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Study Plan for
Study 8.3.1.4.2.2

Characterization of Structural Features in the Site Area

Revision 1

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

Prepared by
U.S. Geological Survey

102.8

YUCCA MOUNTAIN PROJECT

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Study Plan Title Characterization of Structural Features in the Site Area

Revision Number 1

Prepared by: United States Geological Survey

Date: July 8, 1991

4/16/92
Director, Regulatory and Site Evaluation Division / Date

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STUDY PLAN 8.3.1.4.2.2

CHARACTERIZATION OF STRUCTURAL FEATURES IN THE SITE AREA

Abstract

The overall objective of this Study is to determine the frequency, distribution, characteristics, and relative chronology of structural features within the Yucca Mountain site area.

Surface and subsurface structural studies will be performed to identify and characterize fracture-fault systems within the site area. Detailed geologic mapping of zonal features in ash-flow tuffs that crop out at the surface of Yucca Mountain will provide the necessary stratigraphic control for identifying small-scale faults. Characteristics and lateral variability of fracture networks will be studied by detailed mapping and pavement analysis. Subsurface distribution and geologic characteristics of fracture-fault zones will be studied by analysis of core samples, borehole evaluations, exploratory shaft studies, and application of geophysical techniques.

Geologic mapping of the exploratory shaft and drifts will include conventional mapping, detailed fracture mapping, and photogrammetric mapping and recording. Borehole evaluations in the exploratory shaft facility after drilling and coring will include video, geophysical and vertical seismic profiling surveys. Studies of fracture networks in the shaft, drifts, and boreholes will be conducted to evaluate the chronology of fracture development.

The results of these activities will be integrated with results of hydrologic studies to provide information for the development of three-dimensional geologic models of the site. These models will support modeling of hydrologic potential pathways, particularly in unsaturated zones, and are also expected to aid the development of tectonic models and determination of the mechanical response of fractured rock to excavation and thermal loading.

CONTENTS

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STUDY PLAN 8.3.1.4.2.2

CHARACTERIZATION OF THE STRUCTURAL FEATURES IN THE SITE AREA

PREFACE

This study plan summarizes and extends the discussion of Study 8.3.1.4.2.2 in the Site Characterization Plan (SCP). Sections 1, 4, and 5, which show the study in the context of the total site characterization program, are drawn principally from the SCP and related Yucca Mountain Project documents. Sections 2 and 3 discuss the rationales for the planned tests and analyses, and present details of the plans beyond those described in the SCP.

Principal authors of the study plan include C.C. Barton, E.E. Glick, R.B. Scott, R.W. Spengler, R.A. Thompson, and C.K. Throckmorton of the U.S. Geological Survey; S. Beason and M. McKeown of the U.S. Bureau of Reclamation; and E.C. Majer of the Lawrence Berkeley Laboratory.

STUDY 8.3.1.4.2.2

CHARACTERIZATION OF THE STRUCTURAL FEATURES IN THE SITE AREA

This study plan summarizes and supplements the discussion of section 8.3.1.4.2.2 of the SCP. This study consists of five activities:

- 8.3.1.4.2.2.1: geologic mapping of zonal features in the Paintbrush Tuff at a scale of 1:12,000,
- 8.3.1.4.2.2.2: surface fracture-network studies,
- 8.3.1.4.2.2.3: borehole evaluation of fractures and faults,
- 8.3.1.4.2.2.4: geologic mapping of the exploratory shaft and drifts, and
- 8.3.1.4.2.2.5: seismic tomography and vertical seismic profiling.

The relation of the study to the rock characteristics program is shown in figure 1-1.

1 PURPOSE OF THE STUDY

1.1 Information to be obtained and how that information will be used

The purpose of this study is to define the geologic structure of the Yucca Mountain site area (fig. 1-1). Data will be collected on the geometry, spatial distribution, chronology, and physical features of fault and fracture systems at Yucca Mountain. The study will also contribute lithostratigraphic data to the program (from the geologic mapping of the shaft and drift walls), although stratigraphic data will be collected mainly in Study 8.3.1.4.2.1.

Fracture and fault systems within the controlled area will be identified and characterized by surface and subsurface studies. The stratigraphic control necessary for identifying small faults will be provided by detailed geologic mapping of zonal features in the ash-flow tuffs that crop out on Yucca Mountain. Lateral variability of fracture networks will be studied by detailed mapping and pavement analysis (Barton, 1986; Barton and others, 1986; Barton and Larsen, 1985; Barton and others, 1985; Barton and others, 1986). Subsurface distribution and geologic characteristics of fracture and fault zones will be studied by core-sample analysis, borehole evaluations, exploratory-shaft studies, and use of geophysical techniques. Results of these studies will be integrated with the results of hydrologic studies to provide a basis for developing conceptual geologic models of the site, as further discussed in sections 1.2 and 4.

The information to be obtained from this study will contribute to the geologic framework component of a three-dimensional geologic model of the Yucca Mountain site, which is in turn one of four components of a three-dimensional rock characteristics model (fig 1-2; SCP fig. 8.3.1.4-1). The other three components are the geohydrologic, geomechanical, and thermal-mechanical models (SCP figure 8.3.1.4-1). As shown in SCP figure 8.3.1.4-1, the geologic framework has three components: rock unit geometry and properties, fracture geometry and properties, and fault geometry and properties. Each component encompasses a set of site characterization parameters, and each characteriztion parameter contains a subset of activity parameters. The activity parameters for each activity are discussed in section 3. This information flow exists so that the data collected in this study can provide input to a computer-based representation of the physical properties of the rocks at the site. This highest-level model will then provide input for numerical computer analyses of the repository that involve hydrologic, thermal, thermomechanical, and geochemical processes.

Uses of the information obtained from this study are summarized in figure 1-3. The information will be used in the three-dimensional geologic model of the rock characteristics program. Uses of the information for meeting design and performance goals and regulatory requirements are discussed in section 1.2; uses of the information obtained from each activity for meeting performance goals are discussed in sections 3.1.9, 3.2.9, and 3.4.9; uses of the information for supporting other studies are discussed in section 4.

1.2 Rationale and justification for the information to be obtained

Table 1-1 is a guide to why the information to be obtained in the study is needed to satisfy performance and design goals and regulatory requirements. It shows information needs to be satisfied by this study, and table 1-2 shows how the information will be used to satisfy tentative goals for design and performance issues. Table 1-2 summarizes data from the performance allocation tables for design issues 1.11 (SCP sec. 8.3.2.2), 1.12 (sec. 8.3.3.2), and 4.4 (sec. 8.3.2.5) and for performance issues 1.1 (sec. 8.3.5.13) and 1.6 (sec. 8.3.5.12). The *application* column of the table describes how the information from design and performance parameters will be used in issue resolution. The *design/performance parameter* column contains data categories receiving information gathered under site-characterization parameter categories in this study. The *tentative goal* column shows the accuracy with which measurements are to be made for design parameters or the nature of the measurement to be made for performance parameters. The tentative goals are explained in the SCP. The *needed confidence* column shows the needed confidence which is associated with the given goal for the design and performance parameters that must be known to satisfy the design and performance issues.

The study also provides input to performance issues 1.8 (NRC siting criteria) and 1.9 (higher-level findings, postclosure system and technical guidelines) through its contributions to issues 1.1 and 1.6.

Although no regulations explicitly call for this study, the information to be obtained is needed to comply with the regulatory requirements discussed in section 8.3.1.4 of the SCP. Briefly, those regulatory requirements, and the means for satisfying them, are--

- siting criteria (10 CFR 60.122), by characterizing structural conditions to determine if favorable or potentially adverse conditions are present;

- performance objectives (10 CFR 60.112 and 60.113), by demonstrating that--

  the overall system performance of the geologic repository limits releases of radioactive material to the accessible environment to levels specified by EPA requirements;

  pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel to the accessible environment is at least 1,000 years;

- design criteria for the underground facility (10 CFR 60.133), for the seals of shafts and boreholes (60.134), and for waste packages (60.135), by characterizing the properties of the host rock and surrounding units.

2 RATIONALE FOR SELECTING THE STUDY

Section 2 discusses the bases for selecting the tests planned for Study 8.3.1.4.2.2. The SCP (sec. 8.3.1.4.2.2) discusses the bases for selecting the study, in the context of the rock characteristics program.

2.1 Activity 8.3.1.4.2.2.1: Geologic mapping of zonal features in the Paintbrush Tuff at a scale of 1:12,000

Geologic mapping has been completed for the area shown in figure 2.1-1. The mapping has been compiled onto 1:12,000-scale topographic bases, and the northeast segment of the mapped area (fig. 2.1-1) has been published (Scott and Bonk, 1984).

Conventional geologic methods were chosen for the field mapping and for transferring the map data to topographic base maps: the selected method (described below) was chosen so as to provide the required parameters (table 2.1-1) with minimal field and compilation time. A primary mapping scale of 1:12,000 was selected because it is large enough to accurately show the zonal features that reveal the geologic structures of interest in this study and small enough to conveniently depict those features across the selected map area on only four map sheets or panels. The selected method is described generally in section 3.1.1 and more specifically in section 3.1.2, as well as in the Technical Procedure for geologic mapping (GP-01).

Emphasis was on mapping zonal features--identifiable textural and mineralogical variations in the ash-flow and bedded tuffs, manifested as mappable subunits distinguished by color, mineralogy, texture, or erosion pattern. These zonal features were mapped as the basis for recognizing and mapping structures (mainly faults) within the area shown on figure 2.1-1 and for identifying fault displacements as small as a few meters. The mapping of the zonal features complements the stratigraphic mapping of Study 8.3.1.4.2.1; the study of the structures revealed by the zonal features complements the detailed study of fractures at the surface (Activity 8.3.1.4.2.2.2).

2.1.1 Rationale for the types of tests selected

Selection of the geologic mapping method required considering what mapping technique and what mapping scale best provide the required parameters. Three conventional mapping techniques were considered: a) aerial photographic reconnaissance (airphoto reconnaissance), b) topographic-map-assisted field mapping (topo-assisted mapping), and c) aerial-photograph-assisted field mapping (photo-assisted mapping).

The photo-assisted field mapping method was selected because it is well suited to semiarid to arid terrain with good to excellent exposures (Lahee, 1961; Compton, 1962); the good exposures at Yucca Mountain allow for quick and accurate location of geologic features and data points. Photo-reconnaissance was rejected because many of the required parameters (table 2.1-1) can be gathered only through extensive field observations. Such parameters (e.g., fault and fault-zone attitudes, fault and fault-zone characteristics, and chronology of faulting) require observation of geologic features too small to be seen on the air photos. For example, the attitudes of striae on slickensided surfaces of faults record the latest direction of movement of faults. Similarly, the detailed zonal features to be mapped (e.g., stratigraphic details in the tuffs) cannot feasibly be identified without field observations. Photo-assisted mapping was chosen over topo-assisted mapping to facilitate accurate extrapolation of zonal contacts and fault traces between field traverses.

A scale of 1:12,000 was selected as the primary mapping scale for mapping the zonal features and revealing the geologic structures of interest to this study in ways that will complement existing and planned mapping. That scale was an obvious extension of published 1:24,000-scale geologic maps (Christiansen and Lipman, 1965; Lipman and McKay, 1965), which delineate regional geologic relations but did not define the thin zonal features and the detailed structures required for this study. A larger scale (e.g., 1:6,000 or greater) was not selected because: a) the 1:12,000 scale is adequate to show the structural geometry necessary to construct structural and tectonic models of Yucca Mountain; b) a map of the entire area shown in figure 2.1-1 at a scale larger than 1;12,000 would require more than four large sheets or panels (16 map panels for a scale of 1:6,000); and c) the time required for geologic mapping is approximately proportional to the square of the map scale. The primary mapping scale will be supplemented by local mapping at larger scales, as appropriate, to show small-scale stratigraphic and structural detail. Complementary studies (e.g., 1:50-scale mapping of surface fractures in Activity 8.3.1.4.2.2.2) also will provide additional detail within the framework established by the mapping of this activity.

2.1.2 Rationale for the number, location, duration, and timing of the selected tests.

2.1.2.1 Number

The photo-assisted mapping method was chosen because it readily allowed for enough tests to provide the required data: photo-reconnaissance would not have provided the required field data, and topo-assisted mapping would have provided data of comparable accuracy somewhat less efficiently. The number of tests (field observations plotted on the maps) was a function of the availability of data and of the relation of the 1:12,000-scale geologic mapping to other studies. In areas having thick unzoned units with few faults, observations of zonal features were necessarily few. By contrast, in areas having thin units and abundant faults, the number of observations was limited to the number that could be expressed at the scale of 1:12,000; further observations will be part of other activities (e.g., Activity 8.3.1.4.2.2.2, as noted above) designed to focus on structural details beyond the scope of this study.

2.1.2.2 Location

The choice of the area to be mapped was independent of the choice of mapping method. The mapped area (fig. 2.1-1) was selected on the basis of the professional judgment that relatively detailed data in the required categories (parameters) are needed for the area surrounding the potential repository. (The perimeter drift bounding the repository is shown in fig. 2.1-1). The area that has been mapped includes all exposures on Yucca Mountain between Jackass Flats and Crater Flat. The area to the north of the repository block was mapped to a locality north of Yucca Wash where the structural style changes from that typical of the repository block. All the exposures south of the block were mapped to the Amargosa Desert because the degree of structural deformation increases southward and the hydrologic flow paths below the water table are also in that direction. Alluvial cover to the east (Jackass Flats), to the south (Amargosa Desert), and to the west (Crater Flat) prevents the continuation of bedrock mapping in those directions.

2.1.2.3 Duration and timing

The duration and timing of the mapping and compilation have been dictated largely by an attempt to provide, early in the program, a detailed geologic map of the area immediately surrounding Yucca Mountain. Mapping began in FY-1982 and continued intermittently to FY-1986; transfer of field data to a topographic base was finished in FY-1987; and compilations of geologic maps and sections will be finished by FY-1988. The photo-assisted mapping method was chosen because it required the minimum amount of field and compilation time compatible with getting the necessary detailed geologic data.

2.1.3 Constraints: factors affecting the selection of tests

The selected mapping method is one of several conventional methods for geologic mapping. In terms of the nine factors discussed below, it differs from alternative mapping methods mainly in that it facilitates efficient compilation of data of uniformly high accuracy throughout the map area.

2.1.3.1 Impacts on the site

None of the alternative mapping methods would have any appreciable effect on the ability of the repository to isolate the waste.

2.1.3.2 Simulation of repository conditions

Not applicable: none of the mapping methods would attempt to simulate repository conditions.

2.1.3.3 Required accuracy and precision

Because the 1:24,000 topographic base was the only base available, the accuracy with which information could be transferred to that base assumed dominance in the choice of test method. If greater accuracy is required locally or regionally, a larger-scale base map will be needed. The photo-assisted mapping method was selected because it allowed for efficient and accurate transfer of zonal and structural contacts to the topographic base. Similarly, because of the high quality of exposure at Yucca Mountain, the photo-assisted method facilitated accurate data-recording, by allowing for efficient and accurate extrapolation between field traverses and thus for uniformly high accuracy in plotting data throughout the map area. (See sec. 3.1.4.)

2.1.3.4 Limits of analytical methods

Not applicable: the choice of mapping method was not affected by the limits of analytical methods.

2.1.3.5 Capability of analytical methods

Not applicable: the choice of mapping method was not affected by the capabilities of analytical methods.

2.1.3.6 Time constraints

The photo-assisted mapping method was selected because it efficiently provided the required data early enough so that they could be used in key documents and decisions (e.g., the site characterization plan).

2.1.3.7 Scale and applicability

Not applicable: the choice of mapping method would not affect the ability of the map to represent the required parameters within the map area either before or after closure.

2.1.3.8 Interference with other tests

The mapping has been completed without interference with other tests. The photo-assisted mapping method was chosen largely because of its efficiency and applicability of results: less efficient mapping methods could conceivably have interfered with other tests.

2.1.3.9 Interference with the exploratory shaft

Mapping has been completed without interfering with the exploratory shaft. The photo-assisted method was chosen so that fieldwork could be completed before construction of the shaft began.

2.2 Activity 8.3.1.4.2.2.2 Surface fracture-network studies

This activity will gather detailed information on fracture properties in the volcanic bedrock units exposed at the surface of Yucca Mountain. These data will be integrated with information gathered in other activities in this study (investigations of regional surficial and local subsurface fractures).

2.2.1 Rationale for the types of tests selected

Three test methods were considered for surface fracture studies: 1) bedrock-pavement (pavement method), 2) uncleared-outcrop method (outcrop method), and 3) photogeologic method. For the pavement method, cleared bedrock surfaces are mapped, and fracture parameters (table 2.2.1) are recorded. For the outcrop method, fracture parameters are recorded from natural outcrops. For the photogeologic method, linear features are mapped from aerial photographs by means of a stereoplotter. The pavement and outcrop methods (sec. 3.2.2) were chosen as complementary means for obtaining the required information on fractures. The photogeologic method was rejected on the basis of early prototype testing, but may be tested again in modified form if larger-scale photographs become available. The bases for selecting the methods are discussed below.

The planned test methods complement each other, in that the pavement method provides more complete data locally and the outcrop method allows for more widespread observations. (In general the methods do not gather data at the same locations.) Similarly, the pavement method provides data on fracture network properties (i.e., trace length, connectivity, spatial distribution) that can be obtained only by mapping the fracture traces, whereas the outcrop method generally provides only orientation, aperture, roughness, and mineral filling data, but may yield trace-length data where exposures are adequate and photographs are available for plotting. The pavement method can be used only on natural pavements or where debris is thin and readily cleared the location is accessible to the equipment needed for clearing, whereas the outcrop method can be used wherever there are natural exposures.

2.2.1.1 Uncleared-outcrop tests

Fractures are to be studied in natural outcrops because such exposures are widespread and allow for observations in many of the volcanic units at Yucca Mountain. Four of the seven required parameters (orientation, aperture, roughness, and fracture fillings) can be studied at outcrops. The incomplete exposure of natural outcrops precludes study of the fracture network (connectivity and spatial distribution).

2.2.1.2 Pavement tests

In order to obtain the required parameters that cannot be obtained from uncleared-outcrops, fractures also will be mapped on bedrock pavements. Whether natural or cleared by man, bedrock pavements that are entirely free of regolith and vegetation offer an opportunity to study, map, and measure fracture networks in two dimensions. If the pavement is large enough and properly situated, all seven of the parameters of this activity are obtainable. However, the traces of one type of fracture, faults, extend well beyond any expected pavement, and their length must be measured on geologic maps (Activity 8.3.1.4.2.2.1). Completed pavements range from 150 m^2 (1,615 ft^2) to 2,000 m^2 (21,500 ft^2 or nearly 0.5 acre).

2.2.1.3 Photogeologic mapping

In prototype tests of the photogeologic alternative (Throckmorton, 1987), most fracture traces were not discerned, because the quality of exposures was too poor and the photographic scale, though large (1:2,400), was too small: 66-87 percent of the fractures observed directly in the field were not detected on the photos. In addition, trace bearings and lengths measured on the photos differed from those measured in the field, indicating that many traces mapped from the photos represented lineations other than fractures.

2.2.2 Rationale for the number, location, duration and timing of the selected tests

2.2.2.1 Number

The number of tests anticipated for this activity (table 2.2-2) is determined by what is required for the mapping, measuring, observing, and sampling of fracture-network characteristics from exposures at the surface of Yucca Mountain. Throughout this activity a phased approach will be employed whereby the results from sites already studied in a given unit will be considered in determining the need for additional data from that unit.

The number of pavements to be studied is limited because few locations have adequate exposure and ready accessibility for clearing equipment. Seven sites have been completed to date (fig. 2.2-1), each yielding data from about 100 to 1,000 fractures.

The upper lithophysal unit of the Tiva Canyon Member will be the most extensively studied because it occupies approximately 60 percent of the surface area of Yucca Mountain and, therefore, is the most subject to infiltration of snow-melt and rain and is, by virtue of its extensive exposures, rich in evidence of the relative ages of fractures.

2.2.2.2 Location

Locations are chosen to provide lateral coverage and vertical sampling through the stratigraphic section exposed at the surface of Yucca Mountain. Pavement sites are limited to locations where debris cover is thin and where clearing equipment can operate. Outcrop sites are selected to provide systematic coverage of data from these surface-fracture network studies. Location of existing and potential pavement sites at Yucca Mountain are shown in figure 2.2-1.

The number of sites studied in each unit will be approximately proportional to its extent. Consequently, more sites will be located in the

Tiva Canyon Member of the Paintbrush Tuff, as it is the most widely exposed unit in the Yucca Mountain area.

2.2.2.3 Duration

The duration of the tests is dictated by the time required for making detailed field observations at the outcrop sites, mapping the pavement sites, and compiling and reducing the data. Typically, data from a single outcrop can be obtained in two or three days. Cleaning, mapping, and data collecting from a single pavement requires approximately eight weeks. However, production-line methods, and possibly the use of photogrammetric techniques, will appreciably decrease the average time required for each of a series of pavement studies.

2.2.2.4 Timing

Because the selection of pavement and outcrop sites depends in part on data from geologic mapping (Activity 8.3.1.4.2.2.1), the fracture studies were begun after that mapping was well underway. The schedule for future studies is dictated by the need to provide information to other activities, especially those involved in exploratory shaft and drift tests. (See secs. 4 and 5.)

Surface fracture-network studies are in part dependent upon data from geologic mapping (Activity 8.3.1.4.2.2.1) for efficient site selection. As that mapping is now completed, this activity is in line to move forward toward completion so that fracture data, data-handling techniques, and fracture-network concepts can be provided to other activities, especially those involved in exploratory shaft and drift tests.

2.2.3 Constraints: factors affecting the selection of tests

In terms of the nine factors discussed below, the methods planned for this activity have been found to yield the required parameters most efficiently and accurately.

2.2.3.1 Impacts on the site

Section 8.4.2.2.2 of the Site Characterization Plan describes those surface-based activities which may impact the ability of the site to isolate waste. Water usage during the clearing of pavements is the only aspect of this activity which may affect waste isolation characteristics at the site. As presently planned, two additional pavement studies might be conducted in the repository block within the area outlined by the perimeter drift (fig. 2.2-1).

The effects of water usage during site characterization on the performance of the site was analyzed in sections 8.4.3.2.5.1 and 8.4.3.3 of the Site Characterization Plan. Although water usage by this activity was not explicitly considered by these analyses, the water volume required for clearing of two pavements is small in comparison to the bounding analyses presented in section 8.4.3.3, and in comparison to the volumes of water which will be introduced by natural precipitation and other site activities (e.g. dust suppression, artificial infiltration study).

Based on these analyses, it appears that the introduction of water at the surface in conjunction with pavement preparation during this activity will have no effect on the ability of the site to isolate waste. Nevertheless, water usage for clearing pavements will be kept to a minimum. In order to limit the amount of water used, a mixture of water and compressed air (foam method) will be used in clearing pavements if an adequate compressor can be made available at the selected site.

2.2.3.2 Simulation of repository conditions

Not applicable: none of the study methods would attempt to simulate repository conditions.

2.2.3.3 Required accuracy and precision

The accuracy required in surface fracture network studies has not been determined; it was not a factor in selecting test methods. As fractal dimensions from subunits of the tuff sequence are expected to differ only slightly, the required accuracy of field measurements will be high to ensure that the slight differences are meaningful. Close-range photogrammetry may be required to largely eliminate errors emanating from field judgments and human bias, as well as to assist in rectifying measurements from nonplanar pavements.

Required accuracy, by definition, relates to generating data trends that are significant.

The tools and equipment used in these tests are standard and are designed to yield precision within acceptable tolerances. In order to assure consistency, pavement and outcrop study methods were selected partly because essentially the same equipment is used in each.

2.2.3.4 Limits of analytical methods

The planned test methods were selected because they will provide the required parameters for the analyses discussed in section 4. Several computer programs are being written to assist in analysis. Statistical evaluation and validation of field methods (data collecting) and of fractal analyses will be required to determine whether planned tests yield reproducable, significant results.

2.2.3.5 Capability of analytical methods

Not a factor in selecting study methods. Standard analytical and data-reduction methods will be used; most will be computer assisted.

2.2.3.6 Time Constraints

The largely standardized outcrop and pavement methods, and potentially the photogeologic method, were selected in order to get the study under way as early as possible to gain experience in data collecting prior to the beginning of complementary shaft and drift mapping. Techniques developed in this activity will be adopted at least in part by other activities.

2.2.3.7 Scale and applicability

Not applicable: alternative methods and types of equipment would not have affected the potential for extrapolating the measurements and observations.

2.2.3.8 Interference with other tests

The interrelationships of surface and sub-surface based activities are described in section 8.4.2.2 of the Site Characterization Plan. It is not currently possible to perform a final evaluation of the interference potential of this activity, since the location of future pavement areas have not been firmly established.

The most probable source of interference, if it exists, might arise from the use of water during clearance of pavements. Introduction of water at the surface could interfere with near-surface hydrologic monitoring or gas-phase circulation studies. All water used during pavement clearance will be tagged with non-toxic chemical tracers, allowing identification of water introduced during this activity, and providing a basis for correcting for interference effects, if they occur.

Pavement localities will be selected such that interference with other tests will be avoided or minimized. Tagged water used in clearing pavements will be kept to an absolute minimum. In order to limit the amount of water used, a mixture of water and compressed air (foam method) will be used in clearing pavements if an adequate compressor can be made available at the selected site.

2.2.3.9 Interference with exploratory shaft

These tests, irrespective of test method selected, do not interfere with or have the potential to interfere with the exploratory shaft.

2.3 Activity 8.3.1.4.2.2.3: Borehole evaluation of faults and fractures

This activity will gather detailed information on subsurface characteristics of fractures (including faults), from boreholes and cores that penetrate the volcanic bedrock units of the site area. Data from core samples, borehole-video-camera logs, and acoustic televiewer logs will be correlated to help determine the vertical and lateral variability of subsurface fractures and fault zones. Studies of continuous core will help determine stratigraphic variations in fracture characteristics (Scott and Castellanos, 1984). Borehole-video-camera logging and acoustic televiewer logging techniques are planned because of their successful history of use in studying the distribution and attitude of fractures in drill holes (Zemanek and others, 1969, 1970; Storm and others, 1979; Lau, 1980). Section 3.3.1 discusses this activity in more detail.

2.3.1 Rationale for the types of tests selected

Subsurface fractures in the site area will be characterized by (1) core sampling and fracture logging, (2) borehole-video-camera logging, and (3) acoustic televiewer surveys and logging. These three test methods were selected on the basis that they are proven methods for gathering fracture data and because, in combination, they provide information on all of the required SCP parameters (see sec. 3.3.1 for list of parameters). Different fracture characteristics are measured by each of the test methods; hence, all three are essential to the activity. Although all three methods provide useful fracture data, each method has limitations (i.e., biased against vertical fractures and measurement inaccuracies); hence, the reliability and usefulness of these techniques for identifying and characterizing the subsurface fracture distribution will be assessed in this activity.

Cores afford the opportunity to study fractures as they occur in the rocks penetrated by the borehole. Except for examining fractures in the exploratory facilities (Activity 8.3.1.4.2.2.4), no other means are available for directly observing fracture characteristics in the subsurface. However, cores represent only a small sampling of a given rock unit; thus, they offer only a limited "view" of its total fracture system. No distinction can be made, for example, between extensive, through-going fractures and those that have very short trace lengths (Spengler and Chornack, 1984). Because of this limitation, core data will be compared and integrated with data derived from surface fracture-network studies (Activity 8.3.1.4.2.2.2) that provide information based on other sampling orientations to help understand sample bias in core data.

Core fracture logging provides all of the required activity parameters (table 2.3-1), provided sufficient oriented core (estimated at 10 percent of the total oriented core) is available for measuring fracture orientations. Borehole video-camera-logging allows the measurement of fracture location, type, apparent frequency, strike, and dip direction. Parameters measured by the acoustic televiewer include fracture location, type, apparent frequency, and true strike and dip.

The borehole-video-camera method can be used in air-filled and fluid-filled holes (where fluids are clear); thus, the primary advantage of this method is that it allows a continuous record of fractures intersecting the borehole. However, several limitations of the method can be identified: 1) data are biased because vertical fractures are not adequately sampled, 2) irregularities in the roundness and smoothness of the hole causes illumination problems which can prevent fractures from being discerned, 3) fracture dip angles cannot confidently be obtained by this method because generally only some portion of a fracture is visible on the screen and the true interval of intersection with the borehole wall is often not visible, 4) important fracture parameters such as surface roughness, aperture, degree of mineralization (ranging from no mineralization to totally filled), and mineralogy of fracture-filling material cannot be obtained, and 5) adequate video cannot be obtained if mud cake forms on the borehole walls.

The acoustic televiewer method can be used only in fluid-filled (wet) holes. This technique is most effective in holes containing clear water; however, useful logs can be obtained from holes that contain bentonitic drilling mud that weighs as much as 10 lbs/gal. Although acoustic televiewer logging does not identify as many fractures as video-camera logging, it accurately measures fracture orientations. Unlike the video-camera log, the dip angle often can be quantitatively determined from the acoustic televiewer log. The resolution of the acoustic televiewer depends upon hole diameter, wall conditions (roughness), reflectivity of the formation, and acoustic impedance of the well bore fluid (Healy and others, 1984). The extreme horizontal exaggeration in the data makes fractures dipping $< 40°$ appear to be approximately horizontal; thus, identification of fractures is biased toward those of steeper dip (Healy and others, 1984). In spite of these restrictions, acoustic televiewer logging is useful for collecting data where fluids in the hole interfere with video-camera-logging.

Alternative methods considered:

Two geophysical methods were tested as alternatives to the selected test methods near Yucca Mountain-- 1) (borehole-compensated)-acoustic waveform (fraclog), and 2) spectral gamma-ray.

Acoustic waveform (fraclog) methods can be used to identify fracture *zones* and to calculate apparent dip, but they cannot reliably determine properties of individual fractures, such as frequency, azimuth, or aperture in the volcanic tuffs at the site area (R.W. Spengler and Phil Nelson, oral commun., 1989). Like acoustic televiewer logging, they can be used only in the saturated zone, thus eliminating the unsaturated (dry) zone from study.

The spectral gamma-ray method can be used in both dry and wet holes but has met with intermittent success for identifying fracture zones in volcanic tuffs at Yucca Mountain, apparently because relatively high uranium radiation levels in the tuffs mask radiation from uranium that may be concentrated in fracture coatings and fillings (Muller and Kibler, 1983, 1986; Spengler and others, 1984).

In summary, evaluation of these two alternative methods has shown that they identify fracture *zones*, but do not provide the data needed on individual fractures.

In addition to these two rejected methods, an alternative method of core fracture logging was tested early in this study. In this method, only natural fractures were logged. The x-coordinates of fracture locations were measured, including top and bottom locations (depth at which the fracture enters and exits the core) for high-angle fractures. Dip angles were measured with a protractor. A goniometer was used to obtain fracture orientations from oriented core. For unoriented core, fracture inclinations relative to the core axis were measured. An evaluation of this method determined that it does not provide the kinds of data required (surface roughness, aperture), while the chosen method provides data on all the required activity parameters.

One other alternative to the chosen acoustic televiewer method was evaluated for its suitability, but not actually tested at Yucca Mountain. This method involves a visual examination of the borehole, using still camera photos obtained by lowering a properly equipped camera into the boreholes. This method was rejected because it does not provide a data set as comprehensive or continuous as the chosen method. Other alternatives to acoustic televiewer logging include other borehole geophysical surveys (Activity 8.3.1.4.2.1.3, Borehole geophysical surveys) from which fracture identification and orientation, and hole wall irregularities can be determined. These methods include borehole radar, crosshole resistivity, crosshole EM, crosshole radar, high resolution crosshole seismic surveys), dip meter and microresistivity scanlog, and may be considered in available drill holes at the site (Table 8.3.1.4-4 of the SCP).

2.3.2 Rationale for selecting the number, location, duration, and timing of tests

2.3.2.1 Number and location

The three test methods utilized in this activity are performed on boreholes already planned for site characterization studies as part of the integrated drilling program (SCP sec. 8.3.1.4.1). The integrated drilling program combines a systematic-sampling (geostatistical) approach, with a feature-sampling approach, used for the vertical boreholes. This activity will provide nearly full coverage of all boreholes exceeding 500 ft in depth (90 holes; see figs. 2.3-1, 2.3-2) and all available core.

Number and location of boreholes in the systematic drilling program are chosen to characterize spatial variability of rock characteristics of tuff units at Yucca Mountain, and to provide sufficient areal coverage of the site for geologic, hydrologic, and geochemical investigations. In the feature-sampling approach, the location of a single borehole or set of several boreholes is chosen to test a specific hypothesis at that location, or to study structures of interest, such as the Solitario Canyon fault. The location and number of boreholes will be coordinated with repository design to locate boreholes in pillars (SCP sec. 8.4.2.1), to allow a standoff distance from waste canisters and to help prevent the boreholes from becoming preferential pathways for potential radionuclide movement. In addition, statistical methods will be used in planning borehole locations in order to limit their number.

2.3.2.2 Duration and timing

Logging with the video camera or acoustic televiewer is constrained by the drilling schedule and will proceed concurrently with the drilling of additional boreholes (refer to sec. 2.3.2.1). The duration of the core fracture logging will depend on the drilling schedule, the amount of core retrieved, and the number of fractures identifiable in the core. Based on the current drilling schedule, the core fracture logging and analyses of video-camera and acoustic televiewer logs will extend through the drilling program.

The borehole-video-camera and acoustic televiewer logs are obtained as soon as possible after the hole is drilled and before it is plugged. These tests should be run prior to other hydrologic tests to keep the hole as pristine as possible. The core fracture logging tests are performed after the core is deposited at the sample management facility (SMF), and before subsequent sampling of core material for other investigations. It is essential to schedule the core-fracture logging before sampling is done for other purposes in order to prevent gaps in fracture data. Samples of fracture-coating and fracture-filling material are removed during the fracture logging.

2.3.3 Constraints: factors affecting selection of tests

2.3.3.1 Impacts on the site

Neither the chosen methods nor alternative methods would have any appreciable effect on the ability of the repository to isolate waste, as the holes will have been drilled for purposes other than collecting data by the methods chosen in this activity. Potential impacts to the site from drilling activities are addressed in SCP sec. 8.4.3.2.5.2.

2.3.3.2 Simulation of repository conditions

Not applicable: none of the test methods (chosen or rejected) would attempt to simulate repository conditions.

2.3.3.3 Required accuracy and precision

No explicit requirements for accuracy or precision are specified in the SCP for this activity. The planned test methods were chosen on the basis that they offer a reliable means for obtaining accurate data on the designated fracture parameters, whereas alternative methods (discussed in sec. 2.3.1) would not provide data of comparable quality.

2.3.3.4 Limits of analytical methods

Not applicable: analytical methods are not used on test results gathered in this activity.

2.3.3.5 Capability of analytical methods

Not applicable: the choice of test methods was not affected by the capabilities of analytical methods.

2.3.3.6 Time constraints

Time was not a factor in the selection of the planned test methods over the alternative methods, as both the alternative methods and planned methods require an equivalent amount of time.

2.3.3.7 Scale and applicability

The planned tests were selected because they are proven to be reliable in providing the required activity parameters. The alternatives discussed in section 2.3.1 have been found to be unsuited to studies of volcanic tuffs at Yucca Mountain.

2.3.3.8 Interference with other tests

The borehole-video-camera logging and acoustic televiewer logging should be run prior to any testing that would affect the existing conditions of the borehole. None of the considered alternatives has any significant advantage over the selected test methods with regard to interference with other tests.

2.3.3.9 Interference with exploratory facilities

Because this activity is designed to generate fracture data from boreholes and core already planned for site characterization studies, none of the chosen or alternative methods will have any adverse effect on the exploratory facilities in terms of sequencing, physical location, or construction and operational constraints.

2.4 Activity 8.3.1.4.2.2.4 Geologic mapping of the exploratory shaft and drifts

Tests included in Activity 8.3.1.4.2.2.4 were selected to provide many of the specific data required for the characterization of structural features of the site area. These tests will focus primarily on the relationships and physical characteristics of fractures (including faults) (table 2.4-1).

Fractures are emphasized because they may allow rapid transport of radionuclides by water or gases to the accessible environment. Because fracture networks change with lithologic character in the strata at Yucca Mountain (Barton, 1984; Barton and Larsen, 1985), mapping both the vertical sequence of fractures and the lithologic character of strata within the shaft is important in defining variables that affect isolation. Because the diverse patterns of the nearly vertical fractures at Yucca Mountain also change laterally, mapping of drift exposures within the waste emplacement horizon provides another important dimension of information.

2.4.1 Rationale for the types of tests selected

Three methods of underground geologic mapping were considered for use in the exploratory shaft and drifts:

1) Photogrammetric method

2) Photomosaic method

3) Conventional sketch method

The photogrammetric method was selected; it will be complemented by detailed line surveys, conventional sketch mapping, field notes, and photographic images of major structural features of the site, including all faults that exhibit measurable displacement and all lithostratigraphic contacts that are judged important by the onsite subsurface geologist.

All three methods produce maps in the full-periphery format: that is, each completed map, regardless of method, will show geologic features of the circular shaft wall or the vertical drift walls and arched roof. Generally the floor will not be cleaned sufficiently for mapping, but it may be cleaned locally where a feature of consequence, such as a major fault zone, can be traced across the floor.

Accurate surveying by a subcontractor is required for each of the three methods in order to establish a datum (marked by a series of surveyed photographable targets) to which measurements can be related.

A brief discussion of the advantages and disadvantages of each method follows:

1) Photogrammetric Method. This method, selected for shaft and drift mapping, involves taking stereophotographs of the shaft wall and drift walls and roof. Geologic maps (lithostratigraphic and structural data, especially fracture data) will be compiled from the photographs, at an above-ground facility using an analytical plotter (Curry, 1986; Dueholm, 1974, 1976, 1979, 1981; Dueholm and Garde, 1986; Dueholm et al, 1977; Jepsen and Dueholm, 1978; Pillmore, 1959; Pillmore et al, 1980; Scott, 1987).

a. Photography: Stereophotographic coverage of clean exposures is required to record geologic-feature data.

b. Fracture Measurement: Location, strike and dip, and trace length data will be generated from the photographs by means of the analytical plotter. Roughness, aperture, mineralization, and fault surface lineation pitch must be measured manually at the working face.

c. Accuracy: Photogrammetry affords the greatest accuracy of the three methods. Features will be located within 2 cm of true position at 1:1 scale; length will be measured within 2 cm; and attitude will be computed with a maximum error of 1° for extensive planes and 5° for restricted planes.

d. Data Base: In addition to underground measurements, this method develops fully digitized photogrammetric data that are automatically entered into the computer data storage. New data can be compiled from the photographs as needed. The quality and scope of this expandable data base for geologic and hydrologic information are unattainable by either of the other methods.

e. Objectivity/Reproducibility: Photogrammetry is the most objective of the three methods considered. Since fracture trace measurements and data are compiled by photogrammetry technicians and then edited by the geologist who supervised the corresponding underground data collecting, the method eliminates much of the bias associated with conventional sketching. For the same reason, the method will yield good reproducibility.

f. Underground Time: Photogrammetry requires an estimated 2 hr per 2-m blast round (exclusive of travel and set-up time, estimated to be about 1/2 hr). In contrast, the photomosaic and conventional methods require an estimated 4 and 8 hr, respectively. These time estimates are relatively accurate but may be revised on the basis of the actual time required during prototype testing.

2) Photomosaic Method. This method involves conventional (nonstereographic) photographing of the wall of the shaft and walls and roof of the drifts, and the assembling of resulting photos into a photomosaic. Geologic features displayed by the mosaic are traced at photo scale directly onto base maps (Ray, 1960, Goodman, 1976, Scott, 1987).

a. Photography: Requires complete photographic coverage of shaft walls and drifts walls and roof. Photomosaics (an assembly of photos whose edges have been feathered and matched) are prepared, allowing some overlap to reduce photo distortion. Fracture locations and other data are traced onto mylar overlays to generate geologic maps.

b. Fracture Measurement: Attitudes, aperture, and roughness of fractures; fracture-fill material; and fault surface lineation characteristics must be measured and observed underground. Trace lengths and relative locations of fractures can be determined from the photos. Attitudes of fractures can be calculated from mapped traces if time available for underground mapping is minimal.

c. Accuracy: In spite of unavoidable photo distortion, moderate accuracy can be achieved if good photo control is exercised. Geologic features can be located to within 10 cm of true position at 1:1 scale (closer if near a surveyed target); the length of features can be determined to within 10 cm of actual length. The attitude of a plane, such as a fracture surface, is copied from the photomosaic in the form of apparent dip along the trace; except for horizontal or vertical planes, the map display of a trace that crosses a shaft or drift generally is a sigmoidal or U-shaped curve. True dip and strike are measured at the exposure for best results, but can be calculated from the curve. In the photogrammetric method, such calculations are made automatically by the computer. Direct measurement of attitude is expected to provide data with an average of no more than 1° of error.

d. Data Base: The data-base of manually collected underground measurements (roughness and aperture of fractures; pitch of fault surface lineation; characteristics of fracture-filling material; and other special measurements and observations) is barely expandable, if at all, through the reexamination of rock samples and photos. This restriction generally will apply to all methods. The data-base of features recorded from the photomosaics is somewhat expandable as the photos can be reexamined at a later date.

e. Objectivity/Reproducibility: This method is objective, but some mappable fractures may be overlooked because of the reduced scale, generally about 1:15, of standard photographs. Photo data should be reproducible.

f. Underground Time: The photomosaic method requires about twice as much time as does the photogrammetric method--about 4 hr per 2-m blast round (exclusive of travel and set-up time, estimated to be about 1/2 hr).

3) <u>Conventional Sketch Method.</u> This method requires that the attitude of each fracture be measured, and its location sketched, measured, or surveyed while the geologist is underground. Field maps are sketched at the shaft or drift heading with the perspective of the full-periphery view from within the excavation. On a light-table, the map can be traced to the opposite side of the paper for inside- or outside-perspective viewing when wrapped around a mold of proper dimensions. Data may be transferred to profile or cross section by the use of geometric principles (Brown, 1981; Cregger, 1986; Hatheway, 1982; Scott, 1987; U.S. Army, 1970).

   a. Photography: Requires photographic coverage of the walls and roof for archival purposes only.

   b. Fracture Measurement: All fracture characteristics must be measured manually at the shaft or drift heading. These data are recorded on both a map and a data sheet.

   c. Accuracy: The position of any geologic feature exposed in the shaft or drifts can be located accurately by surveying. However, for each point located, x, y, and z coordinates are required--a labor-intensive, slow procedure when done manually at the rock face. Features that are thought to have greater significance to physical and engineering properties of the rock mass are measured first and more carefully. Map completeness and accuracy, therefore, are functions of time available for underground mapping.

   Because of the limited time available, sketching is used extensively as an expedient substitute for surveying after a surveyed framework is established. Sketching is inherently less accurate than the photogrammetric or photomosaic methods. The map will show some features to be as much as 25 cm away from true position at 1:1 scale (much closer if near a surveyed marker). If time is short, fewer planar features may be measured or attitudes of some features may be approximated to within 10° of true attitude. Generally, fewer features are measured as an option of fewer but better data.

   d. Data Base: Original data from this method are on either data sheets or sketch maps. In order to reduce these data by analytical methods, they must be entered manually into the computer from the primary data sheets or from secondary measurements made on the field maps. An inordinate amount of underground and office time would be required to generate a meaningful data set because the method is not designed to record minor features efficiently and accurately.

   e. Objectivity/Reproducibility: This method tends to be subjective and is dependent on the individual doing the mapping, thus creating continuity problems from round to round and map to map. As the exact conditions under which the map was developed cannot be duplicated after the shaft has been lined, archived photographs offer the only potential for checking or reproducing the map.

f. Underground time: Conventional mapping requires approximately 8 hr per 2-m blast round (exclusive of travel and set-up time, estimated to be about 1/2 hr); photogrammetry requires approximately 2 hr.

Comparison Summary .--The photogrammetric method is superior in terms of product quantity, quality, reproduceability, and time requirements (table 2.4-2; Scott, 1987). The shorter time required underground by the photogrammetric method for completion of geologic mapping provides significant cost savings, especially by decreasing contractor down tune while waiting for mapping to be completed. Photogrammetry 's expandable data-base and assurance of reproducibility are long-term assets that can meet a variety of future needs.

2.4.2 Rationale for the number, location, duration, and timing of the selected tests

The number, location, duration, and timing of the selected tests depends not only on the mapping method selected, but also on whether all the rock face exposed by excavation is mapped. A statistically meaningful system of mapping selected intervals (rather than all intervals) is a possible alternative only within specific limitations.

All of the wall of the first shaft (ES-1) will be mapped because each round of excavation will offer an opportunity to observe and measure geologic features of strata previously unseen in the shaft (Barton and Scott, 1987). Complete photographic coverage (Stereographic) of the walls of the second shaft (ES-2) will be obtained; observations and measurements at the rock face will be made; but detailed photogrammetric mapping will have a low priority and likely will be delayed until a need is indicated by another activity.

As drifts tend to either parallel strata or cut across them at a low angle, data redundancy can be kept within an acceptable limit by adopting a system of selected-interval mapping. Structurally complex intervals, such as those at the edge of fault blocks, and a statistically representative number of normal intervals will be mapped photogrammetrically. For the intervals not mapped in detail during excavation, complete photographic coverage (stereoscopic) will be obtained, and routine rock-face measurements and observations will be made. With these data in archive, detailed maps can be made when needed.

Surface excavations associated with construction of the ESF will be mapped as part of this activity. In addition, preliminary reconnaissance of geologic conditions at the surface ESF sites and excavation alignments will be performed.

2.4.2.1 Number

The series of tests that make up the photogrammetric method can be divided into two categories on the basis of test location and related test procedure:

a) Underground data collection

b) Photographic data collection.

A variety of tests are performed within each of these categories (table 2.4-3). This same general subdivision, underground (direct) versus laboratory or office (indirect), also applies to the photomosaic and conventional methods. The difference is in proportions. Only about 20 percent of the primary data of the photogrammetric method are generated underground; nearly all primary data of the conventional method are generated underground, the exception being data from rock samples.

Prototype testing will determine the most efficient and accurate way to collect data for each method and will help determine which measurements commonly will be made on site. In addition, the results of prototype testing will be used as a basis for determining criteria in selecting the level of detail to be incorporated into the study plan, such as the location of the reference mapping line within the excavation round and the detail to be used in mapping features across the reference line.

Each method (photogrammetric, photomosaic, and conventional) produces structural data sets (especially fracture data), as well as some stratigraphic and petrographic data. Without restrictions of time or cost, all three methods would strive to produce the same number and quality of data. The difference in the number and quality of data actually produced relates to the contrasting ability of the various methods to transfer time-consuming tests from the rock face to the laboratory. The advantage lies with photogrammetry because underground data collecting can be completed within about 2 hr per 2-m round of excavation and the laboratory is available 24 hr per day for photographic data collecting.

The number of tests anticipated in this activity is shown in table 2.4-3. Data collected photographically will outnumber measurements made at the exposures by a factor of at least four because underground measurements are restricted to only those not amenable to photogrammetry. Conventional mapping requires more underground measurements and a closer approach to all parts of the exposures. For example, the mapping platform will suffice in the shaft for all methods, but a ladder may be required routinely in drifts for measuring out-of-reach features by the conventional method. Such features are within camera range for other methods and, therefore, generally require no special means of access.

The number of photographs per 2-m round of excavation (12 in the shaft and 12 in the drifts) is fixed by camera angle and by stereoscopic overlap requirements. The number of samples to be taken from the exposed workings after each 2-m round of excavation will vary according to the complexity of geologic features exposed (Bish and Vaniman, 1985). At least 1 sample for petrographic testing will be collected from the walls after each 2-m round of excavation. The number of samples collected at the underground exposures will be kept at a minium because each sample must be selected, marked for orientation (if required) and for photographic identification, photographed in place, and then broken from the rock face.

For tests that do not require oriented samples, material will be collected either at the rock face or from a temporarily isolated pile of excavated rock (muck) from each 2-m round. From the two sources (exposure and muck pile), at least 2 samples per 2-m round will be selected for a series of measurements and observations to be completed by Activities:

a) Petrologic stratigraphy of the Topopah Spring Member (8.3.1.3.2.1.1)

b) Fracture mineralogy (8.3.1.3.2.1.3)

c) History of mineralogic and geochemical alteration of Yucca Mountain (8.3.1.3.2.2.1)

The professional judgment of the onsite subsurface geologist will determine the number of measurements and observations which will be made at the exposed working face and the number of supplemental photographic images which will be recorded to support and augment data generated by the photogrammetric mapping that will be done at the plotter laboratory. A detail line survey along a horizontal reference line (described in sec. 3.4.2.1) will yield a statistical set of measurements from the rock face of each round of excavation. The number of measurements from each detail line survey will be determined by the number of geologic features that are intercepted by each Line and that are meaningful at the level of detail required by this activity. The combined purpose of shaft and drift mapping is to accumulate enough of each of several kinds of data to create statistically meaningful sets for data reduction and to provide geologic data needed for site characterization.

2.4.2.2 location

The tests will be done in the ESF shafts, drifts, and surface excavations and alignments, regardless of mapping method, because they provide the best opportunity to make detailed measurements and observations within the host rock and surrounding units. Photographing, sampling, and underground data collecting will be done in the shaft and drifts. To minimize interference with mining and to maximize data collection, the most time-consuming data collection will be accomplished through the study of photographs in the photogrammetric plotter laboratory. Stereoscopic pairs of photos of the shaft walls and drift walls and roof will furnish data for maps of the fracture network, other structural features, and some lithostratigraphic features. Data obtained from measurements made underground will be incorporated into these photogrammetric maps compiled in the laboratory.

Many of the samples taken from the shaft and drift exposures will be sent to special laboratories for detailed tests that exceed the capability of local facilities. Hand-specimen petrographic descriptions (color, texture and phenocryst mineralogy) will be made at the surface facility of the ESF by geologists of this activity.

2.4.2.3 Duration

Geologic mapping of the exploratory shaft and drifts will be in concert with the mining operation regardless of mapping method. The mapping will be done during periods reserved between rounds of excavation. Under usual conditions, photogrammetric mapping exclusive of wall cleaning, surveying, setting up equipment and personnel for mapping, and photography, will take a minimum of 2 hr, versus 4 or 8 hr for other methods (table 2.4-2).

Where excavations expose unusual geologic features, such as a major fault or breccia zone, the geologists will need sufficient additional time to photograph and describe these features, thus avoiding loss of irretrievable data. Where safety factors allow, the miners will complete up to three rounds of about 2 m each in the shaft prior to the emplacement of wire mesh, thus allowing cleaning, surveying, photographing, mapping, and sampling of an interval as much as 6 m in height. This plan offers one-time-only access to exposed workings because the newly mapped 6-m segment of the shaft will be lined before excavation is resumed. It is unknown whether safety factors will commonly allow as much as 6 m of drift to be exposed before wire mesh is installed. Even though mapping and photography can be done after rock bolts have been installed, mapping and photography must be completed before wire mesh is installed.

Samples will be described as the material is received at surface facilities of the Exploratory Shaft. Samples collected for laboratory testing will be packaged and shipped or hand carried to the various recieving facilities within a few hours after reaching the surface. Sample handling and testing is independent of mapping method.

2.4.2.4 Timing

As each round of tests within this activity can take place only after a round of excavation is completed, both the timing of any given test and the completion of all tests is controlled by mining progress.

Transport of mapping personnel and equipment, wall cleaning, surveying, photographing, underground data collecting, and sampling will begin immediately after one to three rounds of excavation is completed and after the new exposures are cleaned and surveyors have provided orientation and altitude references. Photographs will be developed by the subcontractor as soon as the exposed film is received at the surface facilities. Lining the new interval of the shaft with concrete can begin only after verification that high-quality photographic coverage is complete. Photogrammetric mapping in the plotter laboratory will stay current with incoming photographs to provide current data to other tehnical investigations.

All underground measurements are to be made during the period between exposure of the wall rock and installation of wire mesh or other material that can obscure the exposures. Only rock bolts are permitted prior to mapping.

2.4.3 Constraints: factors affecting the selection of tests

Geologic mapping of the exploratory shaft and drifts will make an obvious contribution to site characterization; therefore, choice of methods hinges on the best scientific method that is within the reasonable limits of cost and engineering efficiency.

Scientifically, close-range photogrammetric geologic mapping, in combination with onsite measurements, is superior to either the conventional sketch method of underground mapping or the photomosaic method, because more and better data are produced. Still more important, an expandable data base consisting of a permanent stereoscopic photographic record will be created and available if future needs arise or if post-testing confirmation of data is required.

For efficiency, the bulk of the time-consuming elements of mapping will be transferred from the underground to the plotter laboratory via the photogrammetric method. This also yields an advantage from the engineering point of view: time saved by geologists in completing mandatory geologic mapping at the rock face reduces cumulative time required for completion of ESF construction.

When examined critically within the context of the constraints listed below, the tests and analyses selected for this activity only negligibly affect the repository block and do not avoidably interfere with other activities.

2.4.3.1 Impacts on the site

Surveying, photographing, sampling and data collection in the newly exposed parts of the shaft and drifts will not affect the site, regardless of the mapping method used. Cleaning the walls in order to make photogrammetric mapping efficient and meaningful will introduce small amounts of water into the underground environment. [However, the impact on the site will be minimal and would be essentially the same for alternative methods of detailed geologic mapping.] This water usage has been considered as part of the construction phase use of water usage, as detailed in section 8.4.2.3.4.4 of the Site Characterization Plan. Water usage will be held to a minimum, and constrained by the limitations mentioned in section 8.4.2.3.4.4 of the Site Characterization Plan, including the use of chemically-tagged water in the ESF.

Potential impacts from hydrologic disturbances associated with the construction of the exploratory shafts are described and evaluated in section 8.4.3.2.5.3 of the Site Characterization Plan. That evaluation of the hydrologic impact concluded that construction of the ESF would not affect the ground-water flux at the repository horizon or create preferential pathways for liquid water flow. It is reasonable to conclude that water usage during this activity will not adversely impact the ability of the site to isolate waste.

2.4.3.2 Simulation of repository conditions

Simulation of repository conditions was not a basis for selecting mapping method: all three alternative mapping methods simulate the repository conditions equally well, in that each involves objective data-gathering at the rock face.

2.4.3.3 Required accuracy and precision

For most types of measurements, the photogrammetric mapping method has both accuracy (quality of results) and precision (quality of methods and instruments) that are better than those of alternate mapping methods (table 2.4-2). However, as measurements of fracture aperture and roughness are obtained underground manually regardless of mapping method, there can be no method-determined difference in the accuracy or precision of these.

Tools and equipment that will be used in photogrammetric tests are designed to yield precision comparable to or in excess of that of tools and equipment of tests in alternative methods. Generally the same measuring devices are used underground regardless of mapping methods; different equipment is used in surface facilities for different methods. In the latter, a map compiled through use of the photogrammetric plotter is more accurate than one traced from a photomosaic or from a sketch map, because of the inherent precision of the photogrammetric method and equipment.

2.4.3.4 Limits of analytical methods

This activity will not include analyses (rigid definition), but it will be involved extensively in data reduction that will require analytical methods.

Photogrammetric mapping, the method selected for this activity, will produce more abundant and more accurate data for reduction than would a conventional mapping method. In addition, many of the data generated during photogrammetric mapping will be in a form specifically designed for reduction by computer. Advances in methods of geologic mapping, therefore, are expanding the limits of present analytical methods and likely will lead to the generation of new methods.

In summary, data-reduction and analytical methods of photogrammetric mapping are restricted largely by the number of data available and the capacity of the computer memory. The memory of the computer designated for this activity is adequate to handle the quantity of data expected. Alternative methods of mapping generate a smaller data base that must be entered into the computer manually. This smaller data base places limits on data-reduction and analytical methods.

2.4.3.5 Capability of analytical methods

Not applicable: the choice of mapping method was not affected by the capabilities of analytical methods.

2.4.3.6 Time Constraints

The planned photogrammetric mapping method was selected over the more time-consuming conventional mapping methods because photogrammetry will reduce the time for underground data collection (table 2.4-2), allowing more time for wall cleaning, surveying, photographing, sampling, and geologic observation.

2.4.3.7 Scale and applicability

Not applicable: the choice of mapping method was not affected by the ability of the data to represent the required parameters.

2.4.3.8 Interference with other tests

Two possible types of interference have been considered during the planning of this activity: interference through contamination of hydrologic conditions in the vicinity of the exploratory shaft, and physical interference due to scheduling overlaps during ESF construction.

Water usage required to clean shaft surfaces prior to photography and mapping are considered part of the ESF construction-phase use of water, which has been evaluated in section 8.4.2.3.4.4 of the Site Characterization Plan. As detailed in section 8.4.2.3.4.4 of the Site Characterization Plan, water usage in the ESF will be tightly controlled, and will be kept to a minimum consistent with operational requirements. The hydrologic impacts of ESF construction were analyzed in section 8.4.3.2.1 of the Site Characterization Plan, which determined that the cumulative effects of all ESF construction-related water usage is projected to be small and to be confined to the immediate proximity of the ESF. The use of chemically-tagged water in the ESF will allow the recognition by other tests of disturbance of hydrologic conditions.

Underground tests associated with this activity (surveying, photographing, mapping, measuring, observing, and sampling) are scheduled during designated time intervals between rounds of excavation. Those intervals of time will be kept at the minimum that is commensurate with the data needs for site characterization.

During that designated time, the underground area will be largely free of workers other than those required by this activity. If scientists associated with other activities do deem it necessary to collect their own samples from new shaft and drift exposures or perform special tests there prior to completion of all excavation, some interference and delay of the mapping test likely will result, especially in the limited space of the ESF shaft.

Above-ground tests and data reduction will occur in separate specialized laboratories and, therefore, will pose no problem of interference with other tests. Test methods selected for this activity are designed to reduce to a minimum the amount of time that geologists and associated technicians are required to spend underground, thereby reducing interference with excavation and other ESF test schedules. Conventional methods of mapping require more underground time and, consequently, interfere more.

2.4.3.9 Interference with exploratory shaft

As the purpose of excavating the shaft is to provide access for underground testing, time for shaft mapping is included in the excavation schedule. In regard to the test methods selected for this activity, no increase or decrease in interference with the exploratory shaft is involved except that the required geologic-mapping time at the rock face is less for photogrammetric mapping than for photomosaic and conventional mapping methods.

Sample collecting is the only part of this activity that will affect the walls of the shaft; however, it will not interfere with the design, construction, or structural stability of the shaft.

The effect of this activity on the exploratory shaft is independent of mapping method selected other than that the photogrammetric method requires less underground time for mapping. Another potentially important attribute of the photogrammetric method is that geologic data accumulated progressively during excavation will be available to engineers promptly and in a flexible and, therefore, more convenient format if structure-related construction problems arise. This speed and convenience cannot be matched by the other mapping methods.

Above-ground tests and analyses of this activity will have no adverse effect on the design and construction of the exploratory shaft, regardless of mapping method.

2.5 Activity 8.3.1.4.2.2.5 Seismic tomography/vertical seismic profiling

2.5.1 Rationale for the type of tests selected

This activity will use a single test method--seismic tomography/vertical seismic profiling (VSP)--to characterize fractures (faults and joints) in areas between surface exposures, underground workings, and boreholes (see table 2.5-1). Although it is possible to directly examine structural features and fracture content on mine walls and in cores, because of variations in these features, it is necessary to extrapolate observations into the surrounding rock. More importantly, features that may not be observed directly or are not intersected by boreholes or mine workings may be detected by imaging the rock. Variations in lithology and fractures in such areas can be detected, located, and characterized by seismic methods, because they represent mechanical anomalies in the rock mass. The only reasonable alternative to the planned method for fracture detection is surface seismic reflection. That alternative method was not selected because previous studies (e.g., McGovern, 1983) have demonstrated that it is very difficult to obtain reflection data in the Yucca Mountain area that can be used to define either near-vertical features or small-scale features at the required scale.

2.5.2 Rationale for the number, location, duration, and timing of the selected tests

2.5.2.1 Number

The number of tests will depend upon the success of the initial tests in drill hole USW G-4 and the C-holes (UE-25C#1, C#2, C#3; fig. 2.5-1) and the resolution obtainable. Twelve offsets will be occupied around the G-4 area (see fig. 3.5-1). The crosshole work in the C-holes will occur over an interval of approximately 150 m, with measurements every 1 m. If the first tests in G-4 and C-holes are successful, then the number and spacing of tests to be selected ultimately will depend upon the requirements of site characterization and, possibly at a later date, the requirements for performance confirmation. Studies to date have used spacing of one-quarter to one-half of the shortest wavelength. The actual spacing will be determined by the frequency content of the transmitted signal and the size and distribution of the targets of interest.

2.5.2.2 Location

The initial tests will be carried out at G-4. This area was selected because of its proximity to the potential repository site, the geologic and geophysical data that already exist for G-4, depth of borehole, and surface access. Single component P-wave near offset (check shot) VSP surveys have been carried out at G-4 and the C-well complex at NTS. Initial velocity models of the P-wave have already been obtained from these data, and will be used to design the G-4 work. The initial crosshole tomography tests will be carried out at the C-holes because of the tracer work and contributing hydrologic data to be collected in this area. If the initial tests indicate that the VSP and crosshole tomography are a viable method for fracture and structural definition, then further work will be carried out in available boreholes and the exploratory facilities as they are excavated. These locations were selected due to the potential of using the seismic techniques for extrapolating the results to a repository wide-scale. Crosshole work will also be carried out using other available boreholes as necessary to complete the desired coverage of the repository area (fig. 2.5-1).

2.5.2.3 Duration

The duration of the field work will depend on the success of the method, but the initial G-4 and C-hole tests will last approximately a total of 1 month. Subsequent tests in the exploratory facilities work will also require 1 month each year for approximately 6 years. This amount of time is required because of the stages in which the repository is to be excavated and the data processing required between the data collection. Additional VSP surveys will normally take 10 days to 2 weeks per hole, as the holes become available.

2.5.2.4 Timing

The timing of the tests is dictated by the availability of access to boreholes and to the ESF. The initial tests are planned for G-4 and the C-holes because those boreholes are expected to be available in time for initial testing and refinement of the test method. Testing in the ESF is scheduled to begin within a few weeks after completion of the first shaft, and to continue as new areas are excavated and become free for testing. It is important that the testing in G-4 and the C-holes begin as soon as possible in order to process and interpret the data for maximum use of the technique in subsequent tests.

2.5.3 Constraints: factors affecting the selection of tests

The main factors affecting the selection of tests is access to the exploratory facilities and to the other boreholes (i.e., G-4 and the C-holes), and the high potential of the technique for defining fracture characteristics between boreholes and underground workings.

2.5.3.1 Impacts on the site

There will be minimal impact on the site. No special considerations for surface work or borehole work will be necessary. Shallow (2.5-m) holes will be necessary in the ES facilities sensor placement.

2.5.3.2 Simulation of the repository conditions

Not a factor in selection of test method; test does not attempt to simulate repository conditions.

2.5.3.3 Required accuracy and precision

No explicit requirements for accuracy or precision are specified in the SCP for this activity. However, the accuracy and precision obtained will be a function of the scale of the survey, ranging from a resolution of a few cm (mapping the tunnel damage zone with borehole spacings of a few meters) to tens of meters (for the VSP work in a borehole several hundred meters deep). For the results to be useful, the positions in space of physical features must be determined within a few meters. That is, the features mapped must be accurately resolved to a few tens of meters on the repository-wide scale, a few meters on the exploratory facilities scale, and to at least a meter on the crosshole scale. The selected test is expected to provide these levels of accuracy, whereas past experience has shown that the alternative method of surface reflection profiling is likely to be much less precise.

2.5.3.4 Limits and capability of analytical methods

The VSP-tomographic processing techniques are limited by the ray coverage and frequency content of the elastic waves illuminating the zone of interest. Resolution obtainable also depends on the quality of the data, i.e., signal-to-noise ratio. Analytical methods used to analyze the data must be able to produce plots and maps of fracture characteristics. VSP and methods that produce tomographic images were selected because of their potential ability to do so. Conventional surface reflection techniques are not capable of the required resolution at the expected frequencies, owing to the anticipated lack of coherent reflection in the Yucca Mountain structure, and impossibility of generating and propagating sufficiently short wavelength energy with conventional surface sources.

2.5.3.5 Time constraints

Time constraints were not a factor in the selection of tests for this activity.

2.5.3.6 Scale and applicability

The scale of the work will vary depending on the resolution, target size, and penetration of the signal. In the VSP work, the spacing of the receivers will be no more than 10 m, with source offsets of several hundred meters spacing. In the cross well C-hole tests the sources and receivers will be no more than 1 m intervals in the holes. For very closely spaced holes (tens of meters) the source and receiver intervals in the holes will be 1/2 to 1/4 m.

2.5.3.7 Interference with other tests

All tests are planned to have minimal, if any, effect on other tests. The seismic work must be carried out at times when there is little or no vibration from construction activities, in order to eliminate as much background noise as possible. The work can be performed at night if necessary. The results will be integrated with the other geophysical data collected in other parts of the program, (i.e., well-log data from the MPBH and G-wells, and the seismic and electrical work done in other phases of the program.)

2.5.3.8 Interface with exploratory facilities

Not a factor in selection of test method: all tests planned in the exploratory facilities are to take place on a noninterference basis.

3 DESCRIPTION OF TESTS AND ANALYSES

Section 3 describes the tests planned for Study 8.3.1.4.2.2.

3.1 Activity 8.3.1.4.2.2.1: Geologic mapping of zonal features in the Paintbrush Tuff at a scale of 1:12,000

The objective of this activity is to map zonal variations in exposed tuffs to aid in the identification of structural displacements and in the detection of subtle differences in structural styles.

3.1.1 General approach

There are three stages to aerial-photograph-assisted field mapping:

a) direct observation of geologic features in the field; recording of data on aerial photographs and in notebooks,

b) transfer of the field data onto a stable topographic base using a mechanical analytical plotter in the photogrammetry laboratory, and

c) collection of data from the completed map.

In the field, the geologist uses aerial photographs (approximately 1:12,000 scale) and basic equipment (sec. 3.1.6). Images of geologic features are identified and marked on the photographs as the actual features are field checked. The locations of all observations are marked on the photographs and correlated with notes taken in the field notebook.

After a period of field mapping, the geologist returns to the photogrammetric laboratory with photographs, notebooks, and a stable topographic base (1:12,000 scale). Stereoscopic pairs of aerial photographs are set within the analytical plotter to remove photographic distortion. The geologist then traces images of features mapped on the aerial photographs onto the topographic base, making certain that the geometry of geologic features matches the geometry of the topography. The location of each data observation point is also transfered onto the base. After the lines have been drawn, the geologist transfers data from the notebook to the appropriate data location points.

The completed map is then used to collect further data. For example, the thicknesses of stratigraphic units, the amount of offset on faults, and the relative ages of faults can be determined by inspection of the map. The map measurements are then compared with field measurements, and inconsistencies are reconciled during field-checking of the map.

Methods and technical procedures for Activity 8.3.1.4.2.2.1 are listed in table 3.1-1.

3.1.1.1 Data to be collected and information to be obtained from the data

Tests and performance-allocation parameters for this activity are listed in table 2.1-1 as outlined in the SCP, p. 8.3.1.4-66.

3.1.1.2 Experimental conditions under which this activity will be conducted

This activity will be conducted in the field, the photogrammetric laboratory, and the office.

3.1.1.3 Number of data

The number of data is a function of the complexity of the geology at the particular locality being mapped. Where stratigraphic units are thick and faults are few, few data were taken. Where thin units or numerous faults exist, the number of data became a function of the number necessary to describe the geometry of the geologic features or became limited by the scale of the map. In some cases, the number of data observations and lines on the map were limited by the space to draw them. In such cases, the geologist selected representative measurements.

3.1.2 Test methods

Standard geologic mapping and compilation methods were used for all tests in this activity; the details of the methods are given in the technical procedures listed in table 3.1-1.

3.1.3 QA level assignment

Quality Assurance (QA) requirements for this activity will be specified in a Yucca Mountain Project QA Grading Report, which will be issued as a separate controlled document. All procedures applicable to this activity will be identified on the basis of the findings in the Grading Report and will be prepared in accordance with applicable QA requirements.

3.1.4 Required tolerances, accuracy, and precision

The accuracy required for large-scale general purpose geologic maps is:

a) location of points or features: within 1/25 in. (1 mm) on base map. (Base maps used in this activity comply with National Map Accuracy Standards: specifically identifiable points are plotted within 1/50 in., measured on the publication scale; and vertically, within one-half the contour interval).

b) attitude measurements with the Brunton compass....generally closer than $\pm 2°$

3.1.5 Range of expected results

Typically, bedding and foliation at Yucca Mountain trend generally north and dip east, and many major faults trend generally north and dip steeply west. But such attitudes vary widely, as shown by Scott and Bonk (1984).

3.1.6 Equipment

The equipment list for geological mapping using aerial photographs as aids is very simple:

a) Brunton compass.

b) Aerial photographs.

c) Pocket stereoscope.

d) Field notebook.

e) Abney level and Jacob's staff

The equipment for transfer of data from the photographs to the topographic base consists only of the mechanical analytical plotter. The only other piece of equipment necessary is the stable topographic base. In most cases this base is a frosted, reverse-reading, green-line mylar sheet, standard for base maps.

No special equipment is necessary for data collection from the compiled map.

3.1.7 Data-reduction techniques

For this activity, data reduction is the process of transfering data on aerial photographs onto the stable topographic base. Also, some data on thicknesses of stratigraphic units are determined after the map has been made by measuring the topographic thickness, corrected for dip. In a similar manner, the amount of offset on a fault is determined by reconstruction of the vertical or horizontal offset of one particular stratigraphic horizon. The relative ages of faults is determined by inspection of the fault intersections on the finished map.

3.1.8 Representativeness of results

The mapping results apply only to the surface of the earth. Even though the dip of strata and faults can be projected into the third dimension (below the ground surface), such features are remarkably nonplanar in detail. Thus, projections into the subsurface based upon surface measurements are geological interpretations, based upon the experience and observations of the geologist. In several cases at Yucca Mountain, drill hole data place known limits on the interpretation of the third dimension (Study 8.3.1.4.2.1). Many of the cross sections drawn at Yucca Mountain use a combination of known surface geological geometries and drill hole geometries (Scott and Castellanos, 1984; Scott et al, 1983; Scott and Whitney, 1987; Spengler and Chornack, 1984).

3.1.9 Relation to performance goals and confidence levels

This activity will contribute to tentative goals for performance issues 1.1 and 1.6, as outlined in section 1.2 and detailed in SCP table 8.3.1.4-1.

3.2 Activity 8.3.1.4.2.2.2: Surface fracture-network studies

The objective of this activity is to provide measurements and analyses of fracture networks to support the hydrologic modeling of potential flow paths, particularly in the unsaturated zone.

Measurements and analyses of fracture networks will be generated by each of the five activities of Study 8.3.1.4.2.2. However, this activity will provide the bulk of these data and will design methods of analysis of fracture networks that will be used in other activities.

3.2.1 General Approach

Measurements and analyses of fracture networks will be generated by each of the five activities of Study 8.3.1.4.2.2. However, this activity (Surface-fracture network studies) will provide the bulk of these data and will lead the way in designing methods of analysis of fracture networks.

Detailed studies included in this activity will provide site-specific data from outcrops (either natural or cleared) on Yucca Mountain in an area approximately 10 mi N-S by 4 mi E-W (fig. 2.2-1). As no detailed surface-fracture network study of this scope, involving comparable rocks, has been attempted, extensive innovation in measurement and analytical procedures will be required.

The site studies already completed for this activity (Barton, and others, in prep.) define the two gradational but distinct types of outcrops (uncleared and cleared) at Yucca Mountain that allow the measurement of fracture parameters and networks:

a) uncleared outcrop--natural surface (horizontal, vertical, or inclined) of intermittently exposed bedrock suitable for fracture studies. Abundant uncleared outcrop areas on Yucca Mountain will furnish the bulk of the elementary fracture data for this activity. Measurements made here are those of individual fractures, and are those measurements that, a) require the exposure of only a short segment of a fracture trace and, b) are independent of the attitude of the exposure. These measurements include: fracture orientation, aperture, and roughness. Data on fracture-filling minerals also will be recorded. At each extensive outcrop of which photographs are available as a base, a judgment will be made on the advisability of attempting to measure enough fracture-trace lengths to obtain a statistically meaningful set.

b) pavement--broad area of continuously exposed or exposable bedrock. Measurements made here include all of those related to uncleared outcrops, plus those, a) that involve well exposed total lengths of fracture traces and b) that involve the interrelationships of fractures in a network. They systematically include the following fracture parameters: trace length, spatial distribution, and interconnectedness. Pavements that are exposed naturally or can be exposed with minimum effort are uncommon and, therefore, are given special attention, including being mapped in detail because they are the prime source of fracture-network data.

Most pavements are horizontal or nearly horizontal surfaces, but inclined pavements are acceptable in that fracture traces can be projected to the horizontal in order to standardize measurements. A pavement plane at any angle, including vertical, can provide a meaningful map, but only those at the same orientation (parallel) are expected to be statistically comparable.

The difference between uncleared outcrops and pavements in this context hinges on mappability: elementary fracture parameters can be measured at both pavements and outcrops; two-dimensional fracture network parameters can be mapped only at pavements. As fracture networks are three-dimensional, data from all five activities of this study will be integrated to map them in their entirety. But the first priority here is to measure parameters of fractures at intercepts with the surface (outcrops) and to map fracture network intercepts (traces) across horizontal surfaces (pavements).

Smaller scale maps, such as those of Activity 8.3.1.4.2.2.1 at a scale of 1:12,000, provide trace lengths of faults. Maps of an intermediate scale, < 1:50 and > 1:12,000, will be tested in an attempt to quantify repetitive fracture "zones" or swarms too widely spaced to be measured statistically on pavements.

Mapping fractures at pavements generally requires clearing to expose bedrock so that the trace length, spatial distribution, and interconnectedness of fractures can be mapped, and other fracture parameters can be measured. The clearing is done in two steps. First, all large boulders and brush are removed by hand. Second, rock debris and soil are removed using pressurized air and (or) water. In some areas,natural "washout strips" on the slopes of ridges provide natural pavements.

As characteristics of fracture networks tend to be strata-specific, all measurements are to be recorded according to stratigraphic position.

Data from pavement sites are recorded in the field on photographs taken from a helicopter or cherry picker; data from outcrop sites are recorded on base maps, on aerial photographs, or (for vertical surfaces) on photogrtaphs obtained through the use of a tripod-mounted camera. Measurements of parameters are taken for each fracture mapped; these data sets are recorded in field notebooks and then are compiled into a fracture data base for each site.

Methods and technical procedures for Activity 8.3.1.4.2.2.2 are listed in table 3.2-1.

3.2.1.1 Data to be collected and information to be obtained from the data

Common parameters and characterization parameters for this activity are listed in table 2.2-1. Measurements of fracture parameters may include one or more of the following: attitude, surface roughness, aperture, pitch of tubular structure, and slickenside pitch. Also noted are presence of mineral coatings and fillings, and other relevant features.

Two-dimensional fracture network models will be compiled from fracture-trace maps and data sets. Fracture orientations (strike and dip) will be plotted on lower hemisphere equal-area projections and examined for groupings into preferred sets. Frequency distributions of fracture trace length, aperture, connectivity, and roughness, as well as spatial and density distributions, will be plotted and characterized for each pavement site. Aperture and roughness frequency distributions will be plotted and characterized for each outcrop site. Most of these diagrams will be computer-generated or computer-assisted.

3.2.1.2 Experimental conditions under which this activity will be conducted

Mapping of fractures and measurements of fracture parameters are done in the field by direct observation. Trace-length, areal distribution, and connectivity will be measured from the maps in the office. All data reduction and plotting will be done in the office.

3.2.1.3 Number of data

The approximate number of samples, photographs, and measurements for the study methods is estimated in table 2.2-2. Multiple sets of fracture parameter data may be collected for each fracture trace.

The scope of this activity indicates that the final fracture data base will be large. Each site has the potential of generating data from between 100 and 1000 fracture data sets; each fracture yielding 3-10 different fracture parameters.

3.2.2 Test methods

Standard methods will be used for all tests in this activity. Those methods are detailed in the technical procedures for this activity (table 3.2-1).

3.2.3 QA level assignment

Quality Assurance (QA) requirements for this activity will be specified in a Yucca Mountain Project QA Grading Report, which will be issued as a separate controlled document. All procedures applicable to this activity will be identified on the basis of the findings in the Grading Report and will be prepared in accordance with applicable QA requirements.

3.2.4 Required tolerances, accuracy, and precision

Required tolerances, accuracy, and precision have not been established for measurements to be made by this activity. Accuracy (quality of results) and precision (quality of method or equipment) are applicable terms, but their relative requirements are not defined.

The measurements from this activity are expected to be accurate. Measurements of fracture orientations are accurate to within 2°. Fracture-trace maps accurately show the fracture pattern, including intersections of fractures and relative ages of fractures.

3.2.5 Range of expected results

In general, the concept of "range of expected results" can be applied only selectively to the tests of this activity. Some measurements, such as fracture orientations and fracture roughness may involve all possibilities. Others, such as fracture apertures will cluster at the lower end of the scale of measurement. Trace lengths of fractures, will be determined in part by the limit of cut-off at the lower end of the scale (20 cm) and, at the upper end by the size of each site.

Some expected ranges are:

Fracture orientation (azimuth of strike)--entire range

Fracture frequency (sum of trace lengths/unit area)--from < 1 to 50 m/m^2.

Roughness of fractures (on a scale of 1 to 20)--entire range

Fracture apertures--generally from <0.03 mm to 1 cm (clustering at the lower end of the range), but locally greater than 1 cm

Measurements of the trace lengths of fractures will be determined in part by the limit of cut-off (20 cm) at the lower end of the range, and by the limit of exposure (site size) at the upper end of the range. Fault traces definitely will extend beyond pavement-site boundaries; their length will be measured on smaller scale geologic maps.

3.2.6 Equipment

All of the equipment to be used is conventional off-the-shelf equipment.

3.2.7 Data-reduction techniques

Standard data-reduction techniques will be used for this activity. Statistical analysis of directional data will be used to determine preferred orientations; cluster analysis of directional data will aid in determining data populations; and frequency plots of fracture attributes will be presented by curve-fits to histograms, which will be used to determine overall fracture network characteristics. Fractal analysis will be performed by the methods presented in Barton and Larsen (1985), Barton et al. (1985), and Barton et al. (1986) to determine the scaling law(s) and spatial distribution(s) for fracture networks.

3.2.8 Representativeness of results

In general, this activity will obtain data that are representative of the surface-fracture networks of the site. Geologic-map, drill-hole, shaft and drift, and seismic data, (Stewart et al, 1981) also will be essential for the extrapolation of the fracture framework throughout the repository block.

Results of statistical analyses will indicate which (if any) specific properties or relationships of fractures can be extrapolated downward from the surface. For example, the attitude of cooling fractures in layers of tuff well below the surface may be in part predictable if post-cooling tectonic tilt of the layers is determined to be the primary cause of the deviation of these fracture from vertical.

In addition, two types of correlations of fracture data are to be tested to determine whether general fracture data can be extrapolated downward:

a) correlation of fracture density with proximity of throughgoing faults

b) correlation of fracture-network fractal dimensionality with readily observable physical characteristics of rock units.

3.2.9 Relations to performance goals and confidence levels

This activity will contribute to tentative goals for performance issues 1.1 and 1.6, as outlined in section 1.2 and detailed in SCP table 8.3.1.4-1.

3.3 Activity 8.3.1.4.2.2.3: Borehole evaluation of faults and fractures

The objectives of this activity are--

- to assess the reliability and usefulness of available subsurface techniques for identifying and characterizing the subsurface fracture distribution
- to determine vertical and lateral variability of subsurface fractures
- to identify subsurface characteristics of fault zones

3.3.1 General approach

This activity gathers systematic information on fractures (faults and joints) from downhole-video-camera and acoustic televiewer logging of about 90 boreholes within or near the site area, and from logging of their cores. Approximately 40 boreholes have been drilled to date and preliminary fracture logs have been obtained (fig. 2.3-1). Future plans for drilling include approximately 50 additional boreholes within or near the site area (fig. 2.3-2). All 50 boreholes will exceed 500 ft in depth; most holes will be drilled to depths between 1000 and 2000 ft. Three holes will be continuously cored to depths of 5000 ft and approximately 30 holes will be continuously cored to depths between 1000 and 2000 ft. Current plans are to log boreholes and all available core from all boreholes exceeding 500 ft in depth (all 90 boreholes). This restriction eliminates the shallow neutron holes that do not provide a significant section of bedrock. One survey per hole is planned for both borehole-video-camera and acoustic televiewer logging. Each borehole-video-camera survey will obtain a continuous log of the unsaturated zone and saturated zone (where fluids are clear). Acoustic televiewer logging will obtain a continuous log in the saturated zone.

Stratigraphic units sampled will include the Paintbrush Tuff, tuffaceous beds of Calico Hills, and the Crater Flat Tuff. Deep (5,000 ft) holes may penetrate older tuff units below the Crater Flat Tuff.

The activity will incorporate information from Activities 8.3.1.4.2.2.4 (Geologic mapping of the exploratory facilities), 8.3.1.4.2.1.5 (Magnetic properties and stratigraphic correlations), and 8.3.1.4.2.1.3 (Borehole geophysical surveys; specifically, hole deviation surveys and caliper logs). Observations from Activity 8.3.1.4.2.2.4 will provide the basis for assessing the reliability of the subsurface techniques for identifying and characterizing the subsurface fracture distribution.

The three planned tests (see next section) are designed to achieve the objectives by measuring the following parameters:

fracture location, type, observed length, orientation, aperture, surface roughness, apparent frequency, relative age, degree of mineralization, and mineralogy of fillings.

The lateral variations in these parameters will be considered as functions of depth, degree of welding, lithology, and proximity to fault zones; the activity will emphasize the lateral variability in apparent fracture frequency and strike direction within lithologic units.

3.3.2 Test methods and procedures

Standard test methods will be used for all tests in this activity. The three methods chosen for this activity are summarized below and detailed in the technical procedures shown in table 3.3-1.

3.3.2.1 Core sampling and fracture logging

Physical characteristics of fractures are documented by observing and measuring fractures in core segments. Sampling of fracture-fill or fracture coatings is performed to determine mineralogy. Fracture location (depth from the ground surface to the center of the fracture and shortest radial distance from the center of the fracture to the core boundary) is recorded. Fracture strike, dip angle and dip direction are obtained from oriented cores. The type of fracture (natural, coring-induced, handling-induced) is recorded. The observed length of fractures (the maximum surface dimension of the fracture as measured on the surface of the fracture), fracture apertures, and fracture surface characteristics (e.g., roughness) are also measured or recorded for natural and coring-induced fractures. Abutting and intersecting relationships of fractures are recorded in order to determine relative ages of the fractures. Tectonic features (e.g., fault gouge, brecciation, slickensides, offset of pumice fragments), and degree of mineralization, are also recorded for natural fractures. Fracture-coating material and fracture-filling material are sampled as part of this procedure for subsequent mineralogic and radiometric age analysis performed in Activity 8.3.1.4.2.1.1 (Surface and subsurface stratigraphic studies of the host rock and surrounding units).

3.3.2.2 Borehole-video-camera surveys and logging

An instrument assembly that includes a borehole television camera with an axial lens, compass, and light source is lowered down the hole, obtaining a continuous visual display (video-camera tape) of the borehole walls in the unsaturated zone or in saturated zones (where fluids are clear). The surface instrumentation includes a digital readout that records the in-hole depth of the camera relative to a known bench mark (top or bottom of surface casing, ground level). From the video tapes, the location, type (joints, faults), orientation, and apparent frequency of fractures are recorded.

3.3.2.3 Acoustic televiewer surveys and logging

Acoustic televiewer logging is used to study the distribution of fractures in the saturated zone by inspection of the borehole walls. The logging tool moves up the hole at about 2.5 cm/s, while a rotating sonic transducer emits pulses in a direction perpendicular to the vertical axis (long dimension) of the tool. The signal is reflected off the borehole wall, detected, and transmitted uphole by wireline to yield a black-and white image of the reflecting surface on the CRT tube. A fluxgate magnetometer is used to orient the signal with respect to magnetic north. The televiewer provides an oriented image of the acoustic reflectance of the borehole, in the form of a continuous log. Where the borehole wall is smooth, reflectance is high, and the resulting image is white or light gray. Where the wall is perturbed by a planar feature, such as a fracture, the televiewer portrays the fractures on the log as dark sinusoids. The borehole is displayed on the log as if it were split vertically along magnetic north and unrolled onto a vertical plane. Nonvertical fractures form distinctive sinuous patterns that are used to determine strike and dip. The location, type (fault, joint), and apparent frequency of fractures are recorded from the log.

3.3.3 QA level assignment

Quality Assurance (QA) requirements for this activity will be specified in a Yucca Mountain Project QA Grading Report, which will be issued as a separate controlled document. All procedures applicable to this activity will be identified on the basis of the findings in the Grading Report and will be prepared in accordance with applicable QA requirements.

3.3.4 Required tolerances, accuracy, and precision

Quantitative/qualitative criteria for tolerances and operating limits are specified in the technical procedures (table 3.3-1).

Depth measurements obtained by the borehole-video-camera method are precise (within .01% of the measured depth). Accuracy requirements have not been established for orientation measurements for this method; however, assignment of confidence codes ("0" for high confidence, "1" for low confidence) to orientation readings insures consistency between measurements recorded by different investigators, as the confidence is dictated solely by the type and quality of a given fracture/hole intersection. For the acoustic televiewer and fracture core logging methods, accuracy measurements have not been established. Fracture resolution on acoustical televiewer logs is limited by the condition of the hole walls, the type of fluid in the hole, the skill of the logger in fine tuning the resolution as the logging proceeds, and the limits of the equipment to discern fractures with small apertures and low angle fractures. Because the acoustic log incorporates a significant horizontal exaggeration, fractures dipping $< 40^{\circ}$ appear as horizontal lines; thus identification of fractures is biased toward those of steeper dip (Healey and others, 1984).

Instrument calibration is required for two of the test methods. The video depth counter (borehole-video logging method) and televiewer tool (acoustic televiewer method) will be calibrated as specified in the appropriate technical procedure prior to obtaining data that will be cited to support licensing the YMP Project. The goniometer (fracture core logging method) does not require calibration, but does require certain set-up specifications and adjustments as outlined in the corresponding technical procedure.

3.3.5 Range of expected results

Table 2.3-1 lists the results expected for each parameter, based on studies of core from core hole USW G-4 (fig. 2.3-1). Preliminary results based on core samples and borehole-video-camera surveys on core hole USW G-4 (Spengler and others, 1984) show that fracture frequencies are higher in the densely welded lithologic zones than in less welded units. This observation is consistent with early studies by Spengler and others (1979, 1981), conducted on drill holes UE25a-1 and USW G-1 (fig. 2.3-1). Because apparent fracture frequency is strongly influenced by the degree of welding, table 2.3-1 lists expected ranges of some fracture parameters for densely welded and less welded lithostratigraphic units.

Fracture data obtained from borehole-video-camera surveys of USW G-4 show no preferential strike of fractures in the Tiva Canyon Member; however, in the Topopah Spring Member most strike between N20°W and

N60°E (Spengler and others, 1984). Dip directions, measured in the Topopah Spring Member and the tuffaceous beds of Calico Hills, indicate that 43% dip toward the northwest; 24% dip to the southeast, and 21% dip to the northeast.

Acoustic televiewer logs were not run on USW G-4; however, data from core holes USW-G-1 (Healy and others, 1984), USW G-2 (Stock and others, 1984), USW G-3 and UE-25p#1 (Stock and others, 1986) show considerable variation of fracture data. Numerous vertical fractures, some of which extend for more than 10 m, were recognized and interpreted to be drilling-induced hydrofractures. Natural fractures identified from USW G-2 televiewer logs were found to have a preferred strike of N10°E to N40°E. Many low- and high angle fractures were identified; most of the high angle fractures were interpreted to be hydrofractures. Orientations and distributions of fractures from acoustic logs of USW G-3 and UE-25p#1 were found to differ considerably. Numerous fractures were observed in UE-25p#1 while very few were observed in USW G-3. In G-3, most fractures have an average strike of N20°E and dip steeply to both the east and west. Fractures in UE-25p#1 have fairly scattered orientations and both steep and shallow dips. In contrast to USW G-1, G-2, and G-3, no hydrofractures were observed in UE-25p#1.

3.3.6 Equipment

Most of the equipment to be used is conventional off-the-shelf equipment. Standard laboratory equipment required includes pens, felt tip markers, tape, data sheets, parallel ruler, and a calculator. Geologic field equipment required includes Brunton compass, hand lens, metal tape, pocket knife, and dilute HCl. Major, conventional equipment used for the three test methods is listed in Table 3.3-2. Non-conventional equipment includes a specially constructed (gyroscopic orientation) camera assembly used for the borehole-video-camera logging. Specific design elements of the camera assembly, such as circuitry, are proprietary. Measurement overlays are used both for borehole-video-camera logging and for acoustic televiewer logging, as illustrated in technical procedures GP-10 and GP-13.

3.3.7 Data-reduction techniques

Standard data-reduction techniques will be used for this activity. Data from all three tests will be entered into computer data bases for processing. Data from each test will be analyzed separately and will be integrated and analyzed with other tests when possible. Fracture data will be compiled to show changes in the characteristics of fractures as a function of depth and lithologic unit. The data will be reduced through standard statistical methods and presented by frequency distribution plots or tables. For example, fracture type, apparent frequency, and roughness characteristics are usually shown by histograms; fracture orientation, fracture aperture and observed length are reduced by rose diagrams, curves, histograms and stereonet contours. These, and similar types of compilations, will provide a means for estimating the lateral variability in strike directions and the apparent frequencies of fractures within lithologic units and near fault zones.

In addition to frequency distribution plots and tables, activity parameters commonly will also take the form of maps and other two- or three dimensional illustrations, such as isopach maps, isopleth maps, structure contour maps, or diagrams displaying statistical distributions of activity parameters.

3.3.8 Representativeness of results

The representativeness of subsurface fracture data collected by these methods relies on the rationale and adequacy of the integrated drilling program (SCP secs. 8.3.1.4.1.1 and 8.4.2). The strategy for the number and location of boreholes is developed in SCP secs. 8.4.2.2 and 8.4.2.1.5. The rationale for the number and location of boreholes/coreholes assumes that variability in the tuff units at Yucca Mountain has nonrandom characteristics that can be appropriately investigated by spatially distributed, surface-based boreholes. The representativeness of the data, however, cannot be fully evaluated before the planned tests for this activity are completed and before the results of other activities, particularly Activity 8.3.1.4.2.2.4 (Geologic mapping of the exploratory facilities) are forthcoming.

The integrated drilling program (SCP sec. 8.3.1.4.1.1) is designed to ensure that data acquired during surface-based site characterization activities represents the range of phenomena and structural characteristics needed for performance assessment. The program combines a systematic-sampling (geostatistical) approach, with a feature-sampling approach, used for the vertical boreholes. The location and number of boreholes in the systematic drilling program is chosen to characterize spatial variability of the tuff units at Yucca Mountain, and to provide sufficient areal coverage of the site for geologic, hydrologic, and geochemical investigations (figs. 2.3-1, 2.3-2). In the feature-sampling approach, the location of a single borehole or set of several boreholes is chosen to test a specific hypothesis at that location, or to study structures of interest, such as the Solitario Canyon fault.

The representativeness of data collected by the three methods will be evaluated by comparing data from stratigraphic intervals (Study 8.3.1.4.2.1, Vertical and lateral variability of stratigraphic units within the site area) where fracture data are available for all three subsurface techniques. Data collected from these subsurface techniques will also be evaluated by comparison with data collected from other activities, including Activity 8.3.1.4.2.2.2 (Surface-fracture network studies) and other borehole geophysical studies.

3.3.9 Relations to performance goals and confidence levels

Data collected from this activity will contribute to tentative goals for one or more of performance issues 1.1., 1.6, 1.11, 1.12, and 4.4 (SCP sec. 8.3.1.4.; table 8.3.1.4-1).

3.4 Activity 8.3.1.4.2.2.4: Geologic mapping of the exploratory shaft and drifts

The objectives of this activity are to determine the spatial distribution of fracture networks in the ESF shaft, drifts, and boreholes; to characterize major subsurface faults and fault zones; to map lithostratigraphic features of geologic units; and to assist in selection of test locations in the exploratory-shaft test facility.

3.4.1 General approach

Geologic mapping of the exploratory shaft and drifts is to be done by two complementary types of tests: a) direct measurement underground of features that cannot be studied by photogrammetric methods, and b) photogrammetric plotter mapping in the laboratory, through the use of stereoscopic sets of photographs taken underground.

Underground geologic mapping will be completed in successive increments, each immediately following one to three 2-m rounds of excavation (the maximum length being determined by safety factors assessed for each increment). After excavation is completed and after the exposures have been cleaned, unobstructed access to the walls of this new increment of the shaft or drift will be temporarily available. Under the geologists' supervision (after the cleaning has passed their inspection), the walls will be marked with location and sample targets, surveyed, and photographed in stereoscopic coverage by subcontractors. The geologists will then collect located (surveyed and photographed) oriented samples and begin direct measurement and observation.

The geologic features that are to be measured underground are: fracture roughness, fracture aperture, and direction of movement along faults exposed in the walls of the ESF shaft and drifts. Lithostratigraphic features and characteristics of fracture-filling minerals will be described. Boundaries of lithologic and stratigraphic domains, locations of faults, sample locations, and other significant geologic features will be identified, where possible, by markers in preparation for photographing the walls. Detailed measurements of fracture roughness and aperture along a surveyed horizontal datum line will provide a random sample from each 2-m interval. The purposes of the underground stage of geologic mapping are: a) to obtain measurements not amenable to photogrammetric mapping methods, and b) to identify, survey, and mark a representative suite of geologic features that will be mapped in detail photogrammetrically.

In contrast to conventional mapping, the photogrammetric mapping will automatically incorporate into the digitized data base all geometric or spatial data related to fractures and other planar surfaces. Continuous geologic and fracture-trace maps of the shaft wall and drift walls and roof, plus data sets for reduction, will be produced as the first step in generating two-dimensional and conceptual three-dimensional diagrams of fracture patterns. Some of these diagrams will be computer-generated; others will be computer-assisted.

Methods and technical procedures for Activity 8.3.1.4.2.2.4 are listed in table 3.4-1.

3.4.1.1 Data to be collected and information to be obtained from the data

The tests and parameters for this activity are listed in table 2.4-1.

3.4.1.2 Experimental conditions under which this activity will be conducted:

a) underground data collection

Tests for this part of the activity (table 3.4-1) will be conducted at the rock face of shaft or drift, following one to three 2-m rounds of excavation.

b) photographic data collection

Tests for this part of the activity (table 3.4-1) will be conducted in the photogrammetric laboratory. The photogrammetric method allows laboratory tests to be conducted under optimum working conditions. Also technicians and geologists in the laboratory can concentrate on obtaining correct initial measurements (from the photographs) that can be rechecked as needed for complete assurance.

c) hand-specimen petrography

These tests will be conducted by geologists of this activity in the surface laboratory at the site facility. Experimental conditions in the laboratory will be better than those underground, especially the lighting.

3.4.1.3 Number of data

The approximate number of measurements and samples expected from each 2-m round of excavation is estimated in table 2.4-3. The scope of this activity indicates that as many as 500 measurements may be made for each of approximately 1,625 2-m rounds of excavation. The number of measurements from each stereoscopic set of photographs is especially difficult to estimate without the needed guidance of prototype testing; it will significantly exceed the number from direct measurements made at the rock face.

For each 2-m round of excavation in the shaft and drifts, the subcontractor will take 12 photographs will be taken to obtain stereographic coverage.

3.4.2 Test methods

Geologic mapping of the exploratory shaft and drifts will employ two complementary test methods: a) photographic data collection, and b) underground data collection. Probably about 80 percent of the measurements from this activity will be generated photogrammetrically (table 2.4-3). Direct observation and measurements at the rock face, however, will precede photogrammetric data collection in each cycle of mapping and is, for that reason, described first here.

3.4.2.1 Underground data collection

Contractors' duties

The rock is drilled and blasted; the area is ventilated; shot rock (muck) is removed; if required, rock bolts are installed; and exposures are cleaned. No wire mesh or other obscuring structures are placed on the exposures.

Subcontractors' duties (preparation for geologic mapping):

Shaft.--Mapping platform is positioned vertically and stabilized horizontally; photographic pedestal is surveyed, centered, and leveled.

Drift.--Camera rail is surveyed, centered, and leveled.

In both shaft and drifts.--Location targets and sample targets are installed as requested by geologists and are surveyed; sets of stereoscopic photographs of the new exposures of this round are taken and sent to the surface for development and quality check.

Geologists' duties:

In both shaft and drifts.--Fracture roughness and aperture are measured along fractures intersecting a horizontal line established for a detailed line survey; the pitch of lineations on fault surfaces is measured to determine the latest direction of movement on each surface; fracture-fill mineralogy is described; samples are collected after being marked for orientation. Lithostratigraphic and structural contacts are drawn on a conventional sketch map.

The detailed line survey (mentioned above) provides a statistical sample of the geologic features exposed within each round of excavation, including some parameters not easily measured and described photogrammetrically--such as mineral fill of fractures and fracture roughness and aperture. Even though data to define locations of these lines will be added to the data base for use in data analysis and on illustrations, each line for a detailed survey underground will be established only in concept at the rock face. The surveyors' laser beam, already aligned along the centerline of the drift, will be deflected 90° to a series of points that define a line as the Pyramid Beam Splitter is moved progressively along the camera rail so that the beam intercepts successive geologic features. If the feature is a fracture, its azimuth, dip, aperture, mineral infilling, and roughness will be measured manually at this accurately established location before moving to the next geologic feature to be described in equal detail. In ES-1, a similar detailed line survey per round of excavation will be accomplished efficiently through the use of the Laser Azimuth Pointer. In ES-2, line surveys will be more widely spaced to reduce the time required for underground mapping.

Pre-testing excavation, cleanup, and safety procedures are performed by contractors and subcontractors. The rock is drilled and blasted; the area is ventilated; shot rock (muck) is removed; rock bolts are installed, if required; and exposures are cleaned. However, no wire mesh or other obscuring structures are placed on the exposures.

The purpose of direct observation and measurement at the rock face is to obtain data that are needed to complement the photogrammetric data set. Following clean-up, collection of data at the rock face is accomplished in the following steps:

Shaft--Mapping platform is positioned vertically and stabilized horizontally by subcontractor; photographic pedestal is surveyed, centered, and leveled by subcontractor; location and sample targets are installed and surveyed by subcontractor; sets of stereoscopic photographs of the new exposures of this round are taken by subcontractor and sent to the surface for development and quality check; fracture roughness and aperture are measured along fractures that intersect a detailed line survey; orientations of fault surface lineations are measured to determine movement directions on faults; fracture-fill is described and samples are collected. Lithostratigraphic and structural contacts are drawn on a conventional sketch map.

In order to avoid gaps in the photographic record and to ensure high-quality photographs, a highly reliable camera will be used and a spare camera will be kept available, and may be used to take dupliate photographs of each round. In addition, exposed film will be developed and printed expeditiously in a film-processing laboratory at the ESF surface facility. This will allow re-photographing of a wall prior to lining (without excessive delay of the construction schedule) in the unlikely event that the photographic record is significantly incomplete or inadequate.

Rock samples collected during each underground tour will be described at surface facilities by geologists of this activity and then released to permanent storage or sent to specific laboratories for further testing.

Drift--Camera rail is surveyed, centered, and leveled by subcontractor; location and sample targets are installed and surveyed by subcontractor; sets of stereoscopic photographs of the new exposures of this round are taken by subcontractor and sent to the surface for development and quality check; fracture roughness and aperture are measured along fractures intersecting a detailed line survey; orientations of fault surface lineations are measured to determine movement directions on faults; fracture-fill mineralogy is described; samples are collected. Lithostratigraphic and structural contacts are drawn on a conventional sketch map.

3.4.2.2 Photographic data collection

Photogrammetric mapping (collecting data from photographs) will be done with a computerized Kern DSR-11 analytical plotter (see Equipment, sec. 3.6). The plotter will use 2.25-by 2.25-in. film diapositives of the shaft and drift exposures. Operators will trace fractures more than 20 cm long and stratigraphic contacts directly from projected photographic images. Spatial coordinates obtained by the analytical plotter will be used to determine the attitude of planar structural and stratigraphic horizons by the methods outlined in Pillmore et al. (1980) and Dueholm (1981).

Fracture traces more than 20 cm long will be digitized, using operating system software tailoring to close-range photogrammetric applications. Subsequent to the determination of fracture attitudes as outlined above, digital fracture data for each wall and roof will be projected onto a common plane. The projected planar data will be stored in a commercial geographic information system to which fracture attribute data (fracture attitude, fracture roughness, fracture aperture, fault lineation pitch, etc.) can easily be added and modified. Fracture, fault, and lithologic maps of the projected plane can be produced using a choice of map scales and selection criteria.

3.4.3 QA level assignment

Quality Assurance (QA) requirements for this activity will be specified in a Yucca Mountain Project QA Grading Report, which will be issued as a separate controlled document. All procedures applicable to this activity will be identified on the basis of the findings in the Grading Report and will be prepared in accordance with applicable QA requirements.

3.4.4 Required tolerances, accuracy, and precision

Required accuracy and precision have not been established for measurements to be made by this activity. The accuracy expected of the tests in this activity is as follows:

a) fracture location--expected to be within ± 2 cm

b) fracture apertures--measurements to ± 0.03 mm are expected. Apertures <0.03 mm wide will be recorded only as such, because 0.03 mm is the practical lower limit of gauges.

c) attitudes of extensive planar features, and trends and plunges of linear features, are expected to be measured within ± 1°.

d) roughness of a fracture is measured with a contour gauge that copies changes in amplitude each 1 mm along its length. Amplitudes are expected to be measured within ± 1.0 mm.

3.4.5 Range of expected results

In general, the concept of "range of expected results" can be applied only selectively to the tests of this activity. Some measurements, such as attitudes of fracture surfaces, may involve all possibilities, but may cluster within each structural domain. Others, such as apertures of fractures, will cluster at the lower end of the measurement scale. The range of trace lengths of fractures, will be determined in part by the limit of cut-off at the lower end of the measurement scale (at 20 cm) and, at the upper end of the scale, by the size of the underground opening.

Some expected ranges are:

Lithophysal cavities--from 0 to 30% volume of the rock

Fracture frequency (sum of trace lengths per unit area)--from < 1 to $50 m/m^2$

Roughness of fractures (on a scale of 1 to 20)--entire range

Fracture apertures--mostly from < 0.03 mm to 1 cm (clustered at the lower end of the range) but locally > 1 cm

3.4.6 Equipment

The major equipment needed for photogrammetric geologic mapping in the exploratory shaft facility is shown in table 3.4-2, which is subject to revision after prototype testing is completed.

3.4.7 Data-reduction techniques

Data-reduction for this activity will be done by a combination of automated computer-controlled tasks, user-interactive computer tasks, and conventional interpretive geologic methods. Some data reduction, transformation, and projection of fracture trace data, calculation of fracture attitudes, etc., will be performed with little user input beyond routine analytical plotter operation. Subsequent manipulation of data to produce fracture trace maps, stereonet projections, histograms, and fractal analysis will be performed either through direct manipulation of the geographic information system database, or by using interactive application programs which access selected data elements from the database. Some data may be reduced by hand to prepare products such as cross-sections, block diagrams, or other elements of a visual three-dimensional fracture network model. In addition, columnar sections illustrating lithostratigraphic and structural domains penetrated by the exploratory shaft may be constructed in part with the aid of the digital mapping system and in part by hand. The purpose of these sections is to aid in correlation with stratigraphic sections determined from core or outcrop sequences of the repository block.

3.4.8 Representativeness of results

In general, this activity will obtain data that are representative of the immediate area of the exploratory shaft and drifts, but that can be extrapolated to the repository block. Although these data will not fully represent the entire repository block, they will be the most complete and representative ones available until similar tests of other parts of the block are completed. Drill-hole, outcrop, and seismic data also will be essential for the extrapolation of the geologic framework in the ESF to the repository block.

Many of the measurements from this activity will be accurate and entirely representative. Continuous geologic maps and fracture-trace maps of the walls of the shaft and walls and roof of drifts will be accurate. They will show the exact fracture pattern, including intersections of fractures and (where possible) relative ages of fractures. Determinations of ages of fracture-fill will provide some constraints on the actual ages of fractures (when they were formed).

Fracture aperture data are critical in site characterization, but the effects of blasting and excavation definitely will alter measurements. Radial borehole hydrologic tests (Study 8.3.1.2.2.4), however, will characterize the degree of blast distortion of fracture aperture as a function of distance from the blast. Corrections based on results of these tests will make the aperture data informative but not totally representative.

In addition to changing the apertures of natural fractures exposed at the face of the excavation, blasting also extends the traces of existing fractures and creates new fractures. Criteria for the recognition of blast-induced extensions of natural fractures and blast-induced new fractures are meaningful only in conjunction with criteria for the recognition of natural fractures.

Criteria for recognition of the preblast extent of natural fractures

The preblast extent of natural fractures is unequivocally indicated by time-dependent additions or alterations, specifically: a) mineral-filling and b) color changes, leaching, and other indications of chemical alteration along the fracture face. Generally these fractures are part of a set oriented by paleostress; some exhibit tectonic offset.

Criteria for the recognition of blast-induced fractures and extensions of natural fractures

Blast-induced fractures and extensions are fresh breaks in the rock that exhibit none of the criteria for recognition of natural fractures. They generally emanate radially from the vicinity of shotholes, preferentially in directions favored by the current stress field. Generally they exhibit no offset.

The area of uncertainty between these two sets of criteria is narrow and tends to belong largely to blast-induced fractures. Fractures that are of uncertain origin will be recorded as such by the geologist at the rock face. Radial borehole hydraulic tests (Study 8.3.1.2.2.4) will, in some instances, provide evidence favoring one of the choices.

3.4.9 Relation to performance goals and confidence levels

This activity will contribute to tentative goals for performance issues 1.1 and 1.6, as outlined in section 1.2 and detailed in SCP table 8.3.1.4-1.

3.5 Activity 8.3.1.4.2.2.5 Seismic tomography/vertical seismic profiling

The objectives of this activity are:

- to investigate, and if successful, provide a means for broadly detecting and characterizing the subsurface fracture network in regions between the surface, boreholes, and underground workings
- to calibrate and relate the seismic propagation characteristics of the host rock to the fracture patterns observed in boreholes and underground workings and to extrapolate the observed fracture patterns to the surrounding region using the seismic image

A single test, seismic tomography/vertical seismic profiling, will be used to pursue these objectives.

3.5.1 General approach

The seismic tomography and vertical seismic profiling (VSP) work at Yucca Mountain is designed to apply seismological techniques for mapping lithology, fracture content, and structure. To do so, the test method will gather information on the SCP parameters--travel time, amplitude, and polarization of the direct, reflected, and refracted compressional (P) and shear waves (both SH and SV), as well as other wave-propagation characteristics identified by investigating the relation of wave-propagation characteristics to fracture properties. The results will be used to define locations of fractures and, it is hoped, details of the fracturing such as fracture orientation and fracture density, as well as to define major lithologic and structural boundaries. Fracture detection using VSP has been applied in several previous studies (Stewart and others, 1981; Crampin, 1984a, 1984b, 1985; Majer, 1988). Single component "check-shot" VSP's have been done near Yucca Mountain, but a technique using multicomponent sources and receivers as planned for this activity has not been tested. The work proposed here is scheduled to be carried out in borehole G-4 and (or) other available boreholes as discussed in section 2.5.2.2. Other VSP work is being planned as part of Activity 8.3.1.2.2.3.2 (Site vertical borehole studies) in the UZ6-UZ9 borehole complex. Although similar in execution, the objective of the planned work for the present activity (8.3.1.4.2.2.5) is on a broader scale and not intended to have the same objectives as the VSP work planned for Activity 8.3.1.2.2.3.2.

The general approach in the VSP work will be to use seismic sources on the surface and in boreholes to create P- and S-wave energy. This energy will be recorded in boreholes (G-4 for the initial test) and in the exploratory facilities. Also planned is crosshole work in the saturated zone at the C-hole locations to determine details on the rock structure for the interpretation of the tracer tests and crosshole hydrologic tests in this area (see fig. 2.5-1 for well locations).

Extensive surface mapping in this area (Scott and Bonk, 1984) shows generally dominant north-south fracture sets. Accordingly, the initial VSP will use P-wave and S-wave vibrators as energy sources, positioned at regular intervals along lines trending parallel and perpendicular to the strike of the major fracture directions. This will also provide information to test the method regarding the effects of fracture azimuth on the propagation of seismic energy. Figure 3.5-1 shows the location of the sources for the initial work in G-4.

In the initial G-4 tests, the concept is to collect the data along lines parallel, perpendicular, and at intermediate angles to the inferred and (or) mapped structure at varying offsets. The offset distances will be spaced 200 to 250 m (depending upon access), with up to five offsets along each line. P- and S-wave vibrators will be used for this work. The locations of the vibrator points in figure 3.5-1 are on similar terrain. Static corrections between source positions are therefore not anticipated to be large. If this approach is extended to other areas, then it may be necessary to obtain static correction with shallow refraction work by extending a line of surface phones from the source to the well, or with a detailed shallow walk-away VSP. At each offset, the P-wave source and the S-wave source will be activated. The S-wave source will be vibrated at least parallel and then perpendicular to each line. Each vibration sequence will be done at each geophone level in the well. The geophone spacing will be no more than 10 m in the well. This combination of offsets and geophone spacing will yield an approximate pixel size of 20 m. Figure 3.5-2 shows an east-west cross-section through borehole G-4 and some of the raypaths. In reality the raypaths will not be straight but curved due to velocity changes. The water table is also shown in figure 3.5-2. We are intentionally extending the survey below the water table to determine the seismic signature and sensitivity to P- and S-waves of the saturated zone relative to the unsaturated zone. Preliminary examination of logs in wells surrounding this area shows generally an increasing velocity with depth, but with interlayered low velocity zones. There is also a very near-surface high velocity zone. Before the field work is actually carried out, the area will be modeled with raytracing programs to determine the optimum placement of sources and receivers. Data from available well logs will be used for this purpose.

The field procedure for the VSP will be to record the data using three-component geophones clamped into the well. If available, a string of 3 or 4 clamped 3-component geophones will be used. Otherwise, a single 3-component clamped geophone will be used. The data at each geophone level will be recorded from each offset along three lines running from the G-4 well (fig. 3.5-1). Multiple sweeps will be taken to improve signal-to-noise ratio; in field stacking may be done. The data will be recorded on a state-of-the-art 16-bit digital field VSP recording and processing system. This 32-channel system is not only capable of recording, but also of performing higher level in-field operations (amplitude and time scale expansion and compression, band pass filtering, first-arrival picks, time-distance plots, auto- and cross-correlation, summing, Fourier analysis (magnitude and phase) and program and data storage). The sweep rates and recording times will be dictated by the actual field conditions, but we are anticipating a 2-msec sample rate with sweep frequencies from 10 to 250 Hz for the P-wave and 10 to 250 Hz for the S-wave. The data will be recorded on 9-track tapes and returned to the laboratory for processing.

The data will be in the form of industry-standard SEGY and (or) SEGB format. These data are time-series data recorded on a field recording system. The number of time series will depend upon the number of recording levels in the wells and in the exploratory facilities. It is anticipated that in the initial G-4 work there will be a total of 50 levels, 12 offsets, and 9 traces per offset per level (for a total of 5,400 traces). For the exploratory facilities work there will be 37 levels and 10 offsets (for a total of 3330 traces). For the C-hole work there will be a different configuration of the source and receiver. In the C-hole work the source and receiver will both be in wells. If all three wells are used and if the zone of coverage is 500 ft with spacing every 3 ft, the total number of rays will be 27,556 for the three wells; assuming three-component receivers, this brings the total number of traces to 82,668 for the C-hole work.

3.5.2 Test Methods

Standard data collection techniques used widely in the petroleum industry will be applied. The specific method to be employed is tomographic/vertical seismic profiling surveys using P- and S-wave data, and is described in Technical Procedure SP-13-SP crosshole tomographic surveys.

3.5.3 QA Level assignment

Quality Assurance (QA) requirements for this activity will be specified in a Yucca Mountain Project QA Grading Report, which will be issued as a separate controlled document. All procedures applicable to this activity will be identified on the basis of the findings in the Grading Report and will be prepared in accordance with applicable QA requirements.

3.5.4 Required tolerances, accuracy, and precision

No explicit requirements for accuracy or precision have been specified for this activity. Industry standards for analogous work indicate that the data must be collected at a data rate of at least 500 samples per second with 16-bit precision, from three-component receivers. The location of the sources and receivers must be known to within 0.5 m accuracy and 0.1 m precision for the VSP work in the G-4 well and in the ESF.

3.5.5 Range of expected results

Information to be obtained in this activity on the travel time, amplitude, and polarization of the direct, reflected and refracted compressional and shear waves is expected to result in a map of the surveyed areas showing fracture content and possibly an estimation of the volumetric content of fractures and their orientation, as well as the degree of saturation of the bedrock. Resolution of fracture properties in the G-4 well and the ESF is expected to be on the order of 10 m with a receiver separation of 10 m. In the C-holes, resolution is expected to be on the order of at least 1 m^2 in the tomographic pixel sizes.

3.5.6 Equipment

The required equipment will be a field recording system, a wireline truck, and a clamping 3-component geophone. For the G-4 work, P- and S-wave vibrators will be used as surface sources. State-of-the-art sources will be used. Because of possible frequency dependence caused by fracture content (Pyrak-Nolte, et al, 1990), a broad sweep is desired. In the crosshole work in the C-holes, a piezoelectric cylindrical source will be used. This source is powered by high voltage electronics and has been used and tested in crystalline rock, sedimentary rock, and fractured gneiss. At the present time this source is an excellent P-wave generator, but a poor generator of SH and SV waves. Sources are under development for controlled SV and SH waves for use in boreholes; if available, these will be used. Previous work with P-wave high resolution surveys (10,000 Hz) indicate that it is possible to achieve the fracture mapping with these sources (Northwood, et al, 1980). For the ESF work the geophones will be emplaced in shallow boreholes in the shafts, thus the geophone need not be of the clamping type used in the G-4 work, but they will be individually clamped in the boreholes. In the drifts it is anticipated that the geophones will be secured to the walls with a plate epoxyed to the drift walls.

3.5.7 Data reduction techniques

The anticipated processing sequence for the VSP studies will be as follows:

(1) The data will be demultiplexed and displayed for editing.

(2) The data will be "de-spiked". (The geophone may slip in the hole, causing it to shake and put a spike on the data. After correlation with the sweep these spikes cause a ringing nature in the data. Therefore, it may be necessary to remove the spikes with a special editing program; however, careful field procedures will minimize the need to do this.)

(3) After de-spiking, the data will be correlated and then filtered with a band-pass Butterworth filter to enhance arrivals.

(4) The data will be plotted for visual inspection. At this point we will look at the individual shots for each offset and each orientation. This is in preparation for stacking the data.

(5) The noisy shots will be discarded.

(6) The data will be displayed.

It is then necessary to separate the SH arrival from the SV arrival for each orientation of the vibrator. This is accomplished by rotating the data into the planes of propagation. This may be accomplished by knowing the orientation of the geophone, either from direct measurement, from looking at the P-wave arrival, or by having a gyroscope or tilt-meter on the geophone sonde.

Once the data have been rotated into the appropriate planes it is now possible to pick the various arrivals (SH, SV, P from both orientations of the shear-wave and the P-wave vibrator). The data are then ready for analysis and interpretation. Before the data are collected it is difficult to tell the exact sequence of processing, but what we are aiming for is to map the anisotropy in the SH, SV, and SV/SH velocity ratios and, if possible, the variation in the amplitudes. With these quantities we will then be able to infer fracture density and orientation through the fracture stiffness and anisotropy theories.

The anticipated processing sequence for the tomographic imaging studies will be as follows:

(1) The data will be displaced and examined for quality of the P- and S-wave arrivals.

(2) Picks will be made of the P- and S-waves for arrival times and amplitudes.

(3) Plots of arrival time vs distance will be made to examine anomalous picks.

(4) Accepted arrival times will be used to produce tomographic images.

(5) Inversion procedures will be based on straight and curved ray tomographic techniques (e.g., ART).

(6) If warranted, and the data are of sufficient quality, amplitudes will also be used in the tomographic inversions.

(7) If the SH, SV, and P wave arrivals are of sufficient quality, tomographic images will be pictured along with differences and Poisson's ratio tomograms.

(8) Anisotropy corrections will be made if general trends on anisotropy can be determined.

3.5.8 Representativeness of the results

The frequencies at which we will be working will be working in the VSP will provide a relatively gross picture of the rock (50 to 100 Hz peak frequency, sweeps from 8 to 120, may be possible); however, the technique has the potential to provide a method for characterizing the geologic and hydrologic parameters of the entire repository block at a much finer scale by using higher frequencies and finer sampling. Crosshole work with available piezoelectric sources vary from 1 to 20 kHz, and from 50 to 500 Hz using mechanical vibrators in boreholes. Explosives may also provide higher frequencies but their use may be limited by other factors such as borehole damage or interference with other experiments. The representativeness of the data, however, cannot be evaluated until the data are compared with actual observations and measurements of fractures in outcrops and boreholes and in the ESF.

3.5.9 Relations to performance goals and confidence levels

This activity will contribute to tentative goals for performance issues 1.1 and 1.6, as outlined in section 1.2 and detailed in SCP table 8.3.1.4.-1.

4 APPLICATION OF RESULTS

The information obtained from this study, along with that from the characterization of vertical and lateral variations of stratigraphic units (Study 8.3.1.4.2.1), will provide a basis for developing a conceptual three-dimensional model of the geology of the area (Study 8.3.1.4.2.3). This geologic model will provide a basis for geohydrologic, geochemical, and thermal-mechanical models. Those models in turn will provide the basis for the model of the three-dimensional rock characteristics of the controlled area.

4.1 Application to performance-assessment studies

The uses of the information from this study for resolving performance issues are addressed in section 1.2.

4.2 Application to design studies

The uses of the information from this study for resolving design issues are addressed in section 1.2.

4.3 Application to characterization studies

The information from this study will provide a basis for other investigations in the site characterization program, as described below.

The lithostratigraphic data collected in the exploratory shaft will assist (through Study 8.3.1.4.2.3, geologic model) in defining the hydrogeologic units and the geometric relations among them for Investigation 8.3.1.2.1 (description of the regional hydrologic system). The geometry and physical properties of fracture systems and faults will contribute to understanding the discontinuities in the hydrogeologic units of the regional hydrologic system. Both the lithostratigraphic and structural data will contribute to Investigation 8.3.1.2.2 (description of the unsaturated zone hydrologic system at the site). And the structural data will provide a basis for Investigation 8.3.1.2.3 (description of the unsaturated zone hydrologic system at the site).

Data on the petrographic variability and internal stratigraphy of the Topopah Spring Member will contribute (through the geologic model) to Investigation 8.3.1.3.2 (mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths); to modeling the three-dimensional distribution of mineral types, rock and mineral compositions, and mineral abundances within the host rock and along potential flow paths to the accessible environment (Investigation 8.3.1.3.2); and to determining the history of mineralogic and chemical alteration at Yucca Mountain (Investigation 8.3.1.3.2).

Structural and lithostratigraphic data from the study will contribute to Investigation 8.3.1.4.2 (stratigraphy and structure necessary to locate the underground facility). Structural and lithostratigraphic data from this study and lithostratigraphic data from Study 8.3.1.4.2.1 (vertical and lateral distribution of stratigraphic units within the site area) will contribute to study 8.3.1.4.2.3 (development of a geologic model of the site area). This geologic model will be used as the geologic framework for Investigation 8.3.1.4.3 (development of a computer-based three-dimensional model of rock properties at the repository site). The geologic model will provide a geologic basis for quantitative interpolation of rock property values between data points. Structural and lithostratigraphic data from this study will be used in Investigation 8.3.1.8.2 (nature and rates of tectonic processes) to construct fault maps of the repository area, showing length and density of faults; similarly, they will provide data for structure contour maps of tuff units over the repository, showing total offset and covered faults. These data will be used to estimate the probability and rate of faulting, to calculate the number of waste packages intersected by faults, and to assess waste package rupture due to faulting.

This study will contribute to Investigation 8.3.1.15.1 (spatial distribution of thermal and mechanical properties) through the geologic model (Study 8.3.1.4.2.3), which provides the stratigraphic and structural framework necessary to describe the spatial distribution of such properties as heat capacity, thermal conductivity, elastic properties, and deformation moduli.

Similarly, structural data from the study (such as fault location, geometry, and physical characteristics) will contribute, through the geologic model, to Investigation 8.3.1.17.2 (fault displacement that could affect repository design and performance). The data are a basis for assessing the potential for surface faulting at surface facilities and for fault rupture intersecting underground facilities.

5 SCHEDULE AND MILESTONES

For the *in situ* tests of activity 8.3.1.4.2.2.4, the schedule will coincide with the schedule for construction of the ESF. For the above-ground tests of this activity and for the tests and analytical procedures of the remaining four activities in the study, the schedules have not yet been determined.

Milestones for Study 8.3.1.4.2.2, as specified by the December 1988 statutory draft of the SCP, are shown in figure 5-1.

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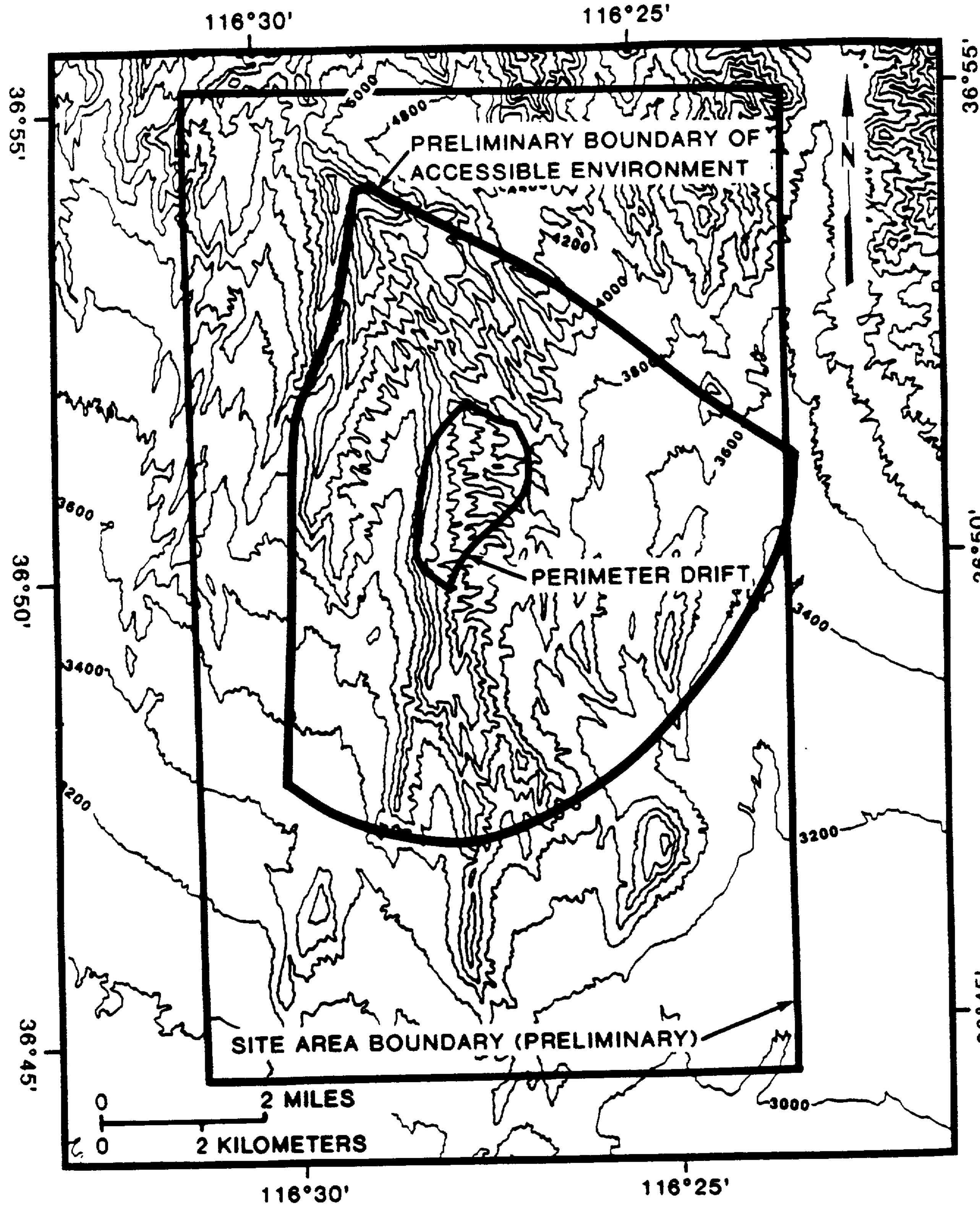

Figure 1-1. Areas of geologic investigation at Yucca Mountain.

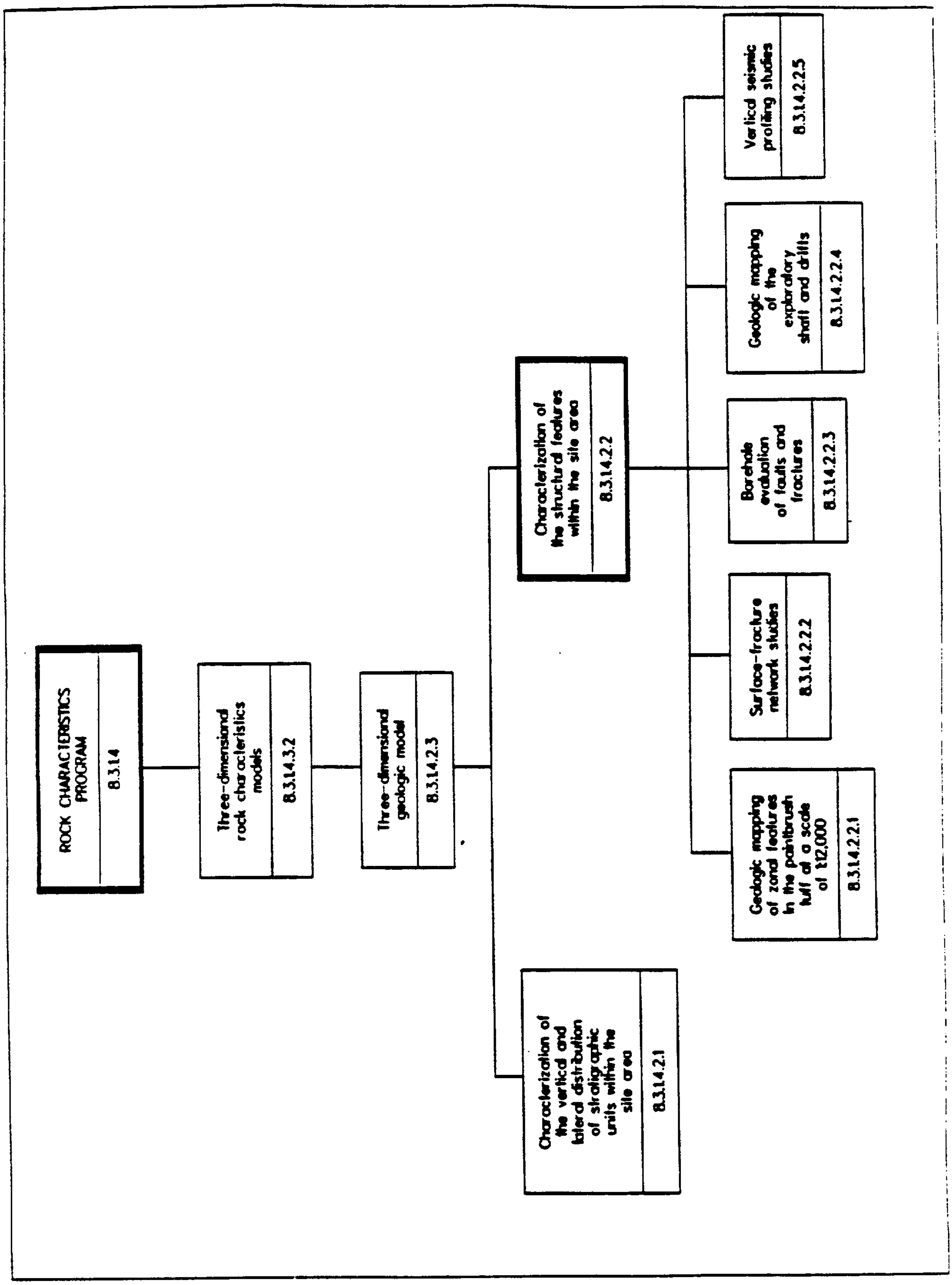

Figure 1-2. Logic diagram showing Study 8.3.1.4.2.2 in context of rock characterization program.

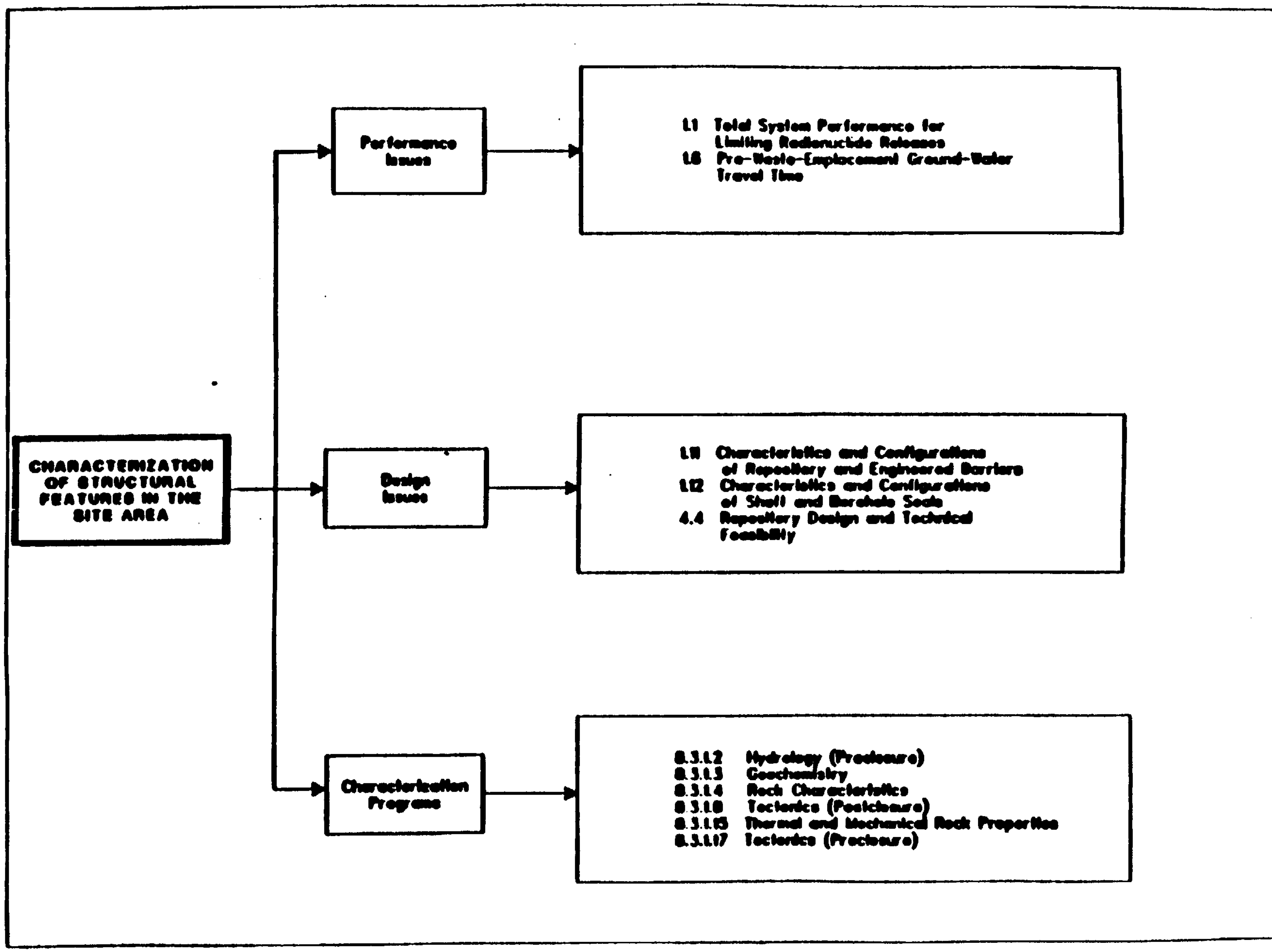

Figure 1-3. Uses of information from rock characterization program for resolving performance and design issues and for supporting other characterization programs.

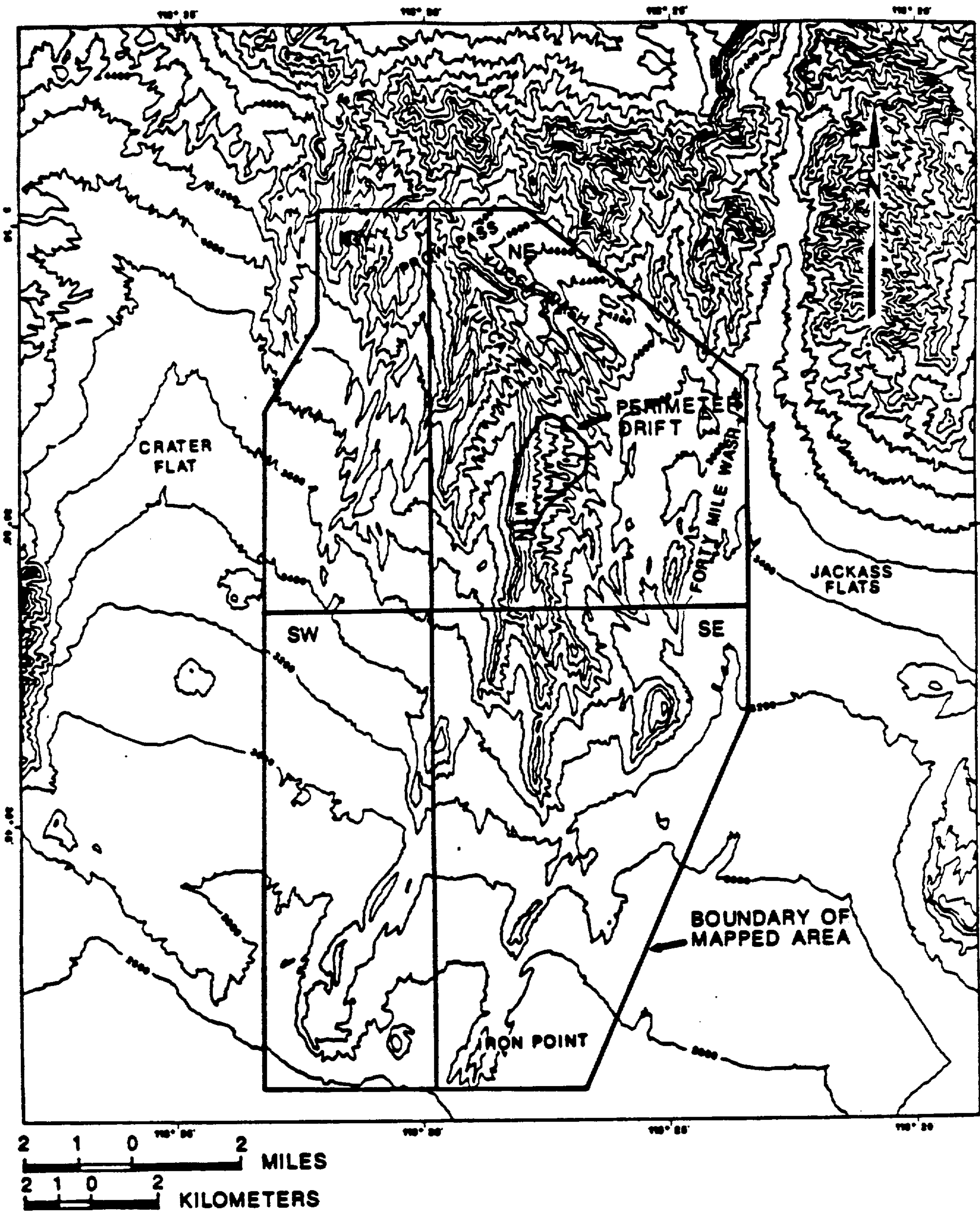

Figure 2.1-1. Location of mapped area at Yucca Mountain, showing separate mapping segments.

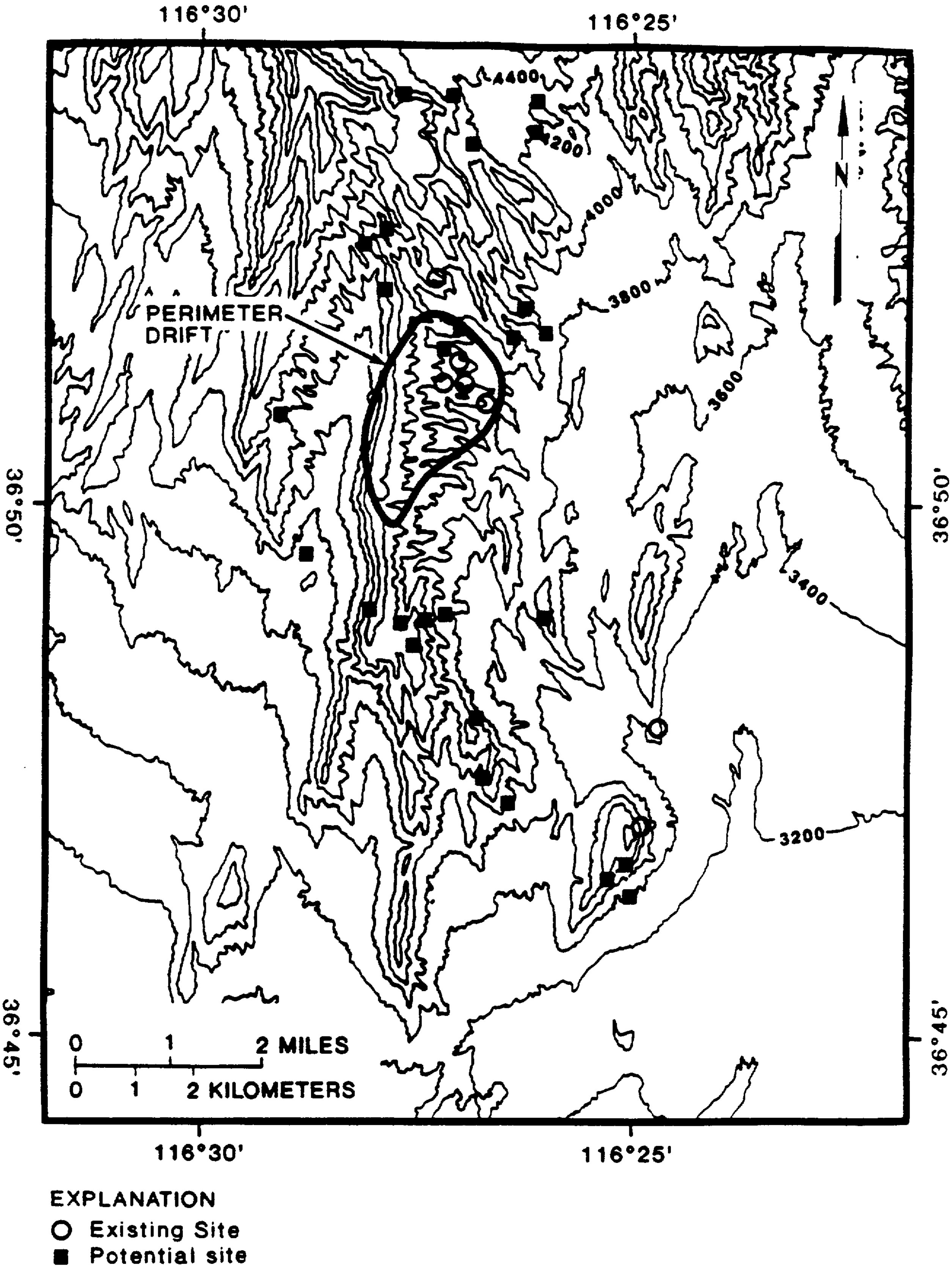

Figure 2.2-1. Location of existing and proposed surface sites for fracture study at Yucca Mountain.

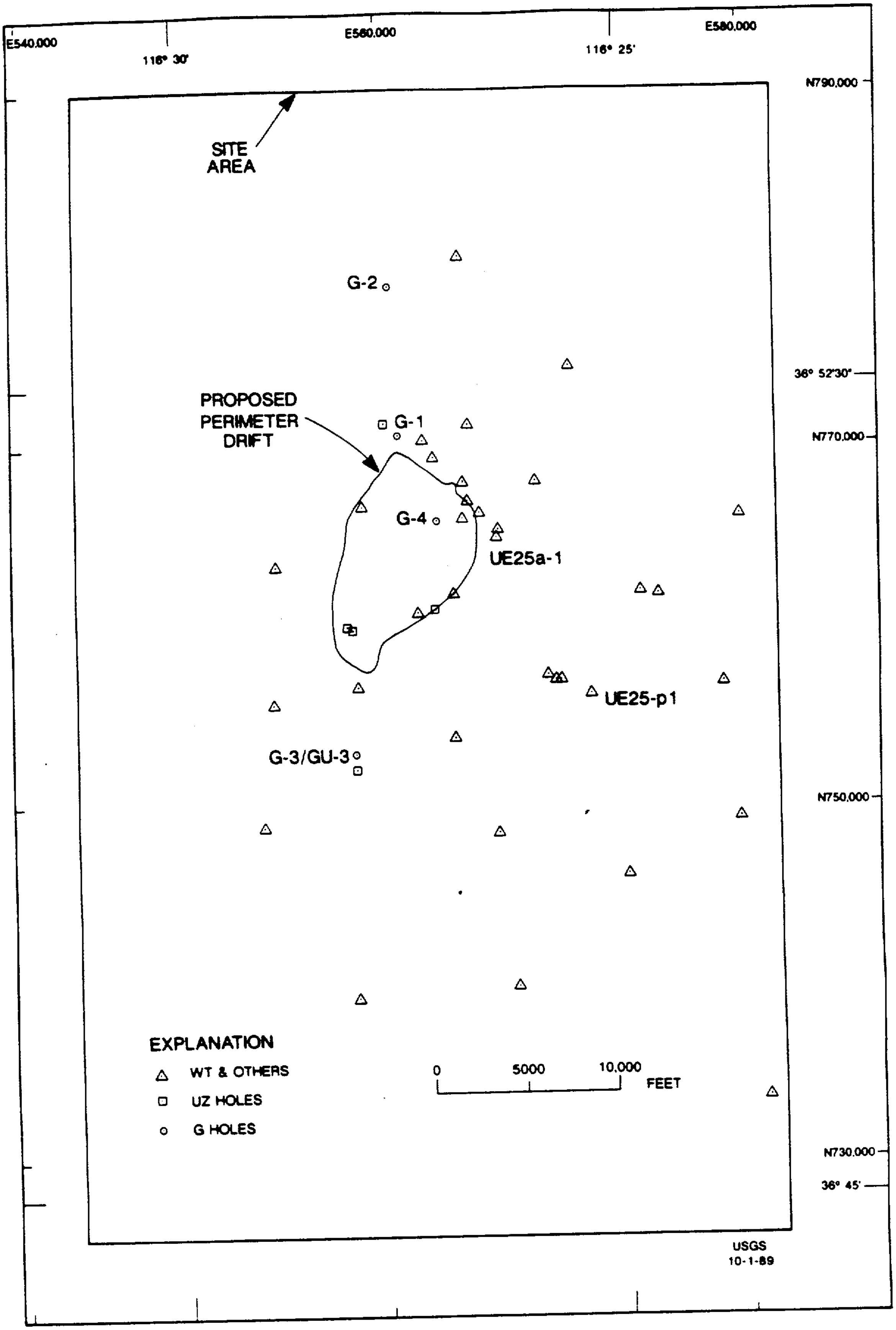

Figure 2.3-1.--Location of existing drill holes exceeding 500 ft in depth.

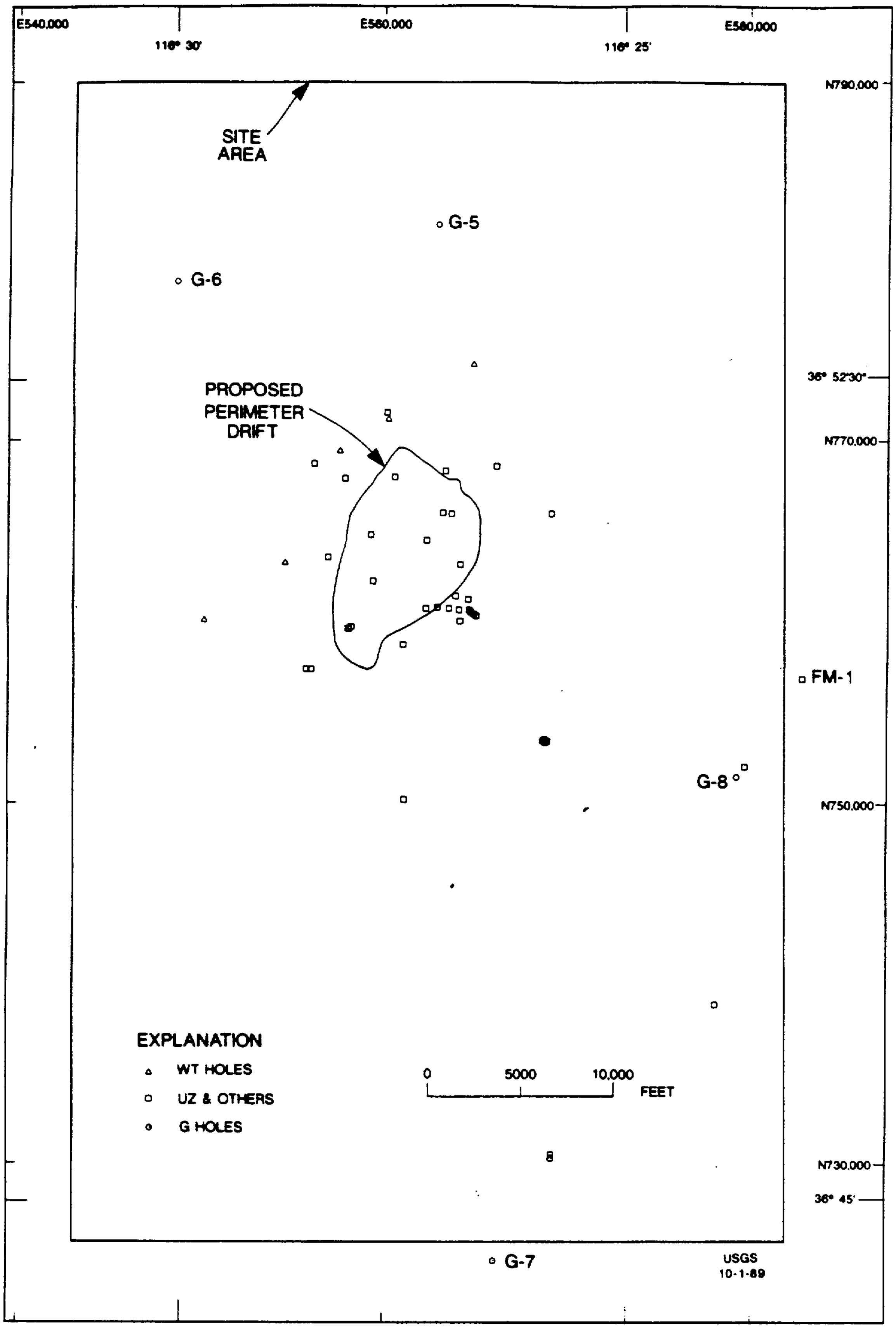

Figure 2.3-2.--Location of planned drill holes exceeding 500 ft in depth.

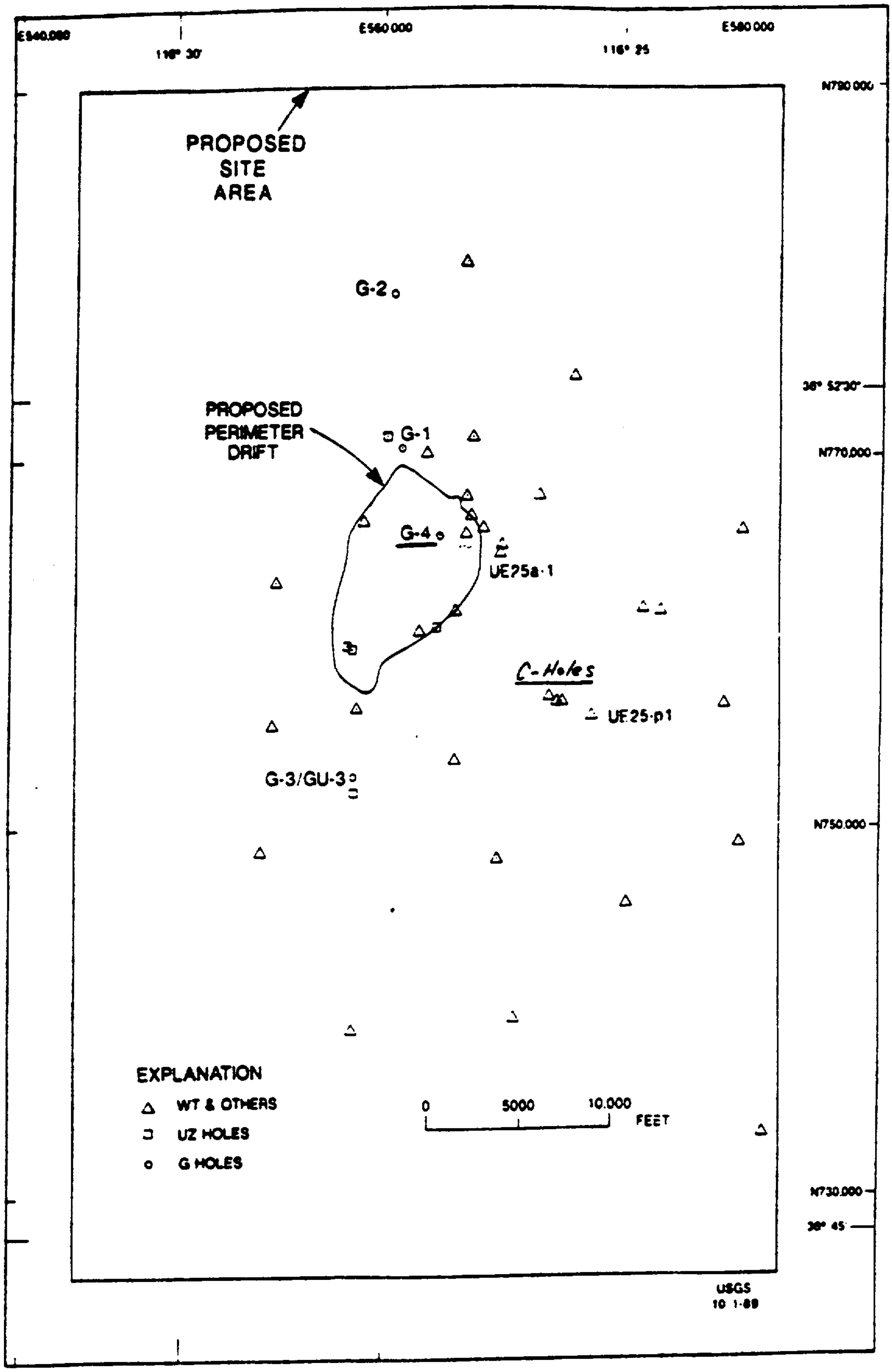

Figure 2.5-1.--Index map showing location of borehole G-4, C-holes, and other existing boreholes in the vicinity of Yucca Mountain.

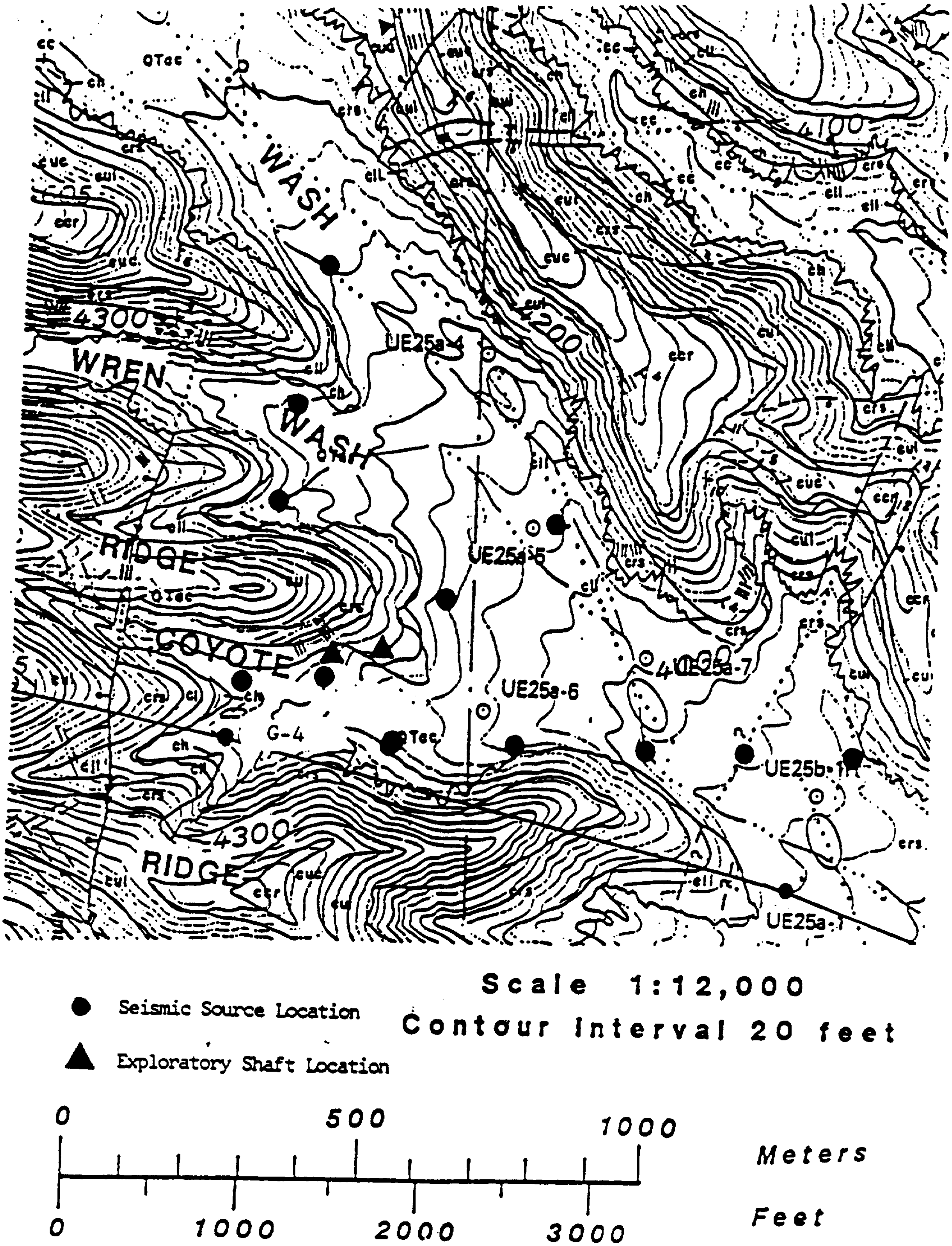

Figure 3.5-1.--Index map showing approximate location of sources for VSP survey at borehole G-4.

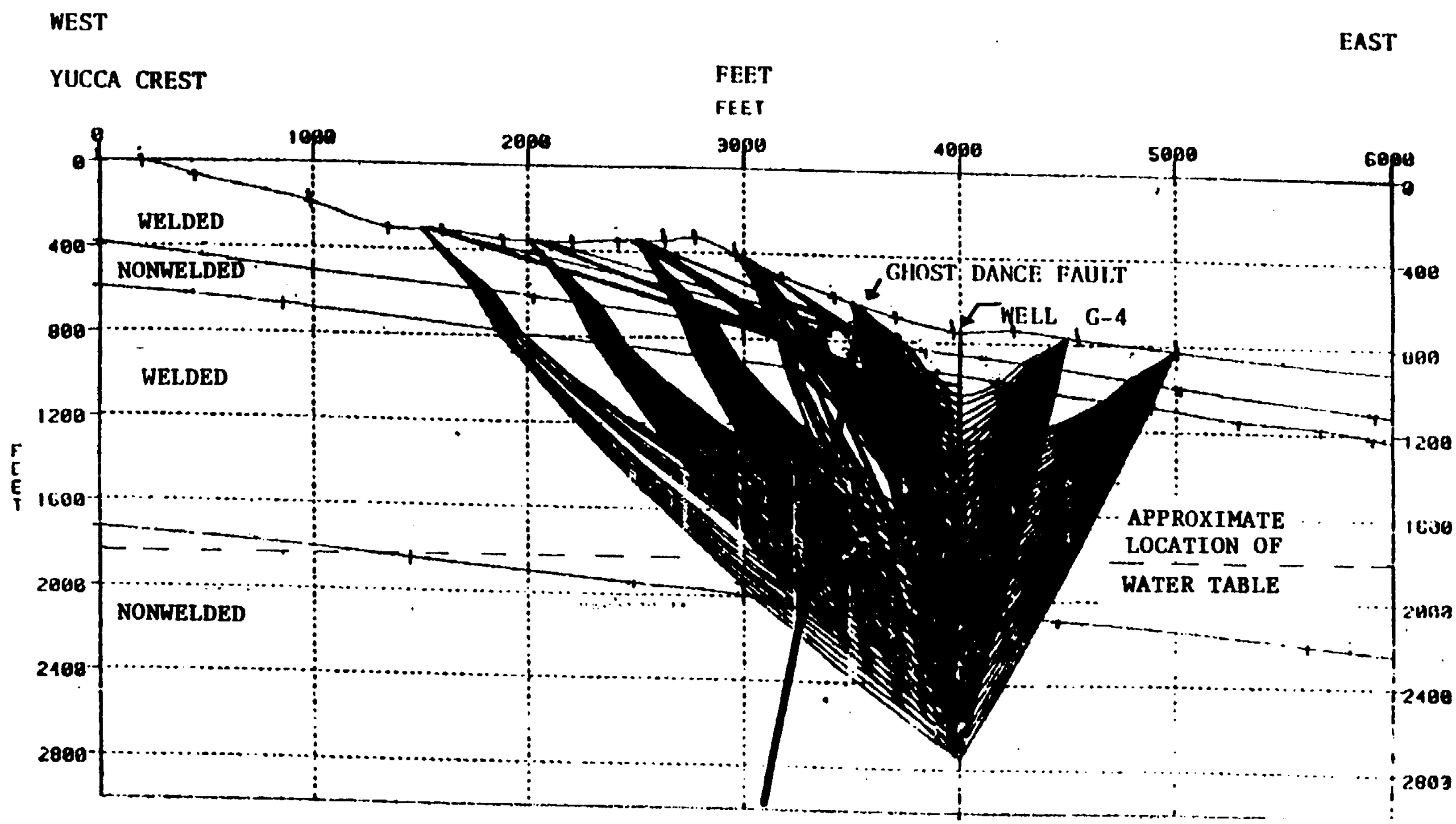

Figure 3.5-2.--An east-west cross-section through borehole G-4 showing some possible raypaths between surface seismic sources and geophones in the well. (Note: This is an example of the method, and is not intended to depict the layout of the experiment shown on figure 3.5-1.)

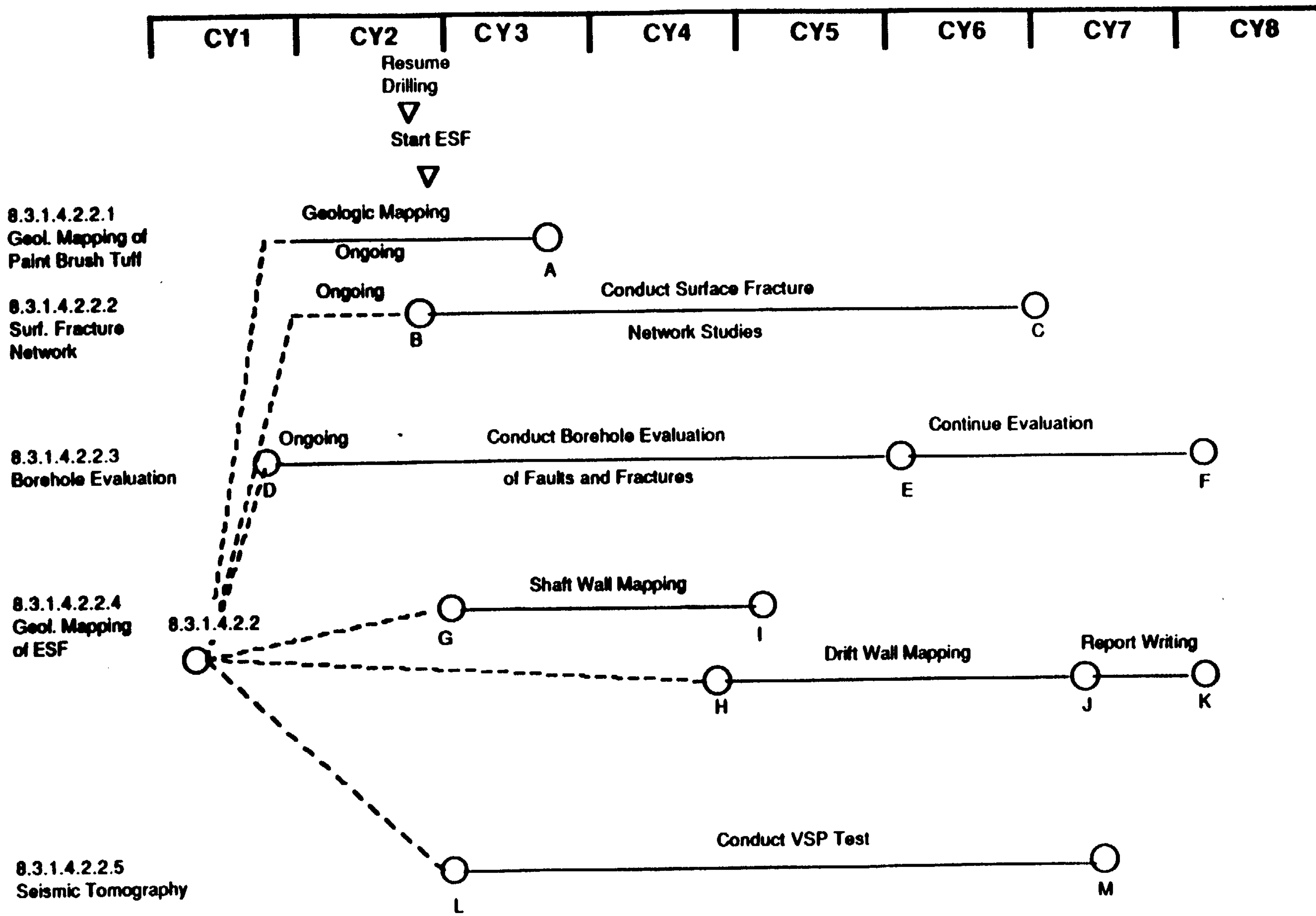

Figure 5-1. Schedule for Study 8.3.1.4.2.2.

Figure 5-1. Schedule for Study 8.3.1.4.2.2 (Continued)

Major Event	Event Description
A	Final report on geologic mapping of the Paintbrush Tuff
B	Interim report on surface fracture network studies; recommendations for future work
C	Report on fracture distribution at Yucca Mountain
D	Start drilling new unsaturated zone wells
E	Report on borehole evaluation of structure/stratigraphy
F	Final report on borehole evaluation of faults and fractures
G	Begin shaft wall mapping
H	Begin drift wall mapping
I	Shaft wall mapping report complete
J	Drift wall mapping complete
K	Drift wall mapping report complete
L	Begin vertical seismic profiling
M	Report on the results of vertical seismic profiling

Table 1-1 Information Needs Requiring Data from Study 8.3.1.4.2.2

(SCP Study 8.3.1.4.2.2)

Information Need Number	Statement of Information Need	Data Provided	Interface Activity
Design Issues			
1.11.1	Site characterization information needed for design	TSw unit contacts; fault locations and geometry.	8.3.1.4.2.2.1; 8.3.1.4.2.2.2; 8.3.1.4.2.2.3; 8.3.1.4.2.2.4; 8.3.1.4.2.2.5
1.11.3	Design concepts for orientation, geometry, layout, and depth of the underground facility to contribute to waste containment and isolation, including flexibility to accomodate site-specific conditions	Site information from 1.11.1, plus vertical extent of lithophysal zones, fracture location and orientation, required to generate design concepts for repository orientation, geometry, layout, and depth.	"
1.11.6	Repository thermal loading and predicted thermal and thermomechanical response of the host rock	Site information from 1.11.1 needed for design of thermal loading.	"
1.11.7	Reference postclosure repository design	"	"
4.4.1	Site and performance assessment information needed for design	Fracture geometry and properties, contact altitudes of hydrogeologic units required for design of repository seal components and Calico Hills exploratory borehole seals.	"
1.12.1	Site, waste-package, and underground facility information needed for design of seals and their placement methods	Fault location and geometry, contact altitutes for TSwz, fracture geometry and properties.	"
4.4.9	Identification of technologies for underground facility construction, operation, closure, and decommissioning	Fault location and geometry, contact altitudes for TSwz, fracture geometry and properties.	"

Table I-I Information Needs Requiring Data from Study 8.3.1.4.2.2

(SCP Study 8.3.1.4.2.2)

Information Need Number	Statement of Information Need	Data Provided	Interface Activity
Performance Issues			
1.1.1	Site information needed to calculate the releases of radionuclides to the accessible environment	Altitudes of hydrogeologic units and location and geometry of fault zones in unsaturated zone overburden; fracture frequency in fracture networks and fault zones; secondary calcite in unsaturated zone units.	8.3.1.4.2.2.1; 8.3.1.4.2.2.2; 8.3.1.4.2.2.3; 8.3.1.4.2.2.4; 8.3.1.4.2.2.5
1.1.2	A set of potentially significant release-scenario classes that address all events and processes that may affect the geologic repository	Site information from 1.1.1 required for formulation of release scenario classes.	"
1.6.1	Site information and design concepts needed to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path	Contact altitudes of hydrogeologic units; fault locations and geometry, fracture geometries and properties.	"
1.6.2	Calculated models to predict ground-water travel times between the disturbed zone and the accessible environment	Site information from 1.6.1 used to address calculation models for ground-water travel time.	"
1.6.5	Boundary of the disturbed zone	Altitudes of hydrogeologic contacts, fault locations and geomtry required for definition of boundary of disturbed zone.	8.3.1.4.2.2.1; 8.3.1.4.2.2.3; 8.3.1.4.2.2.4; 8.3.1.4.2.2.5

Table 1-2. Site Information Provided by Study 8.3.1.4.2.2 to Design and Performance Issues

ISSUE	APPLICATION OF PARAMETER TO ISSUE	DESIGN/PERFORMANCE PARAMETER	GOAL	NEEDED CONFIDENCE
1.11	Vary depth, dip, orientation, and lateral extent of underground facility to provide host rock with favorable containment and isolation characteristics	Elevation of unit contacts for positioning underground facility	TSw2 [a] lower and upper contacts, primary area and extensions: structure contours accurate to ±30m	M [b]
			TSw2 lower contact in areas of minimum overburden: structure contours accurate to ±10m	M
			TSw2 upper contact in areas of minimum ground-water travel time: contours accurate to ±10m	M
		Fault locations	Accurate to ±30m	M
		Fault orientation	Accurate to ±10 degrees	M
		Fault offset	Accurate to ±2m	M
		Fault classification	Standard practice	L
		*	*	*
1.11	Limit temperature changes in selected barriers	TSw2 upper and lower contacts in primary area and extensions (for thermal modeling)	Structure contours accurate to ± 30m	M
	Limit deleterious rock movement on preferred pathways	TSw2 lower contact in areas of minimum overburden (for thermal modeling)	Structure contours accurate to ± 10m	M
	Limit impact on surface environment	TSw2 upper contact in areas of minimum ground-water travel time (for thermal modeling)	Structure contours accurate to ± 10m	M
	Vary borehole and drift spacing to control thermal loading and container temperature	Upper and lower contacts of other units in primary area and extensions	Contours accurate to ± 60m	M
	Limit corrosiveness of container environment			
		*	*	*
1.11	Limit deleterious rock movement of preferred pathways	Fracture orientation: TSw2	(c)	M

Table 1-2 (Continued)

ISSUE	APPLICATION OF PARAMETER TO ISSUE	DESIGN/PERFORMANCE PARAMETER	GOAL	NEEDED CONFIDENCE
		Fracture orientation: TSw1, TSw3, and CHn1[e]	(c)	L
1.11	Limit potential for borehole collapse	Fracture abundance: TSw2	(c)	M
		Fracture abundance: TSw1, TSw3, and CHn1[e]	(c)	L
		Fracture persistence: TSw2	(c)	M
		Fracture persistence: TSw1, TSw3, and CHn1[e]	(c)	L
		Fracture roughness coefficient: TSw2	(c)	M
		Fracture roughness coefficient: TSw1, TSw3, and CHn[e]	(c)	L

* * *

ISSUE	APPLICATION OF PARAMETER TO ISSUE	DESIGN/PERFORMANCE PARAMETER	GOAL	NEEDED CONFIDENCE
1.12	Anchor-to-bedrock plug seal to reduce water entering waste disposal rooms	Fracture frequency in TCw, TSw2, CHn1[e] at base of ES-1 and PTn	TCw: 20 fractures/m TSw2: 40 fracture/m CHn1[e] at base of ES-1: 5 fractures/m PTn: 10 fractures/m	M
1.12	Station plugs to reduce water entering waste disposal rooms			
1.12	Single dam or bulkhead in emplacement perimeter, and drifts to retain and drain water			
1.12	Double bulkheads in emplacements drifts to retain and drain water			
1.12	Backfilled sump to retain and drain water			
1.12	Backfilled channel to divert water away from waste emplacement areas			

* * *

Table 1-2 (Continued)

ISSUE	APPLICATION OF PARAMETER TO ISSUE	DESIGN/PERFORMANCE PARAMETER	GOAL	NEEDED CONFIDENCE
1.12	Calico Hills[e] exploratory borehole seal to reduce potential radionuclide transport through borehole	Unit contacts in exploratory boreholes representing potential pathways to accessible environment and proximate to repository boundary	Accurate to ± 5m	H
		* * *		
4.4	Provide surface facility sites not jeopardized by natural or man-made phenomena	Locations of any faults within 100m of surface facilities with greater than 1 in 100 chance of producing more than 5cm offset in 100 yrs	Accurate to ± 5m	H
		Orientation of any faults within 100m of surface facilities with greater than 1 in 100 chance of producing more than 5cm offset in 100 yrs	Accurate to ± 10 degrees	H
		Probability of above faults exceeding 5cm offset under surface facilities	Less than 0.001 in 100 yrs	H
		* * *		
4.4	Provide underground sites and accesses not jeopardized by natural or man-made phenomena	Locations of Late Quaternary faults in repository block	Accurate to ± 20m	H
		Orientations of Late Quaternary faults in repository block	Accurate to ± 10 degrees	H
		Probability of exceeding 7cm offset in areas of waste emplacement	Less than 0.001 in 100 yrs	H
		* * *		
4.4	Provide host rock thickness for drift construction and waste emplacement; governs potential extent of repository area	Top and bottom contacts, TSw2	Accuracy of ± 10m	H
		* * *		

Table 1-2 (Continued)

ISSUE	APPLICATION OF PARAMETER TO ISSUE	DESIGN/PERFORMANCE PARAMETER	GOAL	NEEDED CONFIDENCE
4.4	Provide physical properties adequate for construction and operation of stable (safe) underground accesses, drifts, emplacement boreholes, and support facilities for normal and credible abnormal conditions	Fracture roughness coefficient	TSw2 (d)	M
		Number of fracture sets	TSw2: 2-3	M
		Fracture frequnecy and spacing	TSw2: 20-40/m^3	M
		Fracture orientation	TSw2: Identify sets and orientation	M
		Fracture roughness and condition	TSw2: Discontinuous to smooth undulating	M
		Fracture alteration	TSw2: Softening or low friction with clay mineral coatings	M
		Fault location (subsurface)	Accurate to ± 5m	M
		Fault orientation (subsurface)	Accurate to ± 10 degrees	M
		Physical, thermal, and mechanical properties of major faults	Offset ± 2m Spacing ± 1m Fill characteristics	M
		* * *		
4.4	Underground facility access for personnel, support materials, waste handling systems during construction, operation (including retrieval), and decommissioning	(Required parameters, goals, and confidences are same as those for application item, "Provide physical properties..." plus those listed below)		
		Elevation of upper Calico Hills[e] contact	Accurate to ± 3m	M
		Upper and lower contact elevations for TSw2 over entire repository area	Accurate to ± 20m	M
		* * *		
4.4	Design drifts compatible with repository sealing	TSw2 top and bottom contact elevations within potential repository area	Accurate to ± 20m	M
		* * *		
4.4	Provide for waste emplacement (emplacement borehole)	Top and bottom TSw2 contacts within repository candidate area	Accurate to ± 10m at selected points within candidate area	M

Table 1.2 (Continued)

ISSUE	APPLICATION OF PARAMETER TO ISSUE	DESIGN/PERFORMANCE PARAMETER	GOAL	NEEDED CONFIDENCE
4.4	Transport waste to emplacement location (personnel safety)	(Required parameters, goals, and confidences are same as those for application item, "Provide physical properties-...")		
4.4	Retrieval of emplaced waste	(Required parameters, goals, and confidences are same as those for application item, "Provide physical properties...")		
		* * *		
1.1	Calculations of specific-discharge field in UZ units; moisture content of UZ units; hydrodynamic response times of overburden	Altitudes of UZ hydrogeologic unit contacts in controlled area	Mean value	M
		* * *		
1.1	Calculation of specific-discharge field in fault zones in UZ units; moisture content in fault zones; hydrodynamic response times of fault zones	Fault zone location, controlled area	Mean value	M
		Fault zone width, controlled area	Mean value	M
		Fault zone offset, controlled area	Mean value	M
		* * *		
1.1	Calculations of coupling factors and radionuclide retardation factors in UZ and SZ units	Fracture frequency, networks, controlled area	Mean value	M
		Fracture frequency, fault-zone rock mass, controlled area	Mean value	M
		* * *		
1.1	Model calibration and validation, gas-phase C^{14} transport in overburden of UZ units	Profiles of abundances of secondary calcite, C^{14} in calcite	No goal	
		* * *		

Table 1-2 (Continued)

ISSUE	APPLICATION OF PARAMETER TO ISSUE	DESIGN/PERFORMANCE PARAMETER	GOAL	NEEDED CONFIDENCE
1.6	Saturated-zone ground-water travel time model, system geometry component	Contact altitude, hydrogeologic units, each UZ hydro unit below repository in repository area	Mean value	M
		Fault displacement, hydrogeologic units, each UZ hydro unit below repository in repository area	Mean value	M
		Fault locations, hydrogeologic units, each UZ hydro unit below repository in repository area	Mean value	M
		* * *		
1.6	Saturated-zone ground-water travel time model, system geometry	Contact altitude, lithologic units, each SZ litho unit in upper 100m, controlled area	Mean value	M
		Fault displacement, SZ, upper 100m, controlled area	Mean value	M
		Fault locations, SZ, upper 100m, controlled area	Mean value	M
		* * *		
1.6	Basic rock mass spatial structure model, system geometry	Contact altitude, lithologic units, each SZ unit in upper 100m, controlled area	Mean Value	M
		Fault offset, SZ, upper 100m, controlled area	Mean Value	M
		Fault locations, upper 100m, controlled area	Mean Value	M
1.6	Fracture hydrologic properties model, material properties	Fracture aperture, fault zones, SZ, each litho unit in upper 100m, controlled area	Mean value	M
		Fracture aperture, fault zones, UZ, repository area, each hydro unit below repository	Mean value	L
		Fracture aperture, fractures, SZ, controlled area, each litho unit in upper 100m	Mean value	M

Table 1-2 (Continued)

ISSUE	APPLICATION OF PARAMETER TO ISSUE	DESIGN/PERFORMANCE PARAMETER	GOAL	NEEDED CONFIDENCE
		Fracture aperture, fractures, UZ, repository area, each hydro unit below repository	Mean value	M
		Fracture frequency, fault zones, SZ, controlled area, each litho unit in upper 100m	Mean value	L
		Fracture frequency, fault zones, UZ, repository area, each hydro unit below repository	Mean value	L
		Fracture frequency, fractures, SZ, controlled area, each litho unit in upper 100m	Mean value	M
		Fracture frequency, fractures, UZ, repository area, each hydro unit below repository	Mean value	M
		Fracture length, fault zones, SZ, controlled area, each litho unit in upper 100m	Mean value	L
		Fracture length, fault zones, UZ, repository zrea, each hydro unit below repository	Mean Value	L
		Fracture length, fractures, SZ, controlled area, each litho unit in upper 100m	Mean value	L
		Fracture length, fractures, SZ, controlled area, each litho unit in upper 100m	Mean value	L
		Fracture length, fractures, UZ, repository area, each hydro unit below repository	Mean value	L
		* * *		
1.6	Fracture hydrologic properties, model, system geometry	Fracture orientation, fault zones, SZ, controlled area, each litho unit in upper 100m	Mean value	L
		UZ, repository area, each hydro unit below repository	Mean value	L

Table 1-2 (Continued)

ISSUE	APPLICATION OF PARAMETER TO ISSUE	DESIGN/PERFORMANCE PARAMETER	GOAL	NEEDED CONFIDENCE
		Fracture orientation, fractures, SZ, controlled area, each litho unit in upper 100m	Mean value	L
		UZ, repository area, each hydro unit below repository	Mean value	M

(a) Stratigraphic terminology from SCP Figure 2-5

(b) L = low
M = medium
H = high

(c) Goal to be evaluated by sensitivity studies.

(d) Existing data insufficient to establish goals.

(e) Data pertaining to the Calico Hills unit to be collected in this study only if the exploratory shaft penetrates the unit.

TABLE 2.1-1: TESTS AND PERFORMANCE-ALLOCATION PARAMETERS, ACTIVITY 8.3.1.4.2.2.1: GEOLOGIC MAPPING OF ZONAL FEATURES IN THE PAINTBRUSH TUFF AT A SCALE OF 1:12,000

TESTS	PARAMETERS
A. Data collection in the field	
a) mapping strata	Attitude, ash-flow tuff zones
b) mapping strata	Attitude, bedded tuff zones
c) mapping strata	Areal extent, exposed bedrock
d) mapping strata	Lateral extent, ash-flow tuff zones
e) mapping strata	Lateral extent, bedded tuff zones
f) mapping strata	Thicknesses, ash-flow tuff zones
g) mapping strata	Thicknesses, bedded tuff zones
h) mapping faults	Fault and fault zone attitude
i) mapping faults	Fault length
j) mapping faults	Fault zone length and width
k) mapping faults	Displacement, faults and fault zones
l) mapping faults	Fault and fault zone characteristics, near-surface
m) mapping faults	Chronology, faulting
B. Data collection based on finished map	
n) map interpretation	Thicknesses, ash-flow tuff zones
o) map interpretation	Thicknesses, bedded tuff zones
p) map interpretation	Displacement, faults and fault zones

TABLE 2.2-1: TESTS AND PERFORMANCE-ALLOCATION PARAMETERS, ACTIVITY 8.3.1.4.2.2.2: SURFACE FRACTURE-NETWORK STUDIES

TESTS	PARAMETERS
a) Fracture aperture	Fracture aperture
b) Fracture roughness	Fracture roughness
c) Fracture-fill mineralogy	Fracture-fill mineralogy
d) Attitude of foliations	Fracture tectonic style
e) Attitude of bedding	Fracture tectonic style
f) Attitude of fractures	Fracture orientation
g) Attitude of faults	Fault physical characteristics
h) Abutting relationships (connectivity) of fractures[1]	Fracture network
i) Fracture trace length[1]	Fracture trace length
j) Continuous fracture-trace maps[1]	Fracture network

----

[1](Normally done for pavement studies only)

TABLE 2.2-2 NUMBER OF TESTS PER SITE, ACTIVITY 8.3.1.4.2.2.2: SURFACE FRACTURE-NETWORK STUDIES

TESTS	NUMBER (PER SITE)
a) Fracture aperture	[2]As many as 1000
b) Fracture roughness	[2]As many as 1000
c) Fracture-fill mineralogy	Average, one or more
d) Samples for hand specimen description[1]	At least one
e) Movement direction on fractures	Highly variable
f) Attitude of foliations and bedding	Highly variable
g) Attitude of fractures	[2]As many as 1000
h) Attitude of faults	Highly variable
i) Fault zone observations	Highly variable
j) Abutting relationships (connectivity) of fractures[1]	As many as 2000
k) Fracture trace lengths[1]	As many as 1000
l) Fracture-trace maps[1]	As many as 50
m) Aerial photographs of pavements[1]	As many as 50

----

[1](Normally done for pavement studies only)

[2](Normally less for uncleared-outcrop studies)

TABLE 2.3-1: EXPECTED RESULTS FOR FRACTURE CORE LOGGING, BASED ON PRELIMINARY CORE STUDIES FROM DRILL HOLE USW G-4 (SPENGLER AND CHORNACK, 1984)

FRACTURE ACTIVITY PARAMETERS	EXPECTED RESULTS
Fracture type (natural, coring, or handling induced)	Varies with unit; most are identified as natural
[1]Observed length	1 cm (smallest dimension measured) to 3 m (most will be less than 0.3 m)
Orientation (strike and dip)	Dominant sets (based on 4% of total fractures): densely welded Tiva Canyon Member N22°E, 65°NW; densely welded Topopah Spring Member N12°W, 89-90°NE and SW; Crater Flat Tuff N50°E, 55°SE. Both high and low angle fractures occur in densely welded and non-to partially welded units
Aperture	[2]0.05 mm (smallest aperture measured) to 20 mm; most are between 0.05 and 0.07 mm
Surface roughness	[3]Cooling joints range from 0-2; tectonic fractures range from 3-18 out of possible 0-20 (based on empirical scale of Barton and Choubey (1977)
Apparent frequency/location	Highest in densely welded units: 13-26 fractures/3-m interval in densely welded units; 1-5 fractures/3-m interval in non-to partially welded units
Relative age	Oldest-youngest up to 6 generations
Degree of mineralization	Unmineralized to completely filled (most are partially coated or stained, few are filled completely)
Mineralogy of fracture fill material	Up to 10 different minerals, fill material including zeolites, opaline silica, calcrete, clay minerals.

[1]The term "observed length" is substituted for the term "dimension" that was used in the list of parameters for this activity in the SCP, p. 8.3.1.4-71.

[2]Apertures were not measured in Spengler and Chornack, 1984. Expected ranges of aperture measurements are from fracture core studies of USW G-4 (Christopher C. Barton, oral commun., 1989).

[3]Surface roughness was not measured in Spengler and Chornack, 1984. Expected ranges of surface roughness measurements are from fracture core studies of USW G-4 (Christopher C. Barton, oral commun., 1989).

TABLE 2.4-1: TESTS AND PERFORMANCE-ALLOCATION PARAMETERS, ACTIVITY 8.3.1.4.2.2.4: GEOLOGIC MAPPING OF THE EXPLORATORY SHAFT AND DRIFTS

TESTS	PARAMETERS
A. Underground Data Collection	
a) Fracture aperture	Fracture aperture
b) Fracture roughness	Fracture roughness
c) Fracture-fill mineralogy	Fracture-fill mineralogy
d) Samples for hand-specimen description	Lateral continuity of repository host horizon
	Lateral variability of units in drifts
	Lithology, stratigraphy
	Petrography, stratigraphy
e) Movement direction on faults	Fault tectonic style
f) Samples for tests other than geologic tests (USGS & LANL)	Not parameter for geologic tests, see text for explanation
B. Photographic Data Collection	
g) Attitude of foliations and bedding	Fault tectonic style
h) Attitude of fractures	Fracture orientation
i) Attitudes of faults	Fault orientation
j) Fault zone observations	Fault physical characteristics
k) Abutting relationships of fractures	Fracture network
l) Fracture trace length	Fracture trace length
m) Continuous fracture-trace maps	Fracture network
n) Lithophysal cavity abundance	Petrography and stratigraphy incl. lithophysal zone characteristics

TABLE 2.4-2: TEST CHARACTERISTICS OF PHOTOGRAMMETRIC, PHOTOMOSAIC, AND CONVENTIONAL SKETCH METHODS OF UNDERGROUND GEOLOGIC MAPPING, ACTIVITY 8.3.1.4.2.2.4: GEOLOGIC MAPPING OF THE EXPLORATORY SHAFT AND DRIFTS

TEST CHARACTERISTICS	Photogrammetric Method [1]	Photomosaic Method	Conventional Sketch Method
Photography	Full-Coverage Stereo Photography	Full-Coverage, Overlapping Photography	Coverage for Archive only
Fracture Measurement	Primarily Remote Measurement	Primarily Manual Measurement	All Measurements Taken Manually
Accuracy [2]	Highest Accuracy; ±2 cm	Moderate Accuracy; ± 10 cm	Lowest Accuracy; ±25 cm
Data Base	Fully Computerized Expandable	Manual Entry, Somewhat Expandable	Manual Entry Not Expandable
Objectivity/ Reproducibility	Objective, Good Reproducibility	Fairly Objective, Mod. Reproducibility	Subjective, Poor Reproducibility
Underground Time [3]	Requires ~2 hrs. per Round	Requires ~4 hrs. per Round	Requires ~8 hrs. per Round

[1] Selected Method

[2] Assuming absolute accuracy in survey control

[3] Exclusive of travel and set-up time

TABLE 2.4-3: NUMBER OF TESTS PER TWO-METER ROUND OF EXCAVATION, ACTIVITY 8.3.1.4.2.2.4: GEOLOGIC MAPPING OF THE EXPLORATORY SHAFT AND DRIFTS

TESTS	NUMBER (per 2-m round)
A. Underground Data Collection	
a) Fracture aperture	As many as 50
b) Fracture roughness	As many as 50
c) Fracture-fill mineralogy	Average, one or more
d) Samples for hand-specimen description	At least one
e) Movement direction on faults	Highly variable.
f) Samples for tests other than those of this activity (for special tests, USGS & LANL)	Variable, at least one
B. Photographic Data Collection	
g) Attitude of foliations and bedding	Highly variable
h) Attitude of fractures	As many as 200
i) Attitudes of faults	Highly variable
j) Fault zone observations	Highly variable
k) Abutting relationships of fractures	As many as 100
l) Fracture trace-lengths	As many as 100
m) Continuous fracture-trace maps	Continuous coverage, number arbitrary
n) Lithophysal cavity abundance	Highly variable

TABLE 2.5-1: TESTS AND PERFORMANCE-ALLOCATION PARAMETERS, ACTIVITY 8.3.1.4.2.2.5, SEISMIC TOMOGRAPHY/VERTICAL SEISMIC PROFILING

TEST	PARAMETERS
Seismic tomography/vertical seismic profiling	Travel time, amplitudes, and polarizations of the direct, refracted compressional and shear waves (SH and SV), as well as other wave propagation characteristics

TABLE 3.1-1: METHODS AND TECHNICAL PROCEDURES FOR ACTIVITY 8.3.1.4.2.2.1: GEOLOGIC MAPPING OF ZONAL FEATURES IN THE PAINTBRUSH TUFF AT A SCALE OF 1:12,000

	Technical procedure	
Test method	Number	Title
	(NWM-USGS-)	
Field mapping using aerial photographs	GP-01	Geologic mapping
Transfer of geologic features to topographic base maps using high-precision photogrammetric techniques	GP-01	Geologic mapping

TABLE 3.2-1: METHODS AND TECHNICAL PROCEDURES FOR ACTIVITY 8.3.1.4.2.2.2: SURFACE FRACTURE-NETWORK STUDIES

	Technical procedure	
Test method	Number	Title
	(NWM-USGS-)	
Fracture mapping of hydraulically-exposed pavements and natural washout strips (pavement method)	GP-12	Mapping fractures on pavements, outcrops, and along traverses
Unclear outcrop studies (outcrop method)	GP-12	Mapping fractures on pavements, outcrops, and along traverses
Photogeologic method	GP-01	Geologic mapping

TABLE 3.3-1: METHODS AND TECHNICAL PROCEDURES FOR ACTIVITY 8.3.1.4.2.2.3: BOREHOLE EVALUATION OF FAULTS AND FRACTURES

Test method	Number (NWM-USGS-)	Technical procedure
Core sampling and fracture logging	GP-11	Logging fractures in core
	AP-6.3Q	Interaction of participants and outside interests with Yucca Mountain Project sample management
	AP-6.4Q	Procedure for the submittal, review, and approval of requests for Yucca Mountain Project geologic specimens
	GPP-06	Rock and paleomagnetic investigations
	GP-18	Volcanic stratigraphic studies
Borehole-video camera-surveys and logging	GP-10	Borehole-video fracture logging
	GP-13	Fracture logging from acoustic televiewer images
Acoustic televiewer surveys and logging	GPP-04	In situ stress investigations
	HP-02	Acoustic televiewer investigations

TABLE 3.3-2: MAJOR EQUIPMENT REQUIRED FOR ACTIVITY 8.3.1.4.2.2.3: BOREHOLE EVALUATION OF FAULTS AND FRACTURES

Borehole-video-camera surveys and logging

Logging truck

Downhole video camera with axial lens

CRT screen

Video cassette player (preferably with fast and slow motion in both forward and reverse, and freeze frame controls)

360°protractor overlay for TV screen

Set of 12 in. parallel rules

Acoustic televiewer surveys and logging

Logging truck

Acoustic televiewer tool

CRT equipment (monitor and scope)

Core sampling and fracture logging

Reflected light microscope

Angled, metal track (10 ft long) for laying core out prior to measuring

Spark plug feeler gauge (for measuring fracture apertures)

Carpenter's shape duplicator (for measuring fracture surface roughness)

Bullet level mounted on planar card

Goniometer

Hand-held goniometer

TABLE 3.4-1: METHODS AND TECHNICAL PROCEDURES FOR ACTIVITY 8.3.1.4.2.2.4: GEOLOGIC MAPPING OF THE EXPLORATORY SHAFT AND DRIFTS

Test method	Technical procedure Number	Technical procedure Title
	(NWM-USGS-)	
Geologic mapping of the shafts	TBD	Procedure for Shaft Geologic Mapping
Geologic mapping of the drifts	TBD	Procedure for Drift Geologic Mapping
Surveying	NNWSI-016	H&N Survey Procedures: Survey Department Document Control and Distribution
	NNWSI-017	Survey Department Work Functions
Film processing and printing	TBD	Procedure for Film Developing and Printing
Photogrammetric geologic mapping	TBD	Procedure for Photogrammetric Geologic Mapping
Borehole logging in the exploratory shafts and drifts	TBD	Borehole Logging in the Shafts and Drifts
Sampling of fracture filling materials	TBD	Sampling of Fracture Filling Materials
Sampling lithologies in the exploratory shafts and drifts	TBD	Sampling Lithologies in the Exploratory Shafts and Drifts

Table 3.4-2: MAJOR EQUIPMENT FOR PHOTOGRAMMETRIC GEOLOGIC MAPPING

Photogrammetric Equipment

DSR-11 Analytical stereoplotter, includes 5-20x differential and common zoom optics, 360 degree image rotation, variable size illuminated floating mark, freehand tracing with Z hand disk, for use with original format black and white or color photography up to 9.5 by 9.5 in. from any camera with any focal length accommodating tilts up to high oblique, with utility software to compensate for earth curvature, atmospheric refraction, camera distortion, restitution instrument calibration coefficients and service diagnostics, with a DEC Micro 11/73 computer for plate processing.

MAPS 350, includes PDP 11/73 with 512kb memory, dual System 5 1/4" 0.4Mb disk drives, 30Mb hard disk, VT220 alphanumeric CRT, Tektronics 4125 graphics display, RM128 mechanical cradle, image superposition monitor, MAPS 350 software.

Correlator, includes two high-resolution CCD cameras, ACOR Imaging Technology digitizing equipment with direct interface to Q-bus of DSR-11 computer, software to specify exterior and interior windows, regular grid intervals.

DH-6300Q5 MicroVAX 11 high capacity 32 bit microcomputer, EA includes MicroVAX 11 CPU, 8Mb memory, TK50 95Mb cartridge tape drive and controller, KDA50 disk controller, DEONA, DHV11, H9642 STYLE JA/JB cabinet w/dual BA23 boxes, documentation and installation diagnostics.

RA81-HA 456 Mb fixed disk drive.

GTCO 24" X 36" digitizing tablet with 16 button cursor and accuracy to 0.001"

Hewlett Packard continuous roll drum-type pen plotter

SP 8.3.1.4.2.2 R1

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TABLE 3.4-2: MAJOR EQUIPMENT FOR PHOTOGRAMMETRIC GEOLOGIC MAPPING--CONT ' D

Shaft Mapping Equipment

a) Geologist's personal equipment; includes acid bottle, geologic hammer, hand lens, sample bags, and other equipment and minor tools necessary for data collecting

b) Data-recording equipment; includes individual field notebooks and other minor items required for keeping complete records of data taken by geologists underground

c) Fracture-data acquisition equipment; includes pocket transits, calipers, gyroscopic compass, contour gauges, feeler and taper gauges, and measuring tapes

d) Photogrammetry equipment: includes camera pedestal, photogrammetric camera, and survey targets

e) Shaft mapping platform

Drift Mapping Equipment

a) Geologist's personal equipment, data-recording equipment, and fracture-data-acquisition equipment the same as those for shaft mapping

b) Photogrammetry equipment; includes camera rail, camera mount, photogrammetric camera, and survey targets