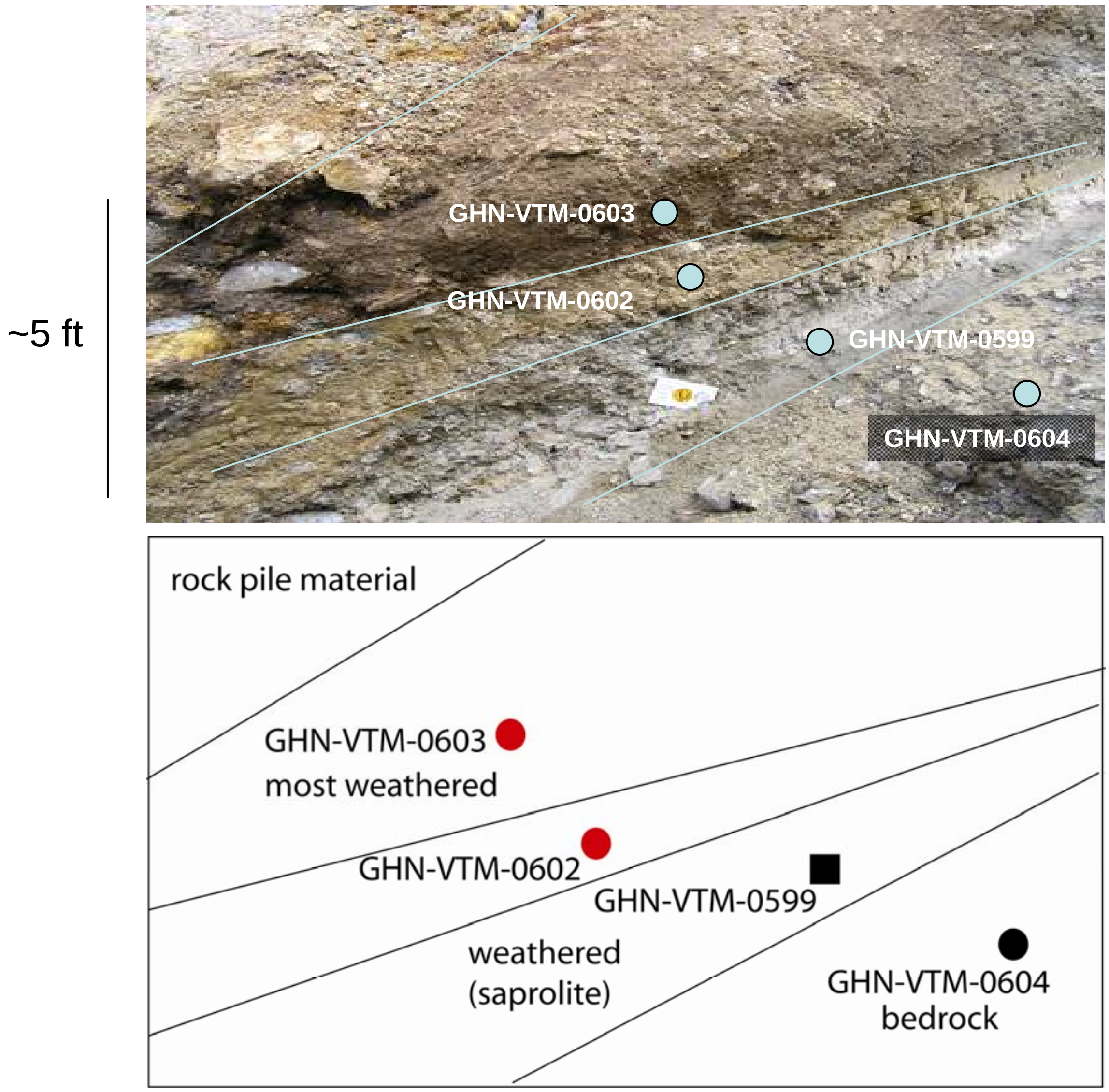


FIGURE 7-15. Photograph looking down into the trench and descriptive sketch of weathering profile in LFG-019, Bench 42. Scale bar is approximate. Symbols show location of collected samples. Red dots are weathered bedrock, the black square is saprolitic andesite and the black dot is unweathered bedrock. Collected samples consist of a bulk grab of rock material stored in 5 gallon buckets and includes matrix (soil) and rock fragments. The dip of the layers is subparallel to the actual slope where the trench was constructed.

LOCATION OF DEBRIS FLOW PROFILE (DRA-22; Ayakwah et al., 2008)

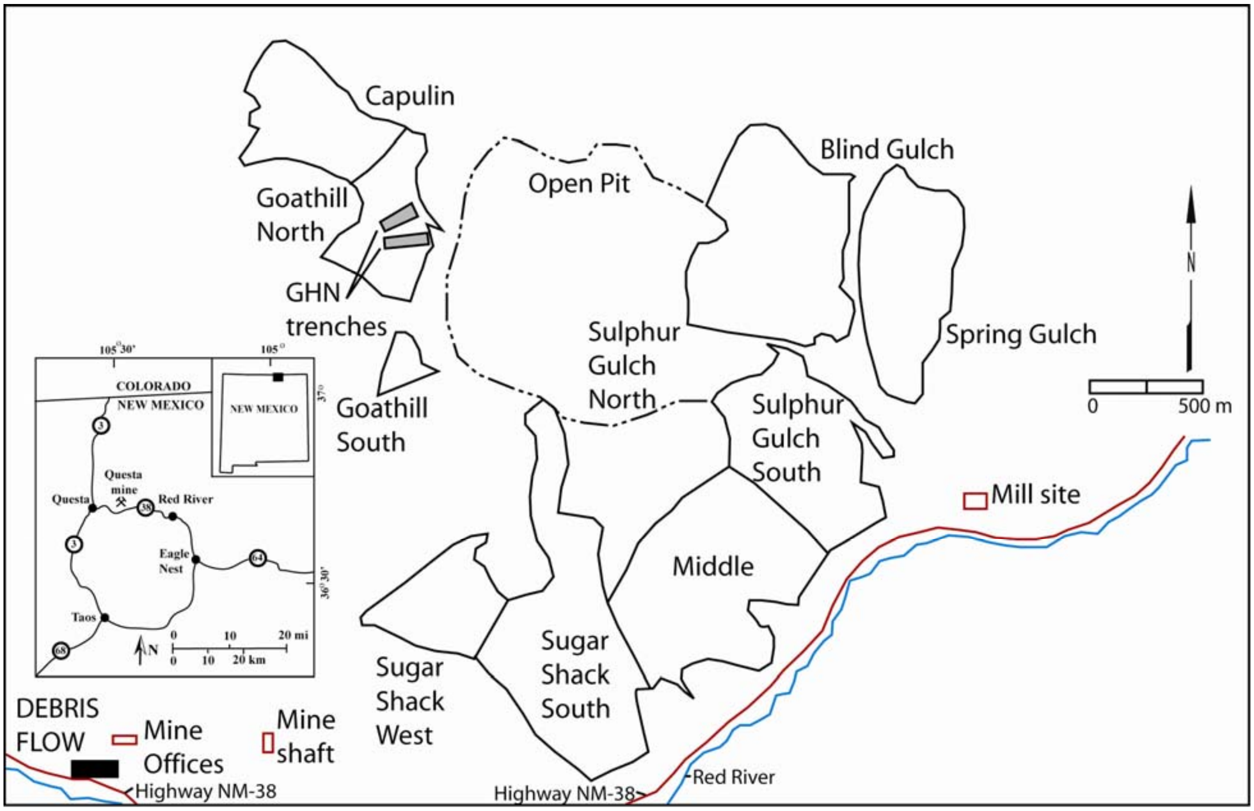


FIGURE 7-16. Location map of the Goat Hill debris flow.

FIGURE 7-17. Location of samples taken from the debris flow.

LOCATION OF WATER SAMPLES

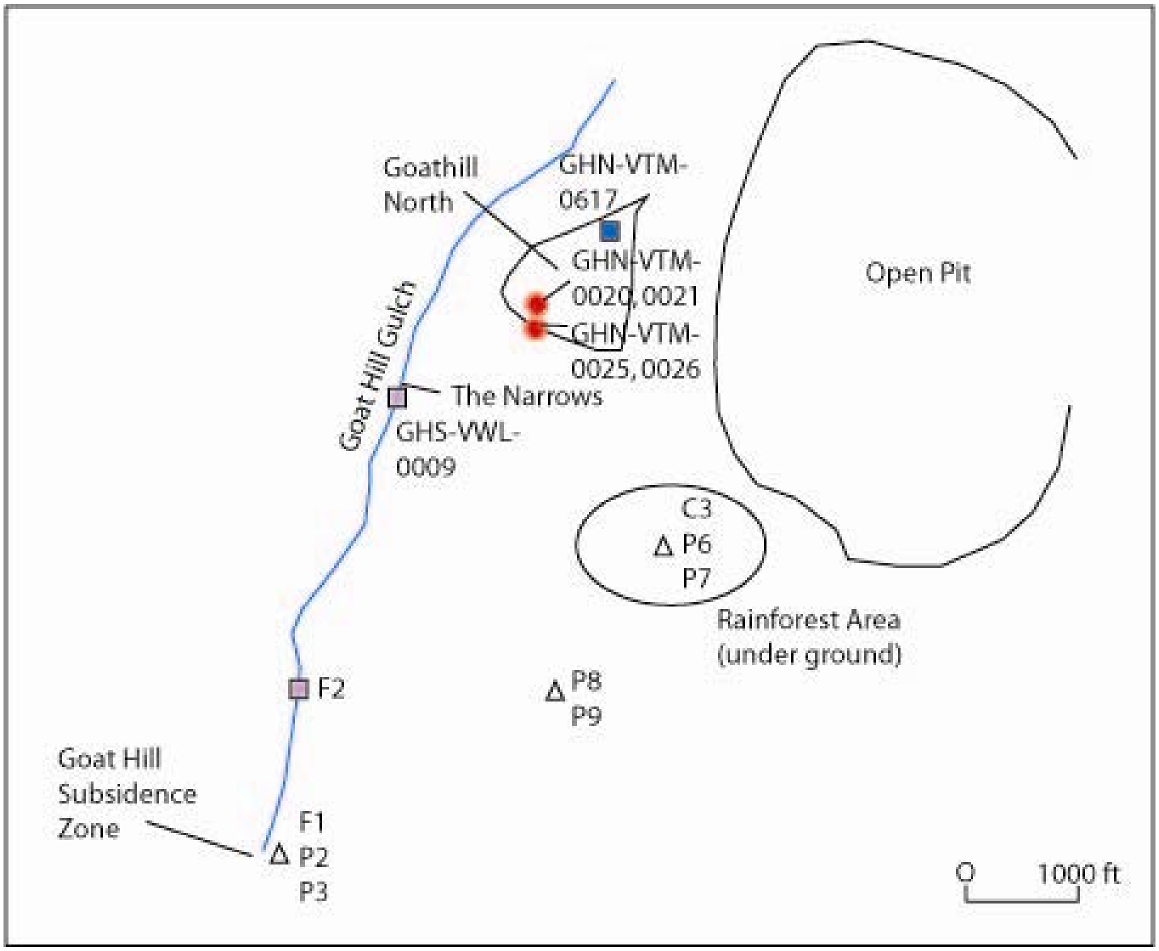


FIGURE 7-18. Location of water samples

TABLE 7-7. Description of water samples from GHN and surrounding areas.

Field id	Area
GHN-VTM-0020	toe of GHN rock pile
GHN-VTM-0021	toe of GHN rock pile
GHN-VTM-0025	toe of GHN rock pile
GHN-VTM-0026	toe of GHN rock pile
GHN-VTM-0617	Trench LFG-021
GHS-VWL-0009	Narrows
F-2	Goathill Gulch surface flow
F-1	Goathill-below subsidence
P-2	Goathill-below subsidence
P-3	Goathill-below subsidence
P-8	old workings
P-9	old workings
C-3	rainforest
P-6	rainforest
P-7	rainforest